Impact of high-speed railway accessibility on the location choices of office establishments

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Invloed van bereikbaarheid per hogesnelheidstrein op de locatiekeuzes van kantoorvestigingen

(met een samenvatting in het Nederlands)

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door

Jasper Williggers

geboren op 14 januari 1979 te Wijk bij Duurstede

Promotor: Prof.Dr. G.P. van Wee
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Contents

Preface

After four and a half years I finished the work on this thesis. Now it's time to evaluate this endeavour that has taken most of my time at this period. From my multidisciplinary and practice-oriented background writing a PhD thesis was not a logical step. It was only at the end of my master thesis work placement that I had first become interested in writing a PhD thesis. I followed my feeling by choosing for this project. Trains in general and high-speed trains in particular had always attracted me and the spatial and economic components made the topic particularly interesting.

My own experiences have contributed to this interest. On my holiday trips by TGV to south-eastern France I have seen it a dozen times by now: the new office buildings around Lille Europe and Lyon Part-Dieu, the many transferring passengers at Charles-de-Gaulle airport, and the isolated stations like Haute-Picardie and Le Creusot that are passed at around 300 kilometres per hour. But also many questions came to mind. Why was the train outside the holiday season so often nearly empty between Lille and Brussels? And how would it be if the relatively short journey from Utrecht to Brussels wouldn't take more than half of the total travel time? It is sure that not all my questions have been answered in this thesis. But the study did enhance my personal view of what I see during my journeys.

No thesis can be written by someone without any help. Therefore I'm grateful to many people for their different kinds of support and contribution to the research. First of all, I owe much to my supervisors, Bert van Wee and Han Floor. Our regular meetings in the station restaurant, however short they sometimes were, every time delivered the necessary ideas and insights into the continuation of my research. The vision of Bert is inspirational and has frequently triggered me to see issues from a different point of view. The no-nonsense approach of Han has greatly contributed to the feasibility of the research; his experience ensured the progress of the research, especially in the final year. Their approaches to the project were excellent complementary, just as their knowledge about the topic.

Of course in four years of work at Utrecht University also everyday colleagues are important. I thank Robbert and Taede for the pleasant and calm company during the time we shared our room. The daily lunch walks with among others Jesse, Rebecca, Sendy, Sjef and Taede were a welcome and necessary break of the working day. Also I've always appreciated the company of them and other colleagues at after-work activities and at conferences.

Participating in a multidisciplinary project offered not only a frequent bureaucracy, but also the opportunity to see the topic in a broad perspective. This led to valuable insights, contributed by the fellow researchers on this project and the members of the guidance committee, who in addition provided the necessary link with practice. Also I am indebted to the many people who provided me with the necessary data. Any list will be incomplete and I will not try to here. But I particularly thank Nathan Rozema and the other people from Onderzoeksbureau Labyrinth for their pleasant cooperation in carrying out the telephone interviews.

Last but not least I thank my parents and sisters for their moral support that was necessary at turbulent times. Their advice and the distraction from work they insisted on were essential for my well-being in these years. Now I have also in practice followed the considerations put forward in this research and have chosen a location to live with view on the central station in Utrecht. I hope that I will have an enjoyable view on the developments that will be going on in this area.

Jasper Willigers
Utrecht, August 2006

1. Introduction

1.1 High-speed rail and its implementation in the Netherlands

High-speed trains are a relatively new generation of trains, which enable operational cruising speeds over 200 kilometres per hour. In Japan high-speed train services have been operational since 1964. The first European high-speed train service was opened in France between Paris and Lyons in 1981. The French TGV was also the first of what are sometimes called 'very high-speed trains': trains using dedicated infrastructure that make operational speeds possible of 250 up to 350 kilometres per hour by the time of writing this thesis. With these high speeds a considerable reduction in train travel time can be reached for long-distance journeys. Based on these travel times high-speed rail is particularly competitive to car and air transport on distances between 200 and 600 kilometres (Vickerman, 1997).

The introduction of the Paris-Lyons line was seen as a success, not only for trips between Paris and Lyons themselves but also for through journeys between Paris and other places in south-eastern France (Bonnafous, 1987). After this success a large optimism on high-speed rail triggered or speeded up new high-speed rail developments in several European countries. Hereby also a presumed regional development potential of high-speed rail was seen as a reason to build high-speed railway infrastructure (Vickerman, 1997). Among others, the PBKAL project (named after the major cities that are involved: Paris, Brussels, Cologne, Amsterdam and London) is an international agreement to link the main urban agglomerations in Western Europe by high-speed rail. This project is financed partly by the EU Trans-European Networks (TEN) programme, which strives for a better connection and inter-operability of the national networks within the European Union (Sichelschmidt, 1999). Integration of national networks is seen as a prerequisite for deriving full benefit from the EU single market.

For the Netherlands the PBKAL project has resulted in two high-speed train services that are active on conventional track by the time of writing this thesis, linking the Randstad region to Brussels/Paris and Cologne/Frankfurt respectively (hereby we ignore some variations on these services and seasonal services, which are both rather infrequent). Both services still use conventional track, whereby no significant travel time gain is achieved within the Netherlands. To accommodate the Amsterdam-Paris connection the HSL South (HSL Zuid in Dutch) is under construction, a new high-speed railway line form Amsterdam via Rotterdam towards Antwerp in Belgium (Min. V&W, 1994). Services on this high-speed railway line are due to start in 2007. The new infrastructure is supposed to decrease train travel time on the Amsterdam-Paris Thalys but also on a new The Hague-Breda-Brussels service and a domestic Amsterdam-Rotterdam-Breda link (see Figure 1.1). Domestic services on the high-speed railway line can be

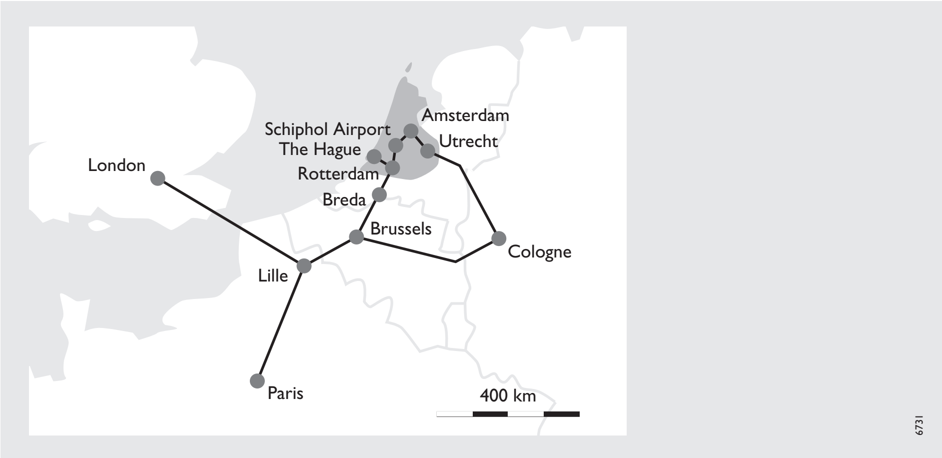

Figure 1.1 Study area and its position in the PBKAL network.

expected to be important for the use of the railway, since train travel time between Amsterdam and Rotterdam will be almost halved from just over an hour to 35 minutes.

Where at the time of writing this thesis the HSL South is soon to be implemented, new infrastructure from Amsterdam to the German Ruhr area for the Amsterdam-Frankfurt service (the HSL East, or HSL Oost in Dutch) was not found to have enough benefits to justify its investment costs (Dijkman *et al.*, 2000a; 2000b). The same accounts for the 'Zuiderzeelijn', a proposed high-speed connection between Amsterdam and Groningen, wherefore high-speed rail was an option next to more ambitious techniques such as magnetic levitation and less ambitious alternatives such as a conventional train connection. Indirect effects of the infrastructure, such as the distribution of economic activities, play a major role in the evaluation of these high-speed railway projects. This thesis especially focuses on these indirect effects.

1.2 Direct and indirect effects of high-speed rail

The evaluation of transport infrastructure projects involves normally three types of effects: direct, indirect and external effects. Direct effects are the costs and benefits for the users, builders and operators of the transport link. In the case of a high-speed railway these are among others the profits of operating the high-speed train connection and the changes in travel time and travel cost for the travellers. Indirect effects are the costs and benefits to actors in the economic system as far as these do not use, build or operate the transport link themselves. From literature it appears that for high-speed railway infrastructure the indirect effects often receive relatively much attention. Indirect effects of a high-speed railway line are among others changes in the level of economic activities at a site or the effects on users of other parts of the transport system (e.g. due to an increased or decreased level of congestion). Especially the regional economic performance is often mentioned in the context of high-speed rail. For some of the high-speed railway projects or project proposals the economic development impacts are even put forward as the most important reason to build the high-speed railway line (see e.g. Thompson and Bawden, 1992). Finally, the external effects of transport infrastructure are costs and benefits to which no direct economic value can be assigned, such as effects on environment, nature and safety; despite their relevance these are not referred to any further in this thesis.

Despite the importance of indirect effects as a reason to build high-speed railway lines, the exact nature and extent of these effects is still not totally clear. Vickerman (1997) noted a "mythical belief that [high-speed rail developments] can solve both transport and regional development problems wherever they are built. This belief is not well founded in evidence" (Vickerman, 1997: p. 36). Where increased concentrations of economic activities around high-speed railway stations on first sight might suggest an economic development impact, closer examination often reveals that much of these effects are actually intraregional distributive effects. That is to say a large part of the employment had been present on another location in the same city or region before the high-speed train service was implemented (for examples of cases see e.g. Sands, 1993; Mannone, 1997). For other high-speed railway station locations the development plans did not result in the increase in economic activities that was anticipated for.

In the Netherlands, several studies on high-speed rail have either focussed on the economic impact of high-speed rail on a high level of spatial aggregation (such as regional-economic productivity, see e.g. Min. V&W, 1994) or on the possible effects for the immediate surroundings of the station (e.g. DEGW and BCI, 1998). Neither of these types of studies deals with the complex network effects that are associated with high-speed railway infrastructure, such as competition between transport modes and the effect on potential accessibility of locations. Nor do these give much detail on the spatial distribution of economic activities among a region, despite of the relevance of intraregional distribution effects. In studies that do take account of network effects and spatial distribution of activities, little attention is given to the importance of subjective factors that are associated to high-speed railway developments. Image effects and the perception of accessibility are seen to be important to the spatial-economic effects of high-speed rail, but are not explicitly taken into account in most modelling studies. Especially for international high-speed train services, being connected to the high-speed railway network (because of its 'option value' or 'value of choice') can be at least as important to the distribution of economic activities as the actual reduction in travel time.

1.3 Research goal and research questions

The above discussion shows that several gaps exist in the knowledge of how high-speed railway developments influence the location of economic activities. Past studies on the indirect effects of high-speed rail either show little spatial resolution or are limited to descriptive analyses thereby ignoring complex network effects. It is, however, not only the physical presence of the station but also the level-of-service provided by the railway network that is of importance to the attractiveness of a location. Changes in the level-of-service for certain places can lead to a different spatial-economic structure within a region, in the sense of changes in the location of activities and changes in related travel patterns.

To further focus the topic of this thesis the research is demarcated geographically and with regard to the type of economic activity. A geographical demarcation is seen to be necessary, because the effect of high-speed rail is very much dependant on the spatial-economic structure of the places it connects. This study specifically aims at the Dutch Randstad. This region is seen as an interesting case since intra-regional effects are expected to be extra strong. Furthermore, the focus on the Netherlands means that this is an *ex ante* research, since no dedicated high-speed railway infrastructure is already operational in the Netherlands. The research in this thesis also specifically focuses on business establishments with an office function[1], because in general for this type of activities the effect of high-speed rail is expected to be largest. For example, Van den Berg and Pol (1998b) mention business services as an 'HST-sensitive' type of activities. Still, among office establishments further differences in the sensitivity for high-speed rail are likely to exist. Therefore the aim this research is formulated as:

To determine to what extent high-speed rail has an impact on the location of office activities within the Dutch Randstad region, and which types of office establishments are most sensitive to high-speed rail.

For the research goal several research questions are relevant. Firstly, the concept of accessibility needs attention, because it is a key aspect in the location of economic activities. The accessibility effect of high-speed rail can be rather complex and not limited to a decrease of long-distance travel time alone. The first research question is therefore formulated as:

What are the effects of high-speed railway developments on accessibility for commuting and business travel in the Netherlands?

Accessibility is hereby seen as 'place accessibility' (as opposed to 'person accessibility', Kwan *et al.*, 2003) from the perspective of an office location decision maker. The following definition of accessibility is adopted in this research:

"The ease with which the transport system enables an office establishment to attract potential employees, customers and business partners."

Furthermore, it is of importance how accessibility and accessibility-related aspects of high-speed rail influence the attractiveness of locations for office establishments, with office establishments being a part of a firm or institution with its own location. The second research question is therefore formulated as follows:

What is the influence of accessibility by train in general and accessibility by high-speed train in particular on the attractiveness of sites within the Randstad area for the location choices of different types of office establishments?

The attractiveness of locations is the basis of the distribution of office employment over these locations. For assessing the impact of high-speed rail on the location of office employment the outcome of different scenarios for (high-speed) railway and land-use developments can be compared. Thereby the effect of the change in accessibility on location attractiveness and the outcome of location choices are to be analysed. The third research question is thus formulated as:

What effects can be expected for the implementation of high-speed rail in the Dutch Randstad area on location attractiveness and on the location choices of office establishments for different scenarios of high-speed railway developments?

These scenarios refer to the (possible) implementation of high-speed railway infrastructure and the development of station areas into urban environments that are more attractive to office establishments. A special focus will be on Amsterdam and the Amsterdam South Axis office park. This location is being developed to become a high status site, aiming to attract national and international head offices (see Rienstra and Rietveld, 1999). It would possibly be directly connected to the national and/or international high-speed railway network. This makes the location very suitable as a secondary case study area within the Randstad to give more detail on a lower spatial level.

1.4 General outline

To answer the research questions an empirical study is conducted on the location choices of office decision makers, resulting in model components that can be used in a scenario study. In the next chapter the focus is on the one hand on theories that describe the interaction between the location of activities (also referred to as the wider concept of 'land use') and transport and on the other hand on what location and transport effects of high-speed rail can be expected from literature. These two aspects are then synthesised into a conceptual model that serves as a guideline for this research. Chapter 3 and 4 focus on the methodology followed for determining respectively the land-use and transport effects of high-speed rail in the Randstad. In the transport part of the empirical study a spatial interaction model is constructed and accessibility indicators are formulated, the results of which are presented in chapter 5. A ceteris paribus study on the accessibility effects of domestic high-speed rail services gives a first indication of the spatial-economic effects of high-speed rail and compares the properties of different accessibility indicators. In chapter 6 models are presented that relate these accessibility indicators and other location attributes to the distribution of office employment within the Randstad. In chapter 7 the models on spatial interaction and the location choices of offices are used in a scenario study on high-speed railway development. Finally, chapter 8 uses the results of the research to draw some conclusions with respect to the research questions, and ends with a discussion.

2. Theory and conceptual framework

An evaluation of the effects of high-speed rail on office location choices requires a more general insight into how new transport infrastructure influences the spatial economy. This chapter presents a conceptual framework that is used as a guideline in this thesis. Several topics from literature are relevant to come to this framework. The first section of this chapter gives a short overview of approaches that are used for the evaluation of transport investments and policies, with emphasis on the indirect effects. Thereafter, the second and third sections go deeper into one of these approaches, the land-use/transport interaction models, by dealing with the theoretical framework and the modelling techniques respectively. Subsequently, the fourth section focuses more specifically on high-speed rail by evaluating literature on foreign experiences with this transport mode. These topics together form the building blocks of the conceptual model for this study, which is derived in the final section of this chapter.

2.1 Appraisal of transport investments and policies

The framework and methodologies used in the evaluation of transport infrastructure are relevant for the current thesis, firstly because it is the basis of scientific literature on spatial-economic effects of transport infrastructures that is discussed in this chapter and secondly because from the results of the current research lessons can be drawn to improve the evaluation of (high-speed) railway projects. The current section therefore aims to describe how transport infrastructure investments in general and the direct effects of these investments in particular are evaluated. First the overall evaluation framework of transport infrastructure investment projects in the Netherlands is discussed, as it has consequences for how indirect effects are evaluated. Subsequently the second sub-section focuses on methodologies to evaluate the spatial-economic effects of transport infrastructure investments.

2.1.1 Evaluation framework of transport infrastructure

In the Netherlands the appraisal of transport infrastructure investments is prescribed by the OEI guideline (Min. V&W, 2005a, OEI is an abbreviation of the Dutch 'Overzicht Effecten Infrastructuur', meaning 'Overview Effects Infrastructure'). This guideline was originally published in 2000 (Eijgenraam *et al.*, 2000) but several topics were revised in 2004 (for the indirect effects see Elhorst *et al.*, 2004). It gives instructions on the performance of a cost benefit analysis (CBA) to evaluate large transport infrastructure investment projects, with the purpose to achieve consistency across project evaluations after CBA has been increasingly replacing multicriteria analysis. Most European countries use CBA for the evaluation of infrastructure investment projects (for an overview see Bristow and Nellthorp, 2000; Hayashi and Morisugi, 2000).

The application of CBA for project appraisal has several consequences for the prognoses of possible effects. Firstly, effects to be evaluated must be monetised as much as possible before these are incorporated into the CBA. Hereby, difficulties may arise for impacts that are difficult to quantify or for which little appropriate literature is available. Secondly, due to the use of net present values long-term developments have a lower weight than short-term developments, since future expected values are deflated by a discount rate. The Dutch government prescribes a discount rate of four percent for infrastructure investment projects (Eijgenraam *et al.*, 2000). As a result, with this discount rate an effect occurring at the base year accounts for almost five times as much as a similar effect occurring 40 years after the base year. The four percent discount rate is equal to the long-term real risk-free interest rate, and thus reflects only the opportunity costs of the capital investment and not the uncertainty of the project. Uncertainty is partly handled by formulated different scenarios. Furthermore, due to rising uncertainty in the prognoses for the long-term future, the horizon year is usually limited to about 30 years from the base year. In the revision of the OEI guideline also the possibility of a fixed supplement percentage for the project risk is introduced (Min. V&W *et al.*, 2004). In the revised OEI guideline a risk premium of three percent is prescribed to be accounted for on top of the rate of discount.

Intra-national distributive effects are indirect effects that are especially difficult to take account of in CBAs. If CBAs are made on a national scale then shifts of economic activities within the Netherlands cancel each other out (Eijgenraam *et al.*, 2000). From a macro-economic point of view distributive effects are therefore not contributing to the justification of a transport infrastructure project. However, political reasons may exist to take account of distributive effects in transport project appraisal. For example regional development effects can be a goal of an infrastructure investment, such as in the case of the Zuiderzeelijn. A solution can be to specify CBAs per region (see e.g. the CBA of the Zuiderzeelijn, NEI, 2000a), whereby the intranational distributive effects are partly taken into account. But hereby the question remains how to combine these regional CBAs in an overall evaluation framework.

2.1.2 Assessment of the indirect effects

Given the evaluation framework described in the previous subsection, the current subsection focuses on the evaluation methods of the indirect effects. The purpose of this subsection is to give a concise overview of the main streams of research approaches in the indirect effects in order to shed light on especially the context and background of the coming sections on the literature overview and the next chapters on the research methodology. A more extensive overview of methods to evaluate the spatial economic impacts of transport infrastructure investments is given by Rietveld (1994), thereby making a classification on two dimensions: (1) model approaches vs. non-model approaches and (2) the use of aggregate vs. disaggregate data. Elhorst *et al.* (2004) compare the characteristics of several model approaches.

The current section describes seven general approaches to evaluate the indirect effects of transport, or more particular the location of economic activities. Table 2.1 summarizes the main advantages and disadvantages of these methods. For the current application to high-speed railway development some aspects of these methods are thereby especially relevant:

- Their ability to deal with a transport mode that is not present yet within the study area,
- Their ability to take account of 'soft' location factors (i.e. location factors that are typically subjective and not easy to quantify), such as the image of a location and the perceptions of decision makers, and
- Their ability to take account of the various processes and mechanisms that have been observed at existing high-speed railway applications and/or that can be theoretically expected for the high-speed railway implementation in the Netherlands.

A first method is to evaluate the effects of similar projects elsewhere. Examples of this approach are Sands (1993) and Rietveld *et al.* (2001). This method is especially useful for identifying what effects may possibly occur and can also give an indication of how large these effects would be (Eijgenraam *et al.*, 2000). However, because of the different context of the infrastructure projects these case studies can solely be useful to derive rough indicators for the effects to be expected, especially when foreign projects are observed. Furthermore, many case studies on the spatial-economic effects of transport infrastructure investments suffer from methodological weaknesses. Among others (e.g. Miller *et al.*, 1998; Spit, 1999): many studies deal with a very short time period despite the time-lag of the possible land-use effects; the causality of the relationships is hard to determine; and before-and-after studies and regional comparison studies are subject to a full range of exogenous influences since these approaches are no controlled experiments (although these exogenous influences may partly be accommodated for by using a quasi-experimental approach, see e.g. Rephann and Isserman, 1994).

Another method is carrying out surveys or interviews among entrepreneurial decision makers. An example of this approach can be found in Rietveld and Bruinsma (1998). Entrepreneurial surveys are in general a good way to shed light on the motives of location decisions and the role of transport infrastructures and policies for these decisions. Furthermore, surveys can take account of the entrepreneurial perceptions on which the location decisions are based. These perceptions might differ from the real values. However, entrepreneurial surveys also have the drawback that biases in the responses possibly exist. Two important sources of bias are: (1) respondents may give a too positive image of their current location as they will not admit their past location choices were wrong, and (2) respondents also may overstate the importance of transport bottlenecks with the purpose to influence government decisions on infrastructure investments (Rietveld, 1994).

Closely related to entrepreneurial surveys are surveys held among experts. Expert judgement can be a relatively quick way to attain second-hand information on the location decisions of entrepreneurs. Additionally these experts will be able to provide more additional information in the field. However, experts will not in all cases be able to answer specific questions on aspects of location choices, especially when focussing on new developments that cannot readily be judged on the basis of past behaviour.

Among the modelling approaches location choice models are the most straightforward way to study the indirect effects of transport investments (for examples see Rietveld and Bruinsma, 1998; Leitham *et al.*, 2000; McQuaid *et al.*, 2004). The aim of location choice models is to study how changes in both transport-related factors and non-transport factors influence the attractiveness of locations for economic activities or households. Location choice models can be based either on aggregate or disaggregate data. For disaggregate data a distinction can be made between observed location choices (revealed choice data, as is the case for aggregate data) and judgements of hypothetical location choices (stated choice data). As with most modelling studies, revealed location choice models typically use data that are as close as possible to the real values, even though location choices may be based on perceptions that can differ from these real values. A more thorough comparison of stated choice and revealed choice data is given in chapter 3. In general the advantages of location choice models are its comprehensibility and the availability of techniques to take account of new situations and developments (as is also discussed in chapter 3). Location choice models are capable to deal with many location factors, including soft location factors if these can be quantified, and perceptions (see e.g. Adamowicz *et al.*, 1997), although this is not often done.

Land-use/transport interaction (LUTI) models have emerged from location choice models by embedding several feedback mechanisms and adding more related model components (see Wegener, 2004). LUTI models are most often designed for and applied to cities or agglomerations, but some applications deal with larger study areas. Their advantage over simpler location choice models is the comprehensiveness of linkages with which transport and location choices have an influence on each other. This goes at the expense of typically very large data requirements and model complexity.

Another type of models are the spatial equilibrium models originating from economics (Bröcker, 2004). Most recent models of this type are built upon the concepts of the 'new economic geography' (Krugman, 1991; 1999) to model monopolistic competition in the tradition of Dixit and Stiglitz (1977). Spatial equilibrium models are subject to various stringent assumptions to make the models computable. An advantage of spatial equilibrium models is the explicit representation of labour and product markets and the strong theoretical background of the models. However, their reliance on profit maximization would not easily allow soft location factors and perception differences to be embedded in the model.

A final type of model that is considered here is the production function approach. The impact of transport infrastructure on regional production is hereby studied by relating indicators of infrastructure to the regional production function, or more precisely the partial production function since the number of production factors is typically limited. An example of this approach is Biehl (1991) Regional production functions have the disadvantage that the spatial level of detail is rather low. This makes it difficult (if not impossible) to take explicitly take account of the various infrastructure-related processes that take place at lower spatial scales.

Table 2.1 summarizes the advantages and disadvantages of the methods described above. It should be noted that in many cases these approaches could be combined. For example, synergy effects exist between entrepreneurial surveys and location models. Within the modelling approaches models that work on different spatial scales can be combined. Intraregional LUTI models can for example be linked to a regional partial production function to take account of interregional and macroeconomic effects.

On the basis of the above it can be concluded that the non-modelling approaches can provide

Table 2.1 Overview of methods to analyse the spatial-economic effects of transport infrastructure and their (dis)advantages.

Method	Advantages	Disadvantages
Case studies of comparable infrastructure investments	Can easily provide rough indicators for the size of the effects that can be expected	The value of the observations are limitedly transferable because of the different context of projects Typically suffer from methodological weaknesses
Entrepreneurial interviews	Can take account of entrepreneurial perceptions and 'soft' location factors Open questions can be used for explorative surveys	It requires a large effort and large costs to acquire a statistically representative sample, especially in the case of open questions Biases possibly exist since respondents may give a too positive image of their current location and may overstate the importance of transport bottlenecks
Expert judgement methods	Quick and easy way to attain general information on indirect effects	Sometimes less useful when focussing on very specific questions Possibly less reliable when dealing with new aspects of transport, which are not business-as-usual
Land-use/transport interaction models	Can include several feedback mechanisms, especially at an urban level	Require much data Are complex to develop
Location choice models	Are easily comprehensible Techniques and theories exist to take account of new situations and developments	Represents only one aspect that influences spatial-economic structure
Regional partial production functions	Require relatively little and typically easily accessible data	Have little spatial detail Have limited capabilities to embed specific aspects of the transport infrastructure or policy that is considered
Spatial equilibrium models	Include explicit product and employment markets, possibly with market imperfections	Do not take account of 'soft' location factors, such as the image of locations and perception differences between decision makers Are typically static, based on equilibrium assumptions Typically show little spatial detail

Sources: Rietveld (1994), Elhorst *et al.* (2004) and others (see text)

valuable information of the impact of high-speed rail on the location of economic activities. For a more thorough research with respect to the research questions a modelling framework seems to be more suitable. Location choice models are relatively easily comprehensible and their application is generally feasible. However, not taking account of the feedback from land-use to the transport system is a drawback. From the three more extensive model approaches the regional partial production functions would not give enough spatial detail. Finally, within the purpose of this research the traditionally on empirical research based approach of land-use/transport interaction seems to offer more flexibility and is therefore more suitable than the theory-driven approach of spatial equilibrium models. However, the specific requirements of a non-standard application such as high-speed rail would require severe adaptations being made to such a model. This would be practically difficult form the view of data requirements and computational effort and add little to the answering of the research questions. Location choice modelling therefore seems the best alternative for the current thesis. Still, the framework of land-use/transport interaction is useful also for location choice models. The following two sections therefore go deeper into the theoretical and methodological issues of land-use/transport interaction.

2.2 Theories of land-use/transport interaction

The concept of land-use/transport interaction is suitable as a basis for this thesis' conceptual framework because it explicitly addresses to the mutual relationship of transport and the location of activities. This section discusses the theoretical background of various components and interactions within this system. Although interactions exist between transport and many types of activities this review predominantly focuses on *economic* activities, in particular the location of employment. In literature several theories and paradigms can be found that deal with (part of) this interrelationship. In general a distinction can be made between theories focussing on the economic performance of regions as a whole and theories that consider the distribution of activities within a region or city.

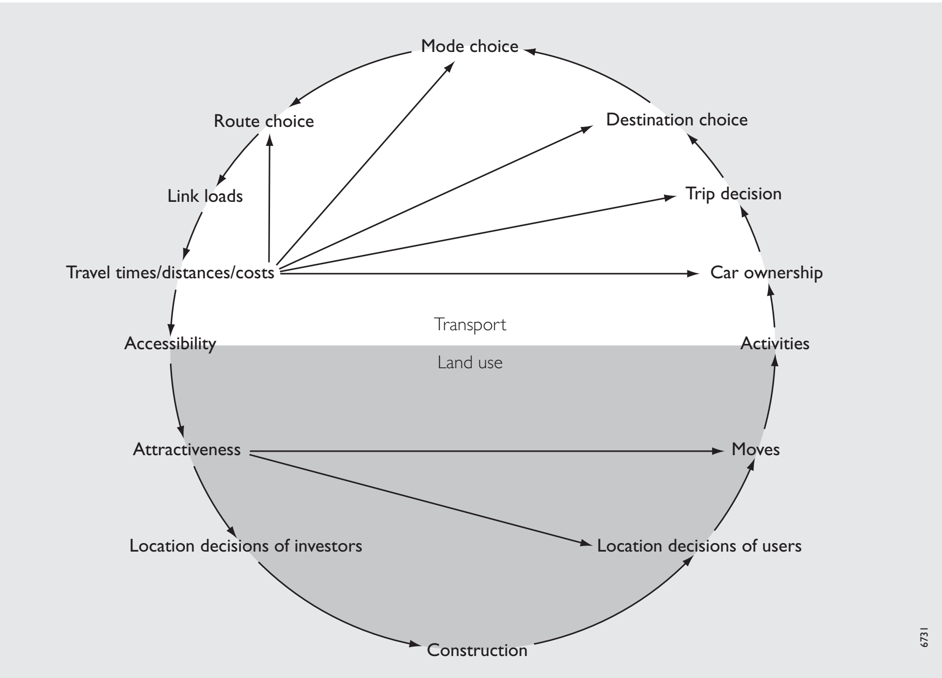

Figure 2.1 The 'land-use transport feedback cycle' (source: Wegener, 2004).

2.2.1 The land-use/transport interaction framework

The interrelations between transport and the location of activities within regions are captured by the land-use/transport interaction (LUTI) framework, which serves as an umbrella over a large variety of theories and methods to evaluate the role of transport in spatial processes. The framework has been used by many disciplines and a range of purposes, including to study urban system behaviour in a general way, to evaluate the (long-term) impacts of specific transport infrastructures, transport policies or spatial planning policies, and to search for an optimal city structure (see e.g. Webster *et al.*, 1988; Wegener and Fürst, 1999; Waddell and Ulfarsson, 2004). From a transport point of view LUTI provides an integral framework to include both direct and indirect effects of transport. For an even more integral assessment of effects this framework has been extended to include also external effects, such as environmental impacts (see e.g. the various contributions in Hayashi and Roy, 1996), although this is less relevant for the current thesis and therefore not discussed in more detail here.

The LUTI framework can be seen as the aggregate of two interlinked subsystems: the land-use system and the transport system (see Figure 2.1). This subsection describes these two components of the LUTI framework and the links between them. The description thereby largely follows the structure proposed by Wegener (2004) in Figure 2.1. The subsection is limited to the theoretical background of LUTI as far as is relevant for the purpose of this thesis. A more extensive review of all aspects of LUTI is given e.g. by Wegener and Fürst (1999).

2.2.2 The land-use system

The land-use system determines the distribution of (several types of) employment, households and other activities over the available space. Land use in a strict sense refers to the type of function of a geographical area, for example a residential land use or an industrial land use. Every type of land use is characterised by the dominant presence of certain real estates or other physical structures, in these examples the presence of dwellings and factories respectively. The real estate can be occupied by population, employment or other activities, or left vacant.

Within the land-use system the attractiveness of a location for these activities is a determining factor. The attractiveness (in a micro-economic context often called the utility of a location) depends on the characteristics of the location itself, the characteristics of its surroundings and on the price of real estate at that location. The attractiveness is of importance for (in general) three categories of actors:

1. Government policy makers, who can stimulate or restrict a particular use (e.g. residential use, industrial locations, office locations) of a piece of land,
2. Developers, who can build real estate on these pieces of land as far as is allowed by the government. Thereby in concept they will make a trade-off between the cost of development and the price they could charge to the users on the basis of the location attractiveness (for a discussion of the land market in the context of LUTI see e.g. Simmonds, 1999),
3. Decision makers of households, firms and other institutions (the eventual users), who choose a location for their activities from the real estate that is available on the basis of the attractiveness of these locations.

There are many interlinkages between these actors. For example, the municipality of Amsterdam started their development policy for the Amsterdam South Axis area only after some internationally oriented head-offices had already located at this site (Rienstra and Rietveld, 1997; Bertolini and Spit, 1998). These offices had located at that site despite of the previous municipal policy mainly focussing at the north and west of the city. This example indicates that location choices do not only depend on the spatial distribution of existing real estate, but can also actively influence the location of new building activities. In practice, transportation planners often tend to blur the distinction between the development of real estate and location choices (Miller, 2004).

Prices of bare ground surface or real estate are an important aspect in the attractiveness of a location and they are also a key factor for some theories in LUTI. This includes some of the earliest theories on this subject, such as Von Thünen's (1826) theory for agricultural land rent and land-use that was later extended to an urban context by Alonso (1964). Actors like relocating firms and dwelling seekers are according to this bid-rent theory willing to pay different amounts of money for different types of locations. If a location has attractive characteristics then activities with a high willingness to pay might drive out activities with a lower willingness to pay via price signals. Under the original assumption of a monocentric city where the attractiveness is dominated by the distance to the central business district this mechanism results in land-use being ordered in concentric circles around the city centre. An alternative approach often used in the context of LUTI is the hedonic pricing approach (Rosen, 1974), which assumes prices to be dependant on the attractiveness attributes of the location (for example the UrbanSim LUTI model uses an hedonic regression for determining land prices, see Waddell, 2003).

Another aspect of location attractiveness that is very relevant in LUTI is the occurrence of clustering of similar types of activities, such as employment within the same or related industries. Several processes can lead to this clustering. First, competition may be a reason for a firm to choose a location in the vicinity of its competitor(s). A game theory approach as in the tradition of Hotelling (1929) can result in the expectation that competitors choose a location at some central place (or perhaps more precisely a good accessible place) within their geographical target market. Furthermore, different types of agglomeration economies can play a role in the clustering of activities (Krugman, 1991): the presence of a pool of specialized labour forces, the presence of other specialized inputs, and the existence of information spillovers. These factors make up what Krugman (1999) calls the 'centripetal forces' for the location of economic activities.

For the dynamics of the land-use system an important aspect is also how often activities move. Because of keep-factors, such as sunk costs, actors are only willing to relocate if there are clear disadvantages of the current location (called push-factors) or major advantages of a particular alternative location (pull-factors). Firm demographic studies (for the Netherlands e.g. Pellenbarg, 1985; Pen, 2002) show that motives to relocate economic activities are mostly factors related to the building, such as the possibilities to grow, or related to the immediate environment of the building, such as the representativeness of the location. Relocation frequency also differs among types of activities at a location: from an analysis of stated relocation probability Van Dijk and Pellenbarg (2000) conclude that the probability a firm relocates is mainly determined by firm internal factors and to a lesser extent by factors related to the location of the firm. Brouwer *et al.* (2004) show that aspects like firm growth, decline and acquisitions and mergers are relevant.

The more frequent location choices are made, the higher the speed with which changes take place. Wegener and Fürst (1999) describe the speed of change for several urban subsystems. The various components in the land-use system generally react slower than for example the transport system (except for transport infrastructures). Within the land-use system physical structures such as the quantity of real estate at a site react at a lower speed than the location choices of population and employment. Land-use, being an aggregate of physical structures at a site, has the slowest response of the urban system.

2.2.3 The transport system

The transport system includes all aspects of transport flows, such as the number of trips between two places in combination with the transport mode that is used and the routes via which is travelled. In this section the discussion on the transport system is limited to personal travel, because this is most relevant within the context of high-speed rail.

A central aspect in the transport system is travel impedance. Impedance can be seen as the aggregate of travel time, cost and more subjective factors such as discomfort for travel between two places. It is thus also the factor that is directly influenced by the implementation of new infrastructure. An aspect closely related to travel impedance is car ownership. On the one hand the choice how many (if any) cars to own is dependant on the opportunities for travel that exist with and without a car, and thus on the travel impedance of the different transport modes, and on the other hand car ownership determines if the car is available as a transport mode and can thus greatly influence travel impedance.

Travel impedance and car ownership together influence the four short-term[2] travel choices that are traditionally distinguished in the transport system (Ortúzar and Willumsen, 1994):

1. Whether to travel or not,
2. To which destination is travelled,
3. Which transport mode is used, and
4. Via which route is travelled.

On an aggregated level the first choice refers to the number of trips that are made to and from a geographical area, the trip generation of the activities within the zone. Consistently, if for example new transport infrastructure leads to an increase in the total number of trips then this is called the generative effect of the infrastructure. The destinations to which is travelled, given the origin of the trips, is the trip distribution; this is often analysed by the average trip length. Mode choices result in a market share for transport modes on an origin-destination combination, in transport analysis called the modal split.

For trip generation a distinction can be made between the number of trips starting at an area (the trip production of this area) and the number of trips ending in an area (the trip attraction). Early theories of travel demand and other types of interactions between cities and regions were based on analogies to the physics law of gravitation, since it had been observed that these interactions were proportional to the 'size' (e.g. the number of inhabitants or work places) of the origins and destinations and inversely proportional to the distance between them (Wegener and Fürst, 1999). Further developments of the models based on spatial-interaction theory were found to be consistent with economic theory, as discussed in more detail in chapter 4.

Within this context it is important to note that most transport is a derived demand (Van Wee, 2002): it is not a goal in itself but serves as a means to reach other goals. The question whether to travel or not thus depends on the purpose of the trip that would possibly be made. The trip purpose determines to what extent alternatives for trips (e.g. the use of telecommunication) are possible. Within the context of economic activities commuting is seen as a trip purpose that has little flexibility for trip production and attraction (Ortúzar and Willumsen, 1994). Business travel is in general more easily replaceable by alternative means of communication, although face-to-face contact can be seen as essential for a part of the business relationships (Blum *et al.*, 1997; Wegener and Fürst, 1999).

Mode and route choices determine how the trips result in traffic over the available transport networks. Several aspects are relevant for this. First, for mode choice car ownership is important, since this determines whether or not the car is available as a transport mode, either as a driver or as a passenger. In a similar way for public transport the distance to the nearest stop or station is of importance (Wardman and Tyler, 2000). Furthermore, the possibility to chain trips is relevant, since it tends to reduce the use of public transport (Hensher and Reyes, 2000) and it affects the route that is chosen. Finally, road congestion and overcrowding of public transport vehicles are relevant, since these are of influence for the time, cost and/or comfort of travel.

In an LUTI context transport infrastructure and services are typically treated as exogenous factors. However, both factors are to some extent influenced by the other aspects in the transport system. Transport infrastructures are among the factors with the lowest speed of change in the LUTI framework (Wegener and Fürst, 1999), because of the long preparation and construction times and the long life time of the infrastructure. New infrastructure is based on government infrastructure policies, which are themselves susceptible to aspects of the transport system, such as capacity problems and possibilities to improve accessibility (Rietveld, 1994). Similar aspects can influence the level-of-service provided by public transport operators.

2.2.4 The impact of land-use on transport

The impact of land use on transport can be split into two aspects: (1) the influence on trip generation and (2) the influence on trip distribution and modal split. The first aspect is generally seen to be relatively direct and straightforward: all else being equal, the more activities are located within a geographical area (i.e. a region, city, or neighbourhood), the more needs and possibilities there are for trips to and from this area. For example if the number of jobs in an area increases, then so will the number of commuting trips and business trips to and from this area (Ortúzar and Willumsen, 1994). Hereby it is very well possible that the characteristics of the activities are important: in the previous example some jobs will lead to more business trips than others, depending on the exact function of the job.

The influence on mode choice and trip length is more complex than the former relationship. Much research has been done on this topic, studying the impact of among others city density, neighbourhood design and the distance of residential and employment locations to public transport stops and stations (for an overview of empirical research in this topic see e.g. Miller *et al.*, 1998; Wegener and Fürst, 1999; Van Wee, 2002). For the current research especially the latter topic is important. As expected, the distance to a stop or station is generally found to be relevant for the use of public transport, especially in the case of railway stations (see e.g. Wardman and Tyler, 2000). Thereby egress distance of public transport trips seems more relevant than access distance (Blom, 1982; Van Wee and Van der Hoorn, 1996).

2.2.5 The impact of transport on land-use

For the topic of this thesis the impact of the transport system on land use is the most relevant link. The transport impact on land-use is however less clear and direct than the opposite effect. For the impact of the transport system on the land-use system accessibility is a key factor. Hansen (1959) first showed that a statistical relationship exists between accessibility and the residential development of a site and described a methodology to forecast land-use effects using potential accessibility indicators derived from gravity-type of spatial interaction models. In general, the potential accessibility indicator for a location i is calculated as the product of an attraction function g_j of one or more attributes X_j for a potential destination j and an impedance function f_{ij} of one or more attributes X_{ij} for a trip between i and j, which are summed over the possible destinations within the study area (e.g. Spiekermann and Wegener, 1998):

$$A_i = \sum_i g_j(\mathrm{X}_j) \cdot f_{ij}(\mathrm{X}_{ij}) \qquad [2.1]$$

On the basis of this framework a large variety of indicators is possible (for an overview see e.g. Bruinsma and Rietveld, 1993; Geurs and Van Wee, 2004). In most applications, the attraction function g_j is the number of activities at the potential destination j and the impedance function f_{ij} is declining over one or more impedance attributes X_{ij}. A frequently used variation on the above indicator that is the logsum or inclusive value indicator, which can be seen to be the natural logarithm of Equation 2.1.

The concept of potential accessibility as used by Hansen and following studies (e.g. Vickerman, 1974; Frost and Spence, 1995) can be interpreted as the size of the total pool of possible interactions, such as the size of the labour market in the case of accessibility towards working population. In this way, like transport itself, accessibility can be seen as a derived demand. For this interpretation of accessibility the level of competition is relevant (Geurs and Ritsema van Eck, 2001; Van Wee *et al.*, 2001): the number of competing firms that are attempting to attract employees from a labour market affects potential accessibility from a single firms perspective.

Accessibility is one of the aspects that determine the attractiveness of a location for firms and households. For firms it is often an important factor in location choices. Good transport infrastructure and services are not only important to reduce a firm's transportation costs or to improve labour efficiency but also because it plays a major role in other location factors such as the size of the market that can be served from a location and the ability to attract sufficient potential employees. These are aspects that often rank high in location surveys (e.g. Healey & Baker, 1996; Rietveld and Bruinsma, 1998).

As a result, the total effect of accessibility on location choices is rather complex. Thereby, the importance of accessibility to different types of destinations differs among firms. For example, the accessibility to (potential) customers can be a very important factor to some firms but unimportant to other (see e.g. McQuaid *et al.*, 1996). In quantitative analyses of location choices a proper segmentation is necessary to account for these differences. A 'traditional' segmentation based on branches of industry might often not be optimal, since it gives no information on the type of activities that take place at a specific location. For example, an industrial company's head office has very different accessibility needs than one of its manufacturing plants.

For studying the effect of accessibility on the location of economic activities it is also of importance that more subjective issues influence location choices. A decision maker's perception of the properties of a location may differ from reality (Pellenbarg, 1985; Rietveld, 1994). Related to perceptions is the occurrence of image effects. A location with a very good accessibility can attract extra economic activities because the accessibility raises the status of the location, this is assumed especially relevant for locations near a transportation node with high-quality connections, such as high-speed train services (see Van den Berg and Pol, 1998b). Related to this, proximity to a station can also be seen to affect the perception of accessibility. A large railway station close by can give the impression of a good accessibility.

Furthermore, the possibility of making use of a transport mode (with a reasonable access and egress effort to/from a node in the transport network) may lead to a higher valuation of the accessibility by a transport mode than would be expected on the basis of its actual use. Two relevant concepts for this are the option value and the value of choice (Boon *et al.*, forthcoming; Geurs *et al.*, forthcoming), which are respectively the value of being able to make use of a choice option under unforeseen circumstances and the value of the existence of a choice option regardless of whether this option is actually chosen. The presence of a station nearby a location makes the train a viable choice option for an office's employees and visitors and can thus add value of choice (e.g. by providing convenience to visitors using the train, even if they are a small minority) and option value (e.g. for providing an alternative in case of a car breakdown) on top of the regular benefits for travel time and costs. From this point of view there is a considerable overlap of the value of choice with the image effect, as office may use a good (high-speed) railway connectivity to show their commitment to this transport mode to visitors, even if it is not often used. As a result of these effects, locations near railway stations can be more attractive than would be forecasted when only examining spatial-interaction based accessibility indicators.

Although accessibility can be assumed to be an important factor for location choices, for the intention of firms to relocate most firm demographic studies in the Netherlands (e.g. Pellenbarg, 1985; Pen, 2002) show that accessibility seems only rarely of importance (although few studies assign a larger effect to accessibility, e.g. Hanemaayer and Rekkers, 1998). As mentioned earlier in this section, firm internal factors and aspects related to the immediate environment of the location are seen to be most important for relocation decisions.

2.2.6 Transport and regional development

Whereas studies on LUTI are typically focussing on the distribution of activities and transport within cities, regions or agglomerations, other studies focus more on the impact of transport of regions as a whole. Transport (and other types of) infrastructure can be seen as a factor that determines regional productivity and can thus be included in a region's production function. Hereby distinction can be made between intraregional and interregional infrastructure (Rietveld, 1994). An example of this type of study is described by Biehl (1991); Rietveld and Bruinsma (1998) give an overview of production function studies.

Spiekermann and Wegener (1998) argue that whereas these studies have found clear positive correlations between infrastructure supply and the levels of economic indicators still little success has been reached on explaining changes in these economic indicators due to the implementation of new infrastructures. As a possible reason for this they mention that transport infrastructure only has a strong impact on regional development when removing a bottleneck in the network. Simple accessibility indicators that only measure the total quantity of infrastructure supplied, such as used in Biehl (1991), do not take account of this type of complex network effects. These effects can be included by using indicators of interregional potential accessibility in the production function. This is for example done in the SASI model (Spiekermann and Wegener, 1998; ME&P *et al.*, 2003).

Potential accessibility indicators are frequently used as indicators for regional economic development in Europe, including applications by Keeble *et al.* (1981), Bruinsma and Rietveld (1993; 1998) and Spiekermann and Wegener (1996). Rietveld and Bruinsma (1998) compare the results of a number of these studies. Several studies of regional potential accessibility are performed within the context of the Trans-European Networks programme and high-speed railway implementation, as discussed in section 2.4 below. Indicators that are used in these studies include the gravity-type of accessibility indicators and indicators based on the concept of one-day return journeys. The latter refer to the possibility to travel to a business meeting and be able to return after the meeting within the same day. The accessibility indicator derived from this concept (in literature amongst others referred to as 'daily accessibility' or 'proximity count', Geurs and Van Wee, 2003) represent the number of possible destinations that can be reached within a fixed number of hours travel.

2.3 Land-use/transport interaction models

Models of land-use/transport interaction are a way to apply the concepts of land-use/transport interaction to the evaluation of transport investment and policies. For this thesis LUTI models can be seen as a basis for the research methodology, but it is also relevant for the conceptual model because it illustrates the current state of practice for modelling the land-use effect of transport investments and policies. More than literature on separate location choice models, LUTI models are aimed at practical application and do take account of network effects, as is also done in the current thesis. This section focuses on several aspects of this type of models, as far as is relevant for the scope of the current thesis.

Table 2.2 Structure of land-use/transport interaction models

Model	Structure		
	Location assignment	Transport à Land-use connection	Time representation
DELTA	Discrete choice	Accessibility indicator	Recursive equation
DRAM/EMPAL[3]	Discrete choice	Travel impedance	Recursive equation
Environmental Explorer	Cellular automata	Travel impedance, connectivity	Recursive equation
IMREL	Discrete choice	Residential: Travel impedance Employment: Accessibility indicator	Static
IRPUD	Discrete choice	Travel impedance	Recursive equation
MEPLAN	Discrete choice	Travel impedance	Recursive equation
MUSSA	Bid-rent & discrete choice	Accessibility indicator	Recursive equation
TIGRIS	Discrete choice	Accessibility indicator	Recursive equation
UrbanSim	Discrete choice	Accessibility indicator	Recursive equation
Model	**Typical applications**		**Main sources**
	Size study area	**Spatial resolution**	
DELTA	Agglomeration	Polygon zones	Simmonds (1999)
DRAM/EMPAL	Agglomeration	Polygon zones	Putman (1998)
Environmental Explorer	Agglomeration or interregional	GIS grid cells	De Nijs *et al.* (2001), Van der Meulen *et al.* (2002)
IMREL	Agglomeration	Polygon zones	Anderstig and Mattsson (1991)
IRPUD	Agglomeration	Polygon zones	Wegener (1983; 1998)
MEPLAN	Agglomeration or interregional	Polygon zones	Abraham and Hunt (1999)
MUSSA	Agglomeration	Polygon zones	Martínez (1995; 1996; 2000)
TIGRIS	Agglomeration or interregional	Polygon zones	Eradus *et al.* (2002)
UrbanSim	Agglomeration	GIS grid cells	Waddell *et al.* (2003), Waddell and Ulfarsson (2003)

Additional sources: Webster *et al.* (1988), Mackett (1993), Miller *et al.* (1998), Wegener and Fürst (1999), Timmermans (2003)

LUTI models can be seen as mathematical representations of LUTI theory. The aim of most of these models is the evaluation of government policies, both in the transport and in the spatial planning field. Government policies are therefore typically treated as exogenous to the model. An exception to this is a small class of models that are designed to find the optimal land-use structure and spatial policy. Furthermore, LUTI models have been used as a framework to integrate theories and models from different disciplines.

Lowry's (1964) Model of Metropolis is generally seen as the very first LUTI model. Nowadays some tens of LUTI models exist, a number of which have been under development for more than thirty years by the time of writing this thesis. Some of these models have a rather fixed study area on which they are applied; other models have had numerous applications in the course time in different cities and countries and on different continents. Many studies have made extensive comparisons and typologies of LUTI models, including Webster *et al.* (1988), Miller *et al.* (1998), DSC (1999) and Wegener and Fürst (1999) to name a few. This section shortly describes several features of these models that are relevant for the topic of this thesis. The following subsection describes some aspects regarding the overall structure of the models. Subsequently, the second and third subsections focus on the transport and land-use subsystems respectively.

2.3.1 Structure of land-use/transport interaction models

In literature, typologies and classifications of LUTI models have been based on a large variety of aspects. These surveys do not seem to yield robust classifications, as classes are diffuse and hybrid forms often exist. The characteristics of a number of LUTI models are summarized in Table 2.2. The selection of these models is solely based on the availability of a recent adequate literature source.

A first distinction can be made between models based on bid-rent theory (Alonso, 1964) for assigning land-use and models relying on random utility maximisation or entropy maximizing for modelling location choices. The micro-economic random utility theory (McFadden, 1974; 1978) and the statistical approach of entropy maximizing (Wilson, 1970) were found to yield functionally identical models by Anas (1983). A majority of LUTI models seem to adopt a discrete choice approach rather than the bid-rent alternative. This includes all of the models in Table 2.2. In the remaining of this section it will therefore be referred to 'location choices', although this would not exclude the concepts to be applicable to bid-rent theory as well. For an integrative framework of the two theories see Martínez (2000).

Another common classification criterion is how the models assume transport to have an effect on land-use. Two options for this are:

a. Location choices are directly based on transport and travel impedances, and
b. Location choices are based on (potential) accessibility indicators.

Ad a: This was the method followed by Lowry (1964) and is used in most of the LUTI models that date from the 1970s. It consists of a series of gravity-type spatial-interaction models. In the most elementary form of the Lowry-type LUTI models location choices of households are based on the characteristics of the potential locations and the travel impedance to their work place. Similarly location choices of service employment (that part of the employment that is not exogenously determined) are based on location characteristics and travel impedance to either a household locations or an employment location. Later models have integrated this structure with spatial input-output analysis (Horowitz, 2004), which enable a more thorough segmentation of employment and population. A well-known example of such a model is the MEPLAN model (Abraham and Hunt, 1999).

Ad b: More recent LUTI-models seem to shift from the use of spatial-interaction techniques for modelling location choices to the use of accessibility indicators that are either derived from a gravity-type of spatial interaction model (which in this case does not model location choices directly) or from a disaggregate transport model. The accessibility indicators are of the Hanson (1959) type or of the 'logsum' type. The next subsection gives more detail on the accessibility indicators that are used.

Other important characteristics of LUTI models are the representations of space and time. For space two aspects are of importance: the size of the study area and the spatial resolution. Both aspects are in the first place characteristics of a particular application of the model, but can be restricted by the overall model structure and its underlying methodologies. The spatial scale and resolution for which a model is originally designed is important to the applications for which the model is suitable and for which information can be derived from the model results. With regard to the size of the study area most LUTI models have been applied to agglomerations alone, but some applications deal with much larger study areas. An interregional spatial scale would usually require the model to take account of regional economic processes endogenously.

The spatial resolution of the models is often limited by data availability for the transport part (Miller *et al.*, 1998), making transport model zones (polygon zones in a GIS) the highest level of detail possible. The study areas of LUTI model applications consist of up to several hundreds of these zones. Some models allow the land-use part to be more detailed e.g. by using GIS grid cells or parcel-level data. As travel impedance is usually not available on that spatial scale those models use connectivity indicators in addition to potential accessibility indicators (e.g. Waddell and Ulfarsson, 2003).

With regard to the dynamic behaviour of LUTI models two types of models can be found in literature:

1. Static models that determine the equilibrium situation of an urban system, and
2. Recursive equation systems (semi-dynamic models) with fixed time steps (although time steps can also be based on a queue of events, Miller *et al.*, 2004) and that are usually based on the assumption of a partial equilibrium (i.e. an equilibrium of one or more subsystems, but not of the whole model); recursive equation systems can be further subdivided into:
   a. Aggregated models, which model groups or clusters of actors, and
   b. Microsimulation models, which model individual actors thereby often relying on Monte Carlo analysis techniques.

Most operational LUTI models are aggregated recursive equation models, although several new models based on microsimulation are being developed (e.g. Moeckel *et al.*, 2003; Veldhuisen *et al.*, 2003; Miller *et al.*, 2004). Out of the models in Table 2.2 the IRPUD and UrbanSim models make use of microsimulation techniques, but neither of them can be classified as a full microsimulation model by the time of writing this thesis (Wegener and Fürst, 1999; Timmermans, 2003). Recursive equation LUTI models typically use time steps of one to five years (Wegener and Fürst, 1999). Thereby not all models require the transport sub-model to be run at every time step (e.g. Simmonds, 1999). The length of the time steps can be of great importance to the behaviour and accuracy of the models (see e.g. Sugiki and Miyamoto, 2004).

2.3.2 The transport subsystem and accessibility

Table 2.3 gives an overview of features of the transport system and accessibility indicators used in operational LUTI models. Several of the models do not model transport flows themselves but rely on an external transport model for updating travel impedance. For most of these models there are no restrictions for the exact type of transport model used (e.g. an aggregate model or an activity-based model). Other models do model transport; most of these transport sub-models used are aggregated transport models based on spatial interaction theory. Newer models are being developed that use activity-based transport models (Wegener and Fürst, 1999; Timmermans, 2003).

For the current thesis the formulation of accessibility indicators in the LUTI models is especially relevant. The models in Table 2.3 that use accessibility indicators all make use of indicators with a structure like equation 2.1. Thereby two aspects are relevant. Firstly, a logarithmic conversion can be used. In this way an indicator similar to the logsum indicators are achieved. Theoretically, logsum indicators are derived from disaggregate transport models, whereas Hanson's indicator is derived from aggregate spatial interaction models. However, except for the logarithmic conversion these indicators are practically identical and would give consistent results when applied in a model. In LUTI models however the use of a logarithmic conversion does not seem to be strictly connected to the use of a disaggregate transport model. Secondly, only one of the models in Table 2.3 uses an indicator that takes account of competition, as discussed in section 2.2.5. In the MUSSA model (Martínez, 1995) accessibility indicators are derived from the balancing factors of a doubly-constrained interaction model, which corrects for the competition effect (Geurs and Ritsema van Eck, 2001).

As mentioned in the previous subsection some models use connectivity indicators in addition the potential accessibility indicators. These are for example the distances or travel times to the nearest transport nodes and characteristics that refer to the quality of these transport nodes.

Table 2.3 Transport and accessibility in land-use/transport interaction models.

Model	Transport model		Potential accessibility indicators		Connectivity indicators
	Integration	Type	Log-conversion	Competition	
DELTA	External	n.a.	n.d.	No	n.d.
DRAM/EMPAL	External	n.a.	n.a.	n.a.	n.a.
Environmental Explorer	Internal	Spatial interaction	n.d.	n.d.	Yes
IMREL	Internal	Spatial interaction (no congestion)	Yes	No	Yes
IRPUD	Internal	Spatial interaction	n.a.	n.a.	n.a.
MEPLAN	Internal	Spatial interaction	n.a.	n.a.	n.a.
MUSSA	External	n.a.	Yes	Yes	No
TIGRIS	Internal	Spatial interaction	n.d.	No	No
UrbanSim	External	n.a.	No	No	Yes

n.a. = not applicable, n.d. = no data available
Sources: see Table 2.2.

Table 2.4 Structure of land-use in land-use/transport interaction models.

Model	Supply			Demand
	Endogenous prices	Dwelling supply	Employment supply	Employment classes
DELTA	Market based	Endogenous	Endogenous	Sectors
DRAM/EMPAL	No	Exogenous land vacancy	Not modelled	4 sectors
Environmental Explorer	No	Fixed per land-use type	Fixed per land-use type	7 sectors
IMREL	Let demand match supply boundaries	Exogenous min/max bounds	Exogenous min/max bounds	No segmentation
IRPUD	Update between time steps	Endogenous	Endogenous	Branches of industry
MEPLAN	Time step equilibrium	Endogenous	Endogenous	Branches of industry
MUSSA	Bid-rent	Exogenous	Exogenous	4 sectors
TIGRIS	No	Exogenous min/max bounds	Exogenous min/max bounds	2 sectors
UrbanSim	Hedonic	Endogenous	Endogenous	Branches of industry

Sources: see Table 2.2.

Connectivity indicators give more distinction between locations at small spatial scales (see e.g. Waddell and Ulfarsson, 2003). Furthermore, connectivity indicators can be used to take account of factors such as image factors, perception of accessibility, option value and value of choice. Because of the low spatial scale on which these indicators are mostly effective, they can especially be found in the models with a high spatial resolution.

2.3.3 The land-use subsystem

In Table 2.4 an overview is given of characteristics of the land-use subsystem. Thereby distinction is made between the supply side and the demand side of the real estate market. In general large differences exist between the land-use subsystems in the various models, especially for the supply side.

The way the supply side is modelled seems for a great part to reflect the degree of market regulation in the models' country of origin. On the one end, models like MEPLAN are based on the assumption of equilibrium of real estate supply and demand within time steps. Equilibrium prices can be calculated endogenously. On the other end in the IMREL and TIGRIS models rigid upper and lower boundaries for household and employment location can be imposed to reflect highly regulated real estate markets. Various mechanisms appear to determine real estate prices (even though not all models determine prices explicitly). Besides equilibrium prices and bid-rent theory an approach applied in several models is hedonic pricing (an example is the UrbanSim model, Waddell, 2003; Waddell *et al.*, 2003). According to this approach prices are directly based on the characteristics of the site (Rosen, 1974).

On the demand side a major issue is to what extent segmentation or stratification of users take place. Large differences exist in the number of classes that are distinguished for both employment and households (Table 2.4 only shows employment classes). For employment classification is solely based either on main economic sectors or more detailed on branches of industry. With the latter some tens of classes are possible. The choice of the classification factor seems largely based on data availability. However, the economic classification might not be optimal to study location choices; a classification based on the actual activities at a location might better represent heterogeneity among location preferences (Jansen and Hanemaayer, 1991).

2.4 Land-use and transport effects of high-speed rail

Following the previous sections on the interaction of land-use and transport in general this section focuses more specifically on the transport effects and the land-use effects of high-speed train services. Theoretically possible effects as well as the results of empirical and modelling studies are considered. The overview in this section is used to relate high-speed rail developments to the concept of land-use/transport interaction.

2.4.1 Transport effects of high-speed rail

Theory and concepts
The implementation of new transport infrastructure, such as a high-speed railway line, primarily aims to reduce travel time, and thereby travel impedance as a whole. The European high-speed railway network brings locations closer to each other in terms of travel time, as is for example shown by the space-time maps of Spiekermann and Wegener (1994). Consistent with the four short-term travel choices in the transport system (see section 2.2.3), the reduction in travel impedance for a transport mode can in four ways influence transport volumes for this mode:

- By serving trips that would otherwise have been made via another route by the same transport mode (a reassignment effect),
- By serving trips that would otherwise have been made by another transport mode between the same origin and destination (a modal split effect),
- By serving trips that would otherwise have been made to another destination (partly a distributive and partly a generative effect), and
- By inducing trips that would otherwise not have been made (a generative effect).

The third type is primarily a distributive effect, since the trips would otherwise be made as well, but can be regarded as partly generative if the new infrastructure would allow the length of these trips to be increased.

For the reassignment effect high-speed rail interacts with conventional train services. This interaction can be both competitive (when serving the same corridor and stations) and complementary (conventional rail enables access and egress to high-speed rail services). The outcome of this interaction depends on which stations have a high-speed rail service and to what extent an additional fare for high-speed rail is compensated by a decrease in travel time (Hsu and Chung, 1997).

With regard to modal split high-speed rail is especially competitive on the basis of travel time on distances between about 200 and 600 kilometres (Vickerman, 1997). On shorter distances the higher cruising speed of high-speed trains can in most cases not compensate for the disadvantage relative to the car, namely the egress and access transport and the waiting and transfer times at the stations. On distances over about 600 kilometres airplanes are often faster, despite the generally longer check-in times at airports (for access and egress times airports often have a good location to households but less to the central business district, see Vickerman, 1997).

The appearance of low cost carriers in European air transport is a new development in high-speed train competitiveness (Dobruszkes, 2006). Low cost carriers typically serve connections on relatively short distances, similar to the distances of connections served by high-speed rail. Dobruszkes (2006) observes different outcomes of this competition: in France the TGV (supported by government air time slot policies) seems to have pre-empted low cost carriers to gain foothold, but in Germany and Great Britain low-cost carriers exist alongside high-speed train services.

As with the reassignment effect high-speed rail has besides competition also complementary relationships with the other transport modes. Similar to conventional rail car can serve as an access and egress mode to the high-speed railway stations. On the other hand high-speed rail itself can serve as complementary to air travel. An increasing number of airports also receive high-speed train services (López-Pita and Robusté, 2003b). This enables travellers on long-distance connections, such as intercontinental flights, to use high-speed rail as a feeder to or from the airport (Ferlaino and Garosci, 1996; Givoni, 2003). Several airline companies have taken shares in high-speed railway operators. By replacing intermediate distance flights by high-speed railway services airline companies can overcome air capacity problems at airports they serve (López-Pita and Robusté, 2003a).

Since most research on high-speed rail focuses on specific transport corridors, it is difficult to make a distinction between trip generation and distribution. From a corridor perspective both the generative and distributive effects appear as induced transport on this corridor. Still modelling approaches (e.g. Sonesson, 2001; Yao and Morikawa, 2005) show that generative and especially distributive effects on an interurban level can be quite significant. For high-speed rail, however, little research has been focussing on distinguishing between trip generation and distribution.

Empirical studies
Empirical evidence on the four types of transport effects is available from various high-speed railway lines that are currently operational and from modelling studies on planned and proposed high-speed railway connections. Table 2.5 shows two examples from practice of how transport volumes changed at the time of the implementation of high-speed railway lines. It can be assumed that the differences between the before and after volumes are caused for a considerable part by the new high-speed rail services.

As was already mentioned in the introduction of this thesis, France was the first European country to implement a high-speed train service. The Paris-Lyons TGV Sud-est service that was brought into service between 1981 and 1983 was a success both in trip generation and

Table 2.5 Before and after studies on the transport effects (passengers per year) of three high-speed railway lines.

	TGV Sud-est		AVE Madrid-Sevilla		Svealand line	
Year of implementation	1981-83		1992		1997	
Distance	390 km		565 km		115 km	
HSR journey time	2h00		2h30		1h00	
Modal split effect	3.6 mln.	51%	0.4 mln.	37%	1.0 mln.	70%
• From car	1.3 mln.	18%	29000	3%	0.2 mln.	15%
• From air	2.3 mln.	33%	0.3 mln.	30%	x	
• From bus	x		56000	5%	0.8 mln.	55%
Generative/distributive effect[4]	3.4 mln.	49%	0.7 mln.	63%	0.4 mln.	30%
Total transport effect	7.0 mln.		1.1 mln.		1.4 mln.	
Market share rail with HSR	x		44%		30%	
Source	Bonnafous (1987)		De Rus and Inglada (1997)		Fröidh (2005)	

x = no data, percentages are the contribution to the total transport effect

trip diversion (see Table 2.5). Train journeys between the cities of Paris and Lyons themselves increased by about 150% between 1980 and 1985. Additionally, direct through connections with Paris also resulted in an increase of train travel for other cities in the southeast of France. The increase of train travel on the Paris-Southeast corridor was estimated to be half due to induced traffic (which is a combination of the generative and distributive effects) and half to a modal split effect, mostly at the expense of plane traffic. (Bonnafous, 1987) This TGV Sud-Est link appeared to be an especially advantageous connection. The later TGV Atlantique from Paris to Nantes and Bordeaux (service started in 1990) and especially the TGV Nord, the French part of the PBKAL network (service started in 1993), were less successful (Bonnafous and Crozet, 1997; Klein, 1997; Klein and Claisse, 1997). In 1996 the TGV Nord served only 60% of the projected number of travellers, although an overestimation of travel volumes in the reference scenario played an important role in this (Bonnafous and Crozet, 1997). Overall, the TGV accounts for about half of all railway journeys in France (Batisse, 1998).

Similar to the TGV Sud-est in Spain the high-speed railway line between Madrid and Sevilla led to high figures of trip generation, as can be seen from Table 2.5. However, both the studies on the Paris-Lyons and Madrid-Sevilla lines did only focus on the effects for the specific corridors. As a result it is not known what part of the new travel in this corridor would otherwise have been made to another destination. Furthermore, general economic conditions play a role, which is not corrected for in the Table 2.5 figures.

Attention is also given to the trip purposes of travellers that make use of the high-speed train services. Bonnafous (1987) focuses especially on business travellers on the TGV Sud-est; of all TGV passengers departing from Lyons 23 percent are business travellers, almost half of which are travelling to Paris (Demotz, 1987). A distinction is made between five classes of business trips: journeys to buy or sell products, to buy or sell services, for internal contacts, for external contacts and for other purposes. About 40 percent of business trips (both on the TGV and in total) were found to be for internal contacts. The other purposes each account for between 10 and 21 percent on the TGV. Klein and Claisse (1997) applied the survey of Bonnafous (1987) in an extended form to the TGV Atlantique. Thereby also non-business trips were taken into account. In general the results were consistent with the TGV Sud-est, except for a higher share (30 percent) for buying or selling services. These figures show that a great diversity exists among the trip purposes for business travel, but also that the TGV affects each of these purposes in the same order of magnitude.

Another case summarized in Table 2.5 is the Svealand line, a high-speed commuter line from Eskilstuna to Stockholm in Sweden (Fröidh, 2005). Its distance and travel times are comparable to the domestic services on the HSL South in the Netherlands, so that this line can be seen to be more comparable to the HSL South than the French and Spanish cases for most of the expected use of the new Dutch high-speed railway infrastructure. In the Swedish case some aspects can be seen to be different from the other cases in Table 2.5. Firstly, high-speed rail competes with other transport modes. Instead of air transport, which was the largest source of the modal split effect in France and Spain, bus services are relevant in Sweden. Furthermore, induced trips are lower in the Swedish case than in France and Spain.

In the Netherlands Thalys and ICE International services have been active since 1996 and 2000 respectively. Although with the absence of a dedicated infrastructure these services do hardly or not lead to travel time gains within the Netherlands, some effects have been observed for international rail travel. On the Amsterdam-Paris service already shortly after the introduction both generative/distributive effects and modal split effects have been observed (Savelberg *et al.*, 1998). A survey among travellers on the PBKAL network (Thalys, Eurostar and ICE International, specifically aiming at border-crossing passengers) focussed on the user characteristics of high-speed train travellers (BCI and ACA, 2005). It showed business travel to account for only about 20 percent of total travellers and commuting for just three percent, both for the Netherlands and for the PBKAL network as a whole. It can be concluded that the current effect of high-speed rail on business travel and commuting to and from the Netherlands is still limited.

Modelling studies
In addition to the observed effects for existing high-speed railway lines modelling studies have focussed on the expected effects for future and proposed high-speed rail connections. Table 2.6 below shows the results of a number of these studies. Again, this overview distinguishes between a modal split effect and a combined generative and distributive effect. As a general finding, compared to the figures in Table 2.5 the prognoses in Table 2.6 show lower values for trip generation. A possible explanation for this is the shorter distance of the lines in Table 2.6. This shorter distance also has as a consequence that high-speed rail will compete more with the car instead of with the plane.

The Lyons-Turin high-speed railway line is planned to link the French and Italian high-speed railway networks. Although the horizon year of the study is 2002, the line is not constructed yet in 2006. The line crosses the Alps, making use of a more than 50 kilometres long tunnel between France and Italy. In the base scenario without high-speed railway line most travellers go by air. A modal-split effect from air to rail seems to be the main source of estimated high-speed rail traffic. (Ferlaino and Garosci, 1996)

Travel prognoses for the Dutch HSL South are given by Rietveld *et al.* (2001). Distinction is made between international and domestic travel on this high-speed railway link; domestic travel distances are here much shorter than in the other studies. The estimated increase in the number of domestic high-speed railway travellers is more than twice the increase in the number of international travellers. Thereby, the generative/distributive effect is larger for the international services than for domestic services. This is consistent with the suggestion of the before-and-after study results that for long-distance trip generation and/or distribution is relatively more important. With regard to mode choice the HSL South prognoses differ from the Svealand line results as in the Netherlands bus services are hardly a competitor on the long distances or the high-speed rail services. Finally, as is relevant for the location of offices, business travellers make up about 29 percent of domestic travellers and 39 percent of international travellers on the HSL South. These figures confirm the relevance of business travel for high-speed rail in the Netherlands.

Table 2.6 With and without studies on transport effects (passengers per year) of future and proposed high-speed rail projects.

	Lyons-Turin link		HSL South International		HSL South Domestic	
Horizon year of forecast	2002		2030		2030	
Distance	254 km		125 km		125 km	
HSR journey time	x		1h00		1h00	
Modal split effect	3.0 mln.	88%	1.4 mln.	57%	4.1 mln.	72%
• From car	0.7 mln.	21%	0.5 mln.	22%	4.1 mln.	72%
• From air	2.3 mln.	67%	0.9 mln.	35%	x	
• From bus	x		x		x	
Generative/distributive effect	0.4 mln.	12%	1.1 mln.	43%	1.6 mln.	28%
Total transport effect	3.4 mln.		2.5 mln.		5.7 mln.	
Market share rail with HSR	47 %		x		x	
Source	Ferlaino and Garosci (1996)		Rietveld *et al.* (2001)		Rietveld *et al.* (2001)	
	HSL East		**Link Netherlands-Northern Germany**			
Horizon year of forecast	2020		2010			
Distance	x		x			
HSR journey time	x		x			
Modal split effect per year	1.3-2.2 mln.	83-86%	3.4 mln.	60%		
• From car	1.3-2.1 mln.	81-85%	2.3 mln.	40%		
• From air	10000-40000	1-2%	1.0 mln.	18%		
• From bus	10000-20000	1%	56000	5%		
Generative/distributive effect	0.2-0.4 mln.	14-17%	2.3 mln.	40%		
Total transport effect	1.6-2.5 mln.		5.7 mln.			
Market share rail with HSR	x		x			
Source	Dijkman *et al.* (2000b)		Railforum Nederland (1998), 300 km/h variant			

x = no data, percentages are the contribution to the total transport effect

The final two studies focus on high-speed rail links from the Netherlands to Germany. Neither of these two proposed projects has been shown to be economically feasible thus far. The HSL East was a proposal for new high-speed railway infrastructure in the Netherlands from Utrecht via Arnhem towards the Ruhr area in Germany. Similar to the Lyons-Turin link it has a relatively high modal-split effect. In a cost-benefit analysis, however, the transport effect was by far not high enough to justify the costs of the infrastructure. The other study focuses on a link from the Randstad area to Northern Germany to decrease travel times between the Netherlands and Scandinavia, Berlin and Eastern Europe. The alternative for which the results are summarized in Table 2.6 leads to a relatively high number of border-crossing train passengers. However, this variant is rather ambitious as it assumes infrastructure allowing a maximum speed of 300 kilometres per hour to be build all the way from the Randstad to Berlin (speeds on the existing Hannover-Berlin line would therefore also be increased). A more modest alternative with infrastructure allowing speeds between 200 and 250 kilometres per hour did hardly show an effect on passenger volumes at all.

From the empirical and modelling studies on high-speed railway projects it can be concluded that the transport effect of high-speed rail very much depend on the particular circumstances of the project. The share of generative and/or distributive effects in total traffic varies over the different links.

2.4.2 Land-use effects of high-speed rail

Theory and concepts
Starting with the successful introduction of the TGV Sud-est much interest has arisen in the spatial-economic effects of high-speed railway implementation. Following the concept of LUTI high-speed rail can influence the attractiveness of locations near high-speed railway stations by reducing travel times and improving accessibility for these locations. Especially in an interregional context the possibility to perform one-day return journeys (as described in section 2.2.6 above) is often an important concept in studies of high-speed rail. Furthermore, high-speed rail can improve a location's attractiveness by its image effect: the presence of high-speed railway services makes a station appear modern and dynamic, and thus raises the status of this location (Van den Berg and Pol, 1998b; Pol, 2002).

Accessibility plays a role in the labour market. Firstly, high-speed rail can enlarge a region's labour market by increasing the maximum acceptable commuting distance. By linking regional centres high-speed rail may integrate formerly separated labour markets into one functional region (Blum *et al.*, 1997). Secondly, high-speed rail can facilitate the effectiveness of regional labour markets by reducing information decay thus making labour migration easier (Haynes, 1997).

Another aspect related to accessibility is the interrelationship between businesses in the same industry. For example, Peeters *et al.* (2000) use a model of 'plant location' to study the effect of high-speed train services on a hypothetical settlement and transport network layout. The model was set up to determine the optimal number and locations of production facilities in a sector for a situation with and without a high-speed railway line connecting the centres of two adjacent regions. Thereby several possible effects were observed, the most relevant for this thesis being: (1)

especially for higher fixed costs of a facility the optimal number of facilities is smaller with high-speed rail, and (2) under some conditions a facility located in one regional centre can serve both regional centres, or as Peeters *et al.* (2000) describe this: "one regional centre is swallowed up by its competitor." However, whether or not these effects occur depends on the characteristics of production facilities (fixed cost of the facility), distribution (transport costs) and the settlement pattern (density of demand).

On the level of regions as a whole some different aspects are addressed to in theory. An aspect is for example the possibility of endogenous growth of a region, i.e. economic growth other than caused by the infrastructure investment itself or by distributive effects (e.g. Martin, 1997; Button, 1998). Such an effect might occur when bottlenecks are released or when high-speed rail leads to a higher level of knowledge production (Kobayashi and Okumura, 1997; Rietveld and Bruinsma, 1998). However, in literature still some controversy seems to exist about the significance of endogenous growth effects (Martin, 1997; Rietveld and Bruinsma, 1998).

Empirical studies

In countries with high-speed railway lines empirical studies have focussed on the spatial economic effects of high-speed rail, both at an interregional and intraregional scale. On an interregional scale in Japan studies have showed the existence of a statistical relationship between the presence of a Shinkansen station and regional growth. Hirota (1984; as referred to by Brotchie, 1991) found a positive correlation between the presence of a Shinkansen station in a city and growth indices for several economic sectors and for population, even though the cities with a Shinkansen station have had lower growth rates on average than other cities before the Shinkansen was opened. Nakamura and Ueda (1989; as referred to by Brotchie, 1991) found a similar result when comparing regions with and without Shinkansen station, which was further enhanced when also the presence of an expressway was taken into account. Although these studies provide useful information these are not conclusive on the causality of the relationship that is found. Besides an impact of Shinkansen on regional growth there is also the possibility that the government decision to link a city to the Shinkansen was taken in anticipation to an expected growth of the city.

For France, Plassard (1991) observes a centralizing effect of high-speed rail at an interregional scale. The star-shaped outline of the TGV network facilitates the ongoing tendency that the economic activities concentrate on a limited number of locations, with Paris being the centre of this network. Plassard (1991) further mentions the occurrence of what he calls a 'tunnel effect'. This term refers to the area between cities with a high-speed train station, where many towns and cities are bypassed by the high-speed railway and do hardly or not benefit from the proximity to the line. It is therefore hardly appropriate to see the surroundings of a high-speed railway line as a corridor (Vickerman, 1997): a long drawn area along a line infrastructure that benefits from being close to the infrastructure. Instead the effect of high-speed rail is more focussed around points, similar to the case of airports.

A number of descriptive researches on firm relocations, using entrepreneurial surveys, have studied the effect of high-speed rail. Entrepreneurial surveys can shed light on the motives of location decisions and the role of high-speed rail. This type of research has been carried out mainly in France, such as studies reported by Bonnafous (1987), Sands (1993) and Mannone (1997). As a general conclusion for France (Haynes, 1997), the TGV was of minor importance for the location decisions of most firms. In most cases high-speed railway accessibility is just one of a series of factors that influence location decisions. Especially industrial firms are constrained in their location choice by other factors. In a sample of entrepreneurs located near the Lyon Part-Dieu high-speed railway station Mannone (1997) found only about one-third of the respondents indicating that the high-speed train services had been a predominant factor in their location choice.

These case studies also show that the impacts of high-speed rail are to a large extent intraregional distributive effects. For example in Grenoble, where accessibility impacts of the TGV were much smaller than in Lyon and therefore less important in location choices, the revitalized station area did attract several firms and institutions from other places within the city but not from outside the region (Mannone, 1997). Sands (1993) also describes the relocation of companies from small towns to cities with a high-speed train station. For the case of Grenoble Mannone (1997) suggests image effects to be relevant, as is also mentioned by Sands (1993) for the city of Nantes. However, the importance of image effects in location choices is difficult to assess from these studies.

Besides intraregional distributive effects, interregional effects have been observed as well. For example, in a case study on Nantes, Sands (1993) notices some relocations from Paris to Nantes after Nantes received its TGV connection. Furthermore, Sands (1993) makes notice of a firm cancelling plans for a regional branch office in Nantes since the TGV would allow to serve the Nantes region from the company's head office in Paris. This is a finding that is consistent with the results of the theoretical model of Peeters *et al.* (2000), which is described above.

Other case studies focus on the development of station areas as a whole, thereby putting emphasis on supply-side actors such as government institutes and real estate investors. Studies of this type, for example DEGW and BCI (1998), Van den Berg and Pol (1998a) and Pol (2003), typically rely on interviews with experts to come to a descriptive analysis of developments related to high-speed rail within a particular city or agglomeration. The results can then be used to find consistencies in the developments or to give an indication of possible developments in new situations. These studies have the advantages a large variety of aspects can be dealt with and a relatively reliable image of the upcoming developments at the high-speed railway station and competing locations can be achieved. As a drawback however, several aspects and relations are difficult to assess in much detail. Firstly, the transport system is typically dealt with in a rather crude way, predominantly focussing on connectivity and ignoring complex network effects. Furthermore, where the emphasis is on the supply side of the real estate market less detail is known about the demand side, i.e. how the location choices of the users react on the change in accessibility. Still, the latter can be expected to have a large influence, especially on the long term. Finally, this approach is less suitable to identify long-term feedback relations.

Modelling studies

Modelling studies have primarily focussed on an interregional scale. Firstly, in Europe several studies use accessibility analysis to yield indicators for the potential economic effects of high-speed rail. In the context of the European Union's Trans-European Networks (TEN) programme interest is especially focussed on the distribution of these effects over the regions within the European Union. Bruinsma and Rietveld (1993) analysed accessibility for the road, rail and air transport networks by using a gravity-type of indicator. With respect to high-speed rail they concluded that the new high-speed links would make the distribution of accessibility over Europe more unequal. Spiekermann and Wegener (1996) focussed more specific on TEN high-speed rail projects by using a daily accessibility indicator, which was complemented by a gravity-type of indicator by Vickerman *et al.* (1999). The analyses show that the TEN high-speed rail projects (that make up the majority of the expenses of the TEN programme, see Sichelschmidt, 1999) may lead to wider differences in accessibility between central and peripheral regions; this in contradiction to the claims of the Maastricht Treaty. A further study by Gutiérrez *et al.* (1996) calculated the average travel times to all locations in the European Union weighted by gross domestic product. This analysis showed relative changes in accessibility to be the highest at the main urban centres in Europe. The tunnel effect of high-speed rail will thereby increase the imbalances between the larger agglomerations and their hinterlands.

Accessibility studies have also been carried out to study specific stretches of high-speed railway track. Tira *et al.* (2002) evaluated the accessibility effect of Milan-Verona link, which is part of the Turin-Venice line in Italy. This analysis showed that the accessibility effects of high-speed railway lines are not strictly limited to the places it directly connects. Finally, Gutiérrez (2001) studied the accessibility effects of the high-speed railway line from Madrid to France via Barcelona. The results illustrate the importance of the spatial scale on which interpretation takes place. On a European scale the high-speed railway line decreases the variation of accessibility, since the peripheral Iberian peninsula is better connected to the rest of Europe. But on a national scale it increases accessibility differences, because within Spain it are the larger agglomerations that benefit most from the infrastructure.

Although these accessibility studies provide information on the attractiveness of regions and locations within regions for economic activities, there are some limitations to the interpretation of these results. Firstly, most of the accessibility studies do not take account of competing transport modes. However, as high-speed rail is especially advantageous over other transport modes on medium-long distance (about 200 to 600 km as mentioned in section 2.4.1) the destinations within this range would likely contribute more to an increase in accessibility of a location (as experienced by travellers) than destinations outside of this range, because it is more often a viable option to travellers. An example of an accessibility study embedding different transport modes is carried out by Bruinsma and Rietveld (1993), who calculate accessibility on the basis of the fastest mode, thereby taking account of mode choice but in a rather simple way.

A second aspect is to what extent these accessibility indicators can explain actual economic growth. Most of the accessibility studies do not empirically link their accessibility indicators to regional economic development. Still, this link from the accessibility indicators to actual economic growth is important to improve the predictive capabilities of accessibility indicators (see also Vickerman *et al.*, 1999). Although the general outcome of the accessibility analyses seems rather consistent, for individual cities and regions considerable differences can be observed (see Bruinsma and Rietveld, 1998 for a comparisson of accessibility studies). Furthermore, attempts have been made (e.g. Martín *et al.*, 2003) to integrate separate accessibility indicators into one overall indicator.

A study that does derive spatial-economic indicators from accessibility effects is the application of the SASI model to study the effects of the TEN programme. Schürmann *et al.* (2004) use the SASI model to show that a scenario with all TEN high-speed rail investments (all else being as the reference scenario) yielded about one percent higher gross domestic product per capita in the European Union compared to the reference scenario without the TEN programme. For the TEN programme as a whole the model indicated a growth of gross domestic product per capita of over two percent.

Another modelling approach on the interregional level is followed by Sasaki *et al.* (1997) for the Japanese Shinkansen network. In a recursive equation model an accessibility indicator (specified as the average of an impedance function, weighted on the basis of travel flows) is used to determine regional investment and interregional migration. This model is applied to study to what extent the Shinkansen leads to dispersion of population and economic activities. Dispersion is seen as a way to solve excessive agglomeration (see also Amano *et al.*, 1991). It was concluded that Shinkansen leads to dispersion to some extent, but even an extensive network cannot increase dispersion very much.

In the Netherlands the possible indirect effects have been analysed for several future and proposed high-speed rail projects. The first high-speed railway line studied was the HSL South between Amsterdam and Paris, which is under construction by the time of writing this thesis. The study of indirect effects was mainly based on macro-economic analysis (Min. V&W, 1994). The estimated increase of international trade and employment was small, especially given the large uncertainty margin.

For the proposed HSL East from Amsterdam to the German Ruhr area the increase of employment due to the high-speed rail project was estimated to be between 955 and 1610 work places (Dijkman *et al.*, 2000a; 2000b). However, because of the low expected travel time gain only five percent of the estimated employment effect was caused by the high-speed infrastructure itself. The other 95% was ascribed to complementary developments, such as the image effect, the avoidance of a transfer in Cologne, improvements of the station areas and improvements of station accessibility by local public transport.

For the previously proposed high-speed connection between Amsterdam and Groningen (the Zuiderzeelijn, where besides high-speed rail also a magnetic levitation connection has been considered) much research is especially focussed on the indirect effects. This is because the project specifically aims at improving the regional economy of the North-Dutch relatively sparsely populated provinces. For the cost benefit analysis the indirect effects are calculated using several models on different spatial scales (both international and within the Netherlands), including a bid-rent model and spatial equilibrium models (Eding *et al.*, 2000). It was concluded that for all alternatives the impact on location choices for both firms and households was limited, although it would to some extent contribute to the economic development of the north of the

Netherlands. Furthermore, for the cost benefit analysis the indirect effects were calculated to be not substantial enough to result in an overall positive net present value (NEI, 2000a).

A final proposed high-speed rail project in the Netherlands is a high-speed connection between the four largest cities in the Dutch Randstad region, the so-called Rondje Randstad. Again, for this project besides high-speed rail also magnetic levitation is considered. Several models have been applied to study indirect effects, including a spatial equilibrium model and a spatial interaction model to study the location effects of employment and households (Haubrich, 2001). In general the study led to the conclusion that the effect on migration of households and economic activities to the Randstad area would be limited in size, but within the Randstad region more effects could be observed. An example of the latter is a dispersion of population from the main cities to the surrounding urban regions.

2.5 Conceptual framework

The theories as described in the previous sections (both on land-use/transport interaction and on high-speed rail) and the results of empirical and modelling studies can give information on what effects can be expected for the upcoming high-speed railway implementation in the Netherlands. This section aims to draw a conceptual model based on the literature that is reviewed in this chapter. Therefore in the first subsection some specific issues are considered concerning the transferability of the above case study and model results to the particular Dutch situation. Thereafter in the second subsection a synthesis is provided of the reviewed literature. This then forms the basis of the conceptual model that is presented in the third subsection.

2.5.1 Transferability of results from case and modelling studies

Besides the general methodological drawbacks of case studies that are mentioned in section 2.1, there are some specific aspects that limit the transferability of results to the case on the Netherlands. It is important to mention these aspects before coming to a conceptual model that are partially based on these foreign experiences. This subsection describes the most notable reasons why the introduction of high-speed rail in the Netherlands might give different results than its foreign counterparts: (a) differences in the national spatial-economic structure and (b) border effects.

Ad a: Most empirical evidence comes from high-speed rail experiences in France and Japan. However, compared to the Netherlands both of these countries have a different structure with regard to the location of economic activities and the arrangement of their railway network and the competing and supplementing transport networks. France has a dominant monocentric structure, which expresses itself in a relatively large concentration of office employment in Paris (Bonnafous, 1987) and a star-shaped railway network with Paris as it centre (Plassard, 1991). This may lead to very different interaction patterns than in a polycentric country as the Netherlands. Compared to the Netherlands in Japan much larger concentrations of economic activities exist around railway stations; several private railway companies exist that own a considerable share in commercial real estate around their stations (Batisse, 1998). Together with a well-developed railway network this provides a good starting point for the train's market share (see also Bertolini and Spit, 1998).

Ad b: As high-speed rail is especially competitive at distances between 200 and 600 kilometres, for the case of the Netherlands this means that international journeys are of great importance. However, as a consequence border effects or (more generally) barrier effects become relevant. For spatial interaction barrier effects can be seen as discontinuities in the impedance. Nijkamp *et al.* (1990) give a typology of these effects. For high-speed rail especially relevant are the institutional barriers (such as law differences which may hinder firms setting up foreign branch offices), and the category of cultural, language and information barriers. Where the first category has to a large extent been reduced by the efforts of the European Union, the latter category seems longer lasting. The barrier effects reduce the probability that a firm has business partners or employees residing on the other side of a border and therefore have a reducing effect on the travel potentials of international high-speed railway links. This reduction in travel potential leads to a reduction in the accessibility effect of high-speed rail and consequently to a reduction of high-speed rail's effect on economic activities. Bruinsma and Rietveld (1993) study the effect of national borders on car accessibility; their analysis shows that borders especially have an effect on smaller, centrally located countries like the Netherlands, although modal split effects due to bottlenecks in the international road network are not corrected for.

2.5.2 Synthesis of previous sections

The conceptual model in this thesis is based on the literature described in the previous sections. This subsection aims to combine the findings of the previous sections in this chapter, which can be used to form the conceptual model in the next subsection.

For the topic of the current thesis the concept of land-use/transport interaction (LUTI) is seen as the most suitable theoretical foundation. This framework explicitly deals with the interrelationships between components of the land-use system (including the location of activities) and the transport system. Section 2.2 describes the most prominent components and interactions in the LUTI framework. As this thesis especially focuses on the effect of a transport component (namely high-speed train services) on a land-use component (the location of office employment) the link from the transport system to the land-use system is a central focus of this study. The concept of accessibility is a key aspect here. In the context of location attractiveness accessibility is often specified as potential accessibility, i.e. the total sum of potential interactions from a location. It can therefore be interpreted as the size of the labour market or product market in case of commuting or business travel respectively. A theoretical issue of importance here are competition effects, whereby not only reference is made to the number of opportunities but also to the number of competitors that are striving to the same opportunities. Besides of applications of potential accessibility on an urban scale in the context of LUTI, potential accessibility is also seen as an indicator for regional development. Accessibility is thus a concept usable at different spatial scales.

The review of LUTI models in section 2.3 brings to light additional issues concerning accessibility indicators and their use for modelling location choices. Firstly, logarithmic conversions are applied to potential accessibility indicators in several LUTI models, consistent with the log-sum type of accessibility indicators. Furthermore, competition effects are accounted for in only one of the LUTI models in the survey. Little explicit reasoning is found on the choice of the exact form of the indicators used (an exception to this is Martínez, 1995) despite the difference these aspects can cause in an accessibility indicator's reaction to a change in the transport or land-use system. In the context of high-speed rail taking account of competition effects may provide clues about why (e.g. in France) some cities have benefited from high-speed rail while in other cities little or opposite developments have been observed.

Another aspect of accessibility indicators in modelling location choices is that potential accessibility indicators, as are used in practice in LUTI models, have a low spatial resolution as well as a limited study area. Several models therefore introduce simpler connectivity indicators (e.g. the distance or travel time to a transport node) to increase spatial resolution or to take account of access points to interregional transport modes (such as airports). Also in the research described in this thesis data restrictions and computational capabilities impose practical limitations to the accessibility indicators. Furthermore in the context of train accessibility, connectivity can play a role for its effect on image, the perception of accessibility, the option value and the value of choice. For high-speed rail connectivity indicators are particularly relevant, firstly because the contribution of long-distance trips to overall potential accessibility is typically low, and secondly since the image effect of high-speed rail might make connectivity additionally important over potential accessibility. It can therefore be hypothesized that connectivity to the railway network is relevant in addition to its potential accessibility effect.

An important issue shown by studies on the transport effects of high-speed rail in section 2.4 is that the share of business travellers in high-speed rail users is relatively high. Accordingly, high-speed rail can be expected to influence accessibility for business travel more than other trip purposes. As a result high-speed rail is supposed to especially influence the location of activities that are most sensitive to business travel accessibility, such as office activities. The empirical studies on the land-use effects of high-speed rail confirm that particularly office employment is attracted by high-speed railway station.

Finally, studies on the land-use effects of high-speed rail in section 2.4 show that most employment at high-speed railway station areas has relocated from other locations within the same city or region. Therefore it can be expected that the overall effect of high-speed rail is largest at a low spatial scale. This implies a distinction between the choice of a city and the choice of a location within a city. Thereby, changes in location attributes, such as an increase in accessibility, can be expected to have a larger effect on the distribution of office employment within cities than on the distribution of employment over cities.

2.5.3 Conceptual model for the transport and land-use effects of high-speed rail

In this subsection the conceptual model is described that results from the literature discussed above. The concept of land-use/transport interaction is central in the conceptual model. High-speed rail directly affects (domestic) travel impedance and (domestic and international) high-speed railway connectivity, which have a further effect on other aspects in the land-use/transport system. Within the specific case of high-speed rail several aspects of this interaction need to be elaborated on.

Firstly, given the importance of the accessibility concept for the current research the concept of accessibility is specified in more detail. A distinction is made between centrality and connectivity. Centrality is the extent to which a location is centrally located within the transport network relative to activity locations[5], i.e. potential accessibility. It is influenced by the spatial distribution of activities via the trip generation and by other components in the transport system via the travel impedance. Connectivity, on the other hand, is exogenous in the LUTI system since feedbacks to the supply of transport infrastructure and services are not provided in this conceptual framework.

As a second aspect, for spatial development explicit reference is made to the intraregional and interregional scales. The literature on high-speed railway impacts in section 2.4.2 suggests the spatial-economic effects to be largest at smaller spatial scales. In addition, this distinction is especially relevant for the current study because of the particular combination of a relatively large study area (since high-speed rail is a transport mode for medium-long distances) and a high spatial resolution (since the influence of a railway station on location attractiveness can be expected to decline relatively sharp with the distance to the station). Within the land-use system accessibility is among the factors that influence the location attractiveness as perceived by decision makers. These decision makers choose a region and a specific site within this region.

Furthermore, within the land-use system distinction is made between the different types of actors and activities. LUTI models often do not treat land-use as one undividable system. In contrary, typically distinct modules (or even separately usable models) are used to model the locations of economic activities and households (see e.g. Anderstig and Mattsson, 1991; Putman, 1998). Interaction between these land-use components largely goes via commuting and consumer trips (e.g. shopping trips) and thus via the transport sub-model. Although more linkages exist between the land-use components, for example scarcity of available space leads to competition between land-uses, it makes sense to explicitly show the dimensions of the land-use system. By focussing on office locations the current research is dealing with one type of land-use in particular.

Finally, analogous to different land-use activities, within the transport system distinction is made between the different trip purposes. Different trip purposes depend on the location of different activities. Where commuting is a link between economic and residential activities, business travel depends on economic activities only. Hereby also linkages exist between the trip purposes, in the form of congestion. For the current research this distinction is relevant because high-speed rail is supposed to unequally affect different trip purposes. From literature, high-speed rail seems especially an option for business travel.

Figure 2.2 depicts the conceptual model that is used in this research. The general outline is based on Figure 2.1, but with the aspects detailed above. Other aspects related to high-speed rail (complementary developments such as station area development plans) are for simplicity not explicitly related to high-speed rail in this figure, but can be accommodated for in the research.

The conceptual model is used as a basis for the methodology of this research. Hereby the aim is to answer the research questions that are formulated in the introduction of this thesis. Each of the research questions refers to (a part of) the conceptual model.

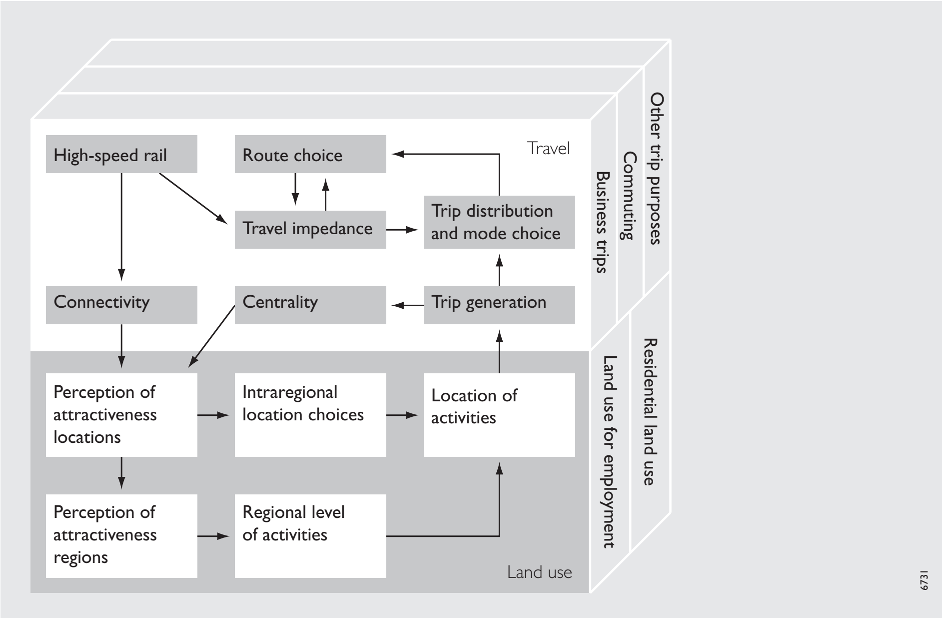

Figure 2.2 Conceptual model for the consequences of high-speed rail for the location of economic activities and patterns of commuting and business travel.

The first research question focuses on how high-speed rail influences a location's accessibility. To do so, accessibility is expressed in accessibility indicators that determine the centrality aspect of accessibility. The specification of accessibility indicators is discussed with the transport methodology in chapter 4. There combined destination and mode choice models for commuting and business travel are specified, from which potential accessibility indicators are derived. Chapter 5 presents the results of the parameter estimations for these models and of a basic accessibility analysis. That chapter also explores how these indicators react if train travel impedance is lowered due to the high-speed railway implementation.

The second research question that is formulated in the introduction refers to how accessibility is of influence in the attractiveness of a location for offices. This question thus focuses on the link from accessibility (both centrality and connectivity) to location choices. Accessibility is based on the methodology and data from the transport component of the model, but is considered a main explanatory variable in the land-use component. The use of accessibility indicators in determining location attractiveness and location choices is discussed in chapter 3 on the location choice methodology. A location choice model is specified that makes distinction between the choice of an urban region and the choice of a site *within* an urban region. The results of this location choice model are presented and discussed in chapter 6.

The third research question builds upon the first two questions by studying how the location attractiveness and location choices react on the change in accessibility caused by the high-speed railway implementation. In chapter 7 therefore a scenario study is applied, whereby the effect of different high-speed train services is assessed. The models developed for the first two research questions are then applied, with different train travel times and costs. A special focus thereby is on the Amsterdam South axis, wherefore also a change in land-use is evaluated. The South Axis is supposed to become a high-status business park located at a major node in the railway network. However, it must compete with other sites in the Randstad area, such as other locations in Amsterdam, the Rotterdam station area and locations in Utrecht, The Hague and at Schiphol airport.

3. Methodology for analyzing the location choices of offices

The first research question relates to the attractiveness of locations for office employment. To determine this attractiveness a model of office location choices is developed. This chapter describes the methodology followed for modelling these office location choices. In chapters 6 and 7 the office location choice model is used to determine the importance of the different aspects of (high-speed) railway connectivity and potential accessibility on the attractiveness of locations and subsequently on the location choices of offices. The first section of this chapter gives a global overview of the different types of models and data used. The second section then discusses aspects of discrete choice theory that forms the theoretic-methodological basis of the location choice models (and also of the transport models described in the next chapter). Section three describes issues related to data collection. Finally, the sections four, five and six consecutively focus on discrete choice models based on stated choice data, RC data and a combination of these.

3.1 Overview of data and models

To assess the importance of accessibility and non-accessibility attributes for the attractiveness of locations for office employment a location choice model for offices is developed. The purpose of the models used in this research is to study changes in the structure of office location preferences within the Randstad area rather than to give exact forecast of the distribution of employment for a future situation. Their nature is thus mainly explorative, although evidently the models should provide results that are in accordance with observations 'in the field'.

This analysis of office location choices is restricted to the Randstad area. The Randstad is hereby demarcated as the provinces of North Holland, South Holland and Utrecht (see Figure 1.1). In many applications the northern part of the province of North Holland is not accounted to be part of the Randstad area. In the current research, however, it is included for two reasons: (1) it facilitates the use of data that is available on a provincial level, and (2) including a less densely populated area gives a better contrast in the independent variables in an econometric analyses with spatial data.

The methodology of this location choice model is based on discrete choice theory, for which the theoretical aspects are discussed in section 3.2. According to discrete choice theory, actors (e.g. office decision makers) choose an option (e.g. a location for their office) out of a set of alternatives (e.g. all locations within an area that are available for office activities). For models based on discrete choice theory different types of data can be used (see also Adamowicz *et al.*, 1997; Louviere *et al.*, 2000).

Practical applications of discrete choice theory typically use data from observed or revealed choices of decision makers that are made in real choice situations. Revealed choice (RC) data has the advantages that it reflects the uncertainty of external influences that is experienced in reality and that the model outcomes typically show plausible values for the market of the alternatives. However, RC data has a number of important drawbacks (see e.g. Hensher *et al.*, 1999; Louviere *et al.*, 2000). Firstly, estimation of model parameters by using RC data might be difficult because of variables showing little variability and/or variables being highly collinear to each other. RC data might also be influenced by restrictions on the supply side of the market, making it difficult to determine to what extent one is actually measuring preferences and to what extent the revealed choices are the consequence of supply side factors. For example in the case of office location choices in the Netherlands building new real estate is subject to government regulations, which hinders the identification of the location attractiveness to office decision makers. Moreover, RC data provide little or no evidence on the causality of the relations that are found. For example, a positive relation between accessibility and employment in a region can be explained by the capabilities of good accessible regions to attract and facilitate economic activities, but also by the incentive of a rising regional economic activity for governments and transport providers to improve transport infrastructure and services. Finally, in RC models all important explanatory variables should be embedded in the model. Omitting key explanatory variables may cause large uncertainties in the resulting model, which makes the model's forecasts of little practical use.

The alternative for revealed choices are stated choices of decision makers in hypothetical choice situations. Stated choice (SC) analysis enables to conduct a controlled experiment of choice situations. Using SC data for analysis[6] avoids the problems of RC data mentioned above. Hypothetical alternatives can be formulated in such a way as to reduce correlation between attributes. Furthermore, SC experiments are not subject to external influences or causality problems. In addition to this, SC experiments can be used to ex ante study the effects of new products with new attributes or attribute levels for which no RC data is available. This is an especially relevant feature in the context of high-speed rail in the Netherlands. However, besides of these favourable characteristics, SC data have some disadvantages. At first, respondents might behave differently in reality than they state in the survey. This might occur on purpose, if respondents use the survey to express a message, or unintentionally. Applications of SC experiments typically yield good estimations of parameters that determine how choices are adapted to a change in an attribute value, but give poor prognoses on the market share of the available alternatives (e.g. Louviere *et al.*, 2000). Furthermore, SC data does not reflect the correct uncertainty that is experienced in reality. Finally, other disadvantages may be difficulties to take account of complex or a large number of attributes, although techniques have emerged to deal with this (for example hierarchical information integration, see e.g. Oppewal *et al.*, 1994; Oppewal, 1995).

To summarise the above, RC data can be seen to be essential for practical applications, because of its good representation of market shares and exogenous uncertainty. The use of SC data per se is especially relevant for theoretical applications studying the impact of new products or technologies, or if the researcher is only interested in the trade-off of attributes such as in the value-of-time literature (e.g. Gunn, 2001). However, an increasing number of studies focus on data enrichment, whereby discrete choice models are based on a combination of SC and corresponding RC data with the aim to combine the strengths of these data sources (see Swait

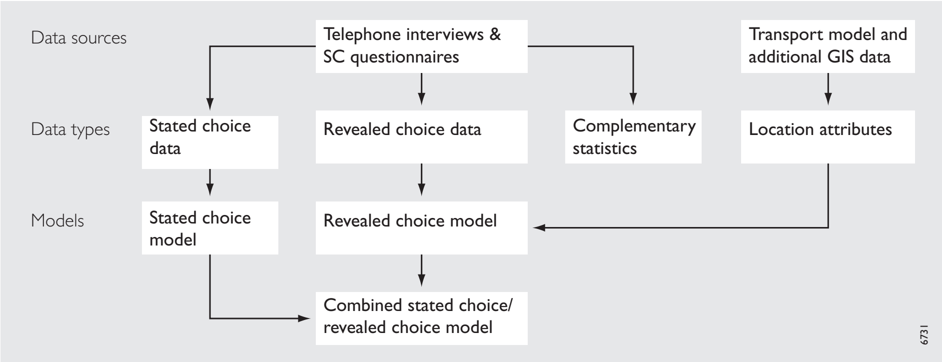

Figure 3.1 Overview of data and models for office location choices.

et al., 1994; Louviere *et al.*, 2000). These studies have been facilitated by further theoretical and methodological advancements in discrete choice theory.

For the current ex ante research on high-speed rail SC data have the advantage of being able to study the expected effect of different aspects of railway connectivity in general and high-speed railway connectivity in particular on the attractiveness of office locations. Furthermore, data enrichment makes it possible to put these findings into a context of 'real' market variations and would thus enable to study the location and transport effects of high-speed rail in an LUTI model. Because of these reasons and since synergic effects occur if data is obtained on both revealed and stated choices as well as the respondent's characteristics by means of a single interview, for the current research both SC and RC data are collected and analysed.

Figure 3.1 shows the data and models used for modelling office location choices. The main data collection is in the form of telephone interviews accompanied by SC questionnaires, as further specified in section 3.3. This yields data for the discrete choice models as well as complementary statistics. The SC and RC data are first analysed in separate models per data source; these are described in the sections 3.4 and 3.5 respectively. For the RC model additional data is required in the form of location attributes. These are potential accessibility indicators from the spatial interaction model described in the next chapter, and connectivity and non-accessibility attributes derived from external data sources and processed by GIS analyses. Finally, the SC and RC models are integrated into a combined SC/RC model, as described in section 3.6.

3.1.1 Perception of accessibility

Within this research also the respondents' perception of attribute values (especially railway accessibility components) is studied. As discussed in the next section it are these perceptions on which location choices are actually based. Several possibilities exist to study the role of accessibility perceptions in location choices. As a first option, following Adamowicz et al. (1997) perception data can be directly used to construct a discrete choice model and to enrich a model based on measured attribute data. This approach allows improving the parameter estimations for a location choice model. However, it also has some drawbacks. Firstly, for every respondent data should be available on the perceived attributes for a number of alternative locations, which could demand a high effort from the respondents since they would have to know a set of locations and their characteristics. Furthermore, it would be burdensome to estimate the parameters of such a location choice model, since these typically have many choice alternatives.

A second possibility is to ask respondents to judge the accessibility of a set of locations and then relate their responses to the locations (measured) attributes. Judgements can be made either quantitatively (e.g. in the form of scores) or qualitatively (e.g. in the form of a ranking). In this approach accessibility indicators can be related explicitly to the perception of accessibility. The results of the analysis can then be related to the location choices that have been made. However, this approach also has the drawback that respondents should be able to judge a set of locations that are sufficiently diverse in their location attributes. Furthermore, the approach would not be compatible with the combination of stated and RC data, since location attributes are not directly related to the choices that are made.

For the current research neither of these two modelling methods seems completely suitable. However, as little is known about the topic of attribute perceptions for railway accessibility it is also of great value to obtain more explorative statistics. Therefore, perception data is collected only for the location that is actually chosen by each respondent, which should be easier to obtain from the respondents than data for the above two modelling approaches. Comparison of perceived values with data from secondary data sets should reveal the awareness of attribute levels by the respondents.

3.1.2 Overview of methodology

The methodology in this thesis is divided over two chapters: the current chapter focuses on location choices and chapter 4 deals with the methodology of this research's transport and accessibility part. Figure 3.2 gives an overview of the relationships between the sections in the two methodology chapters. The next section has a central place in the methodology of this study. It discusses discrete choice theory, which is the theoretical-methodological basis of the location

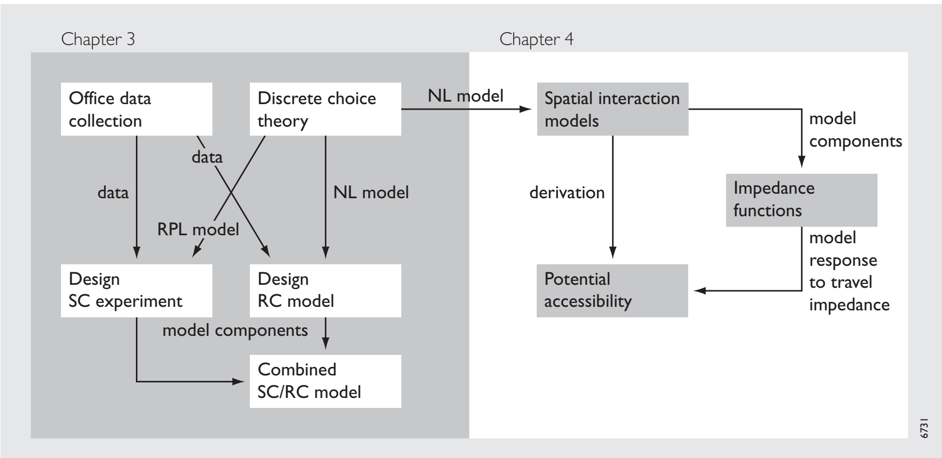

Figure 3.2 Overview of methodology aspects in this thesis.

choice models as well as the transport and accessibility models. The next section describes the underlying theory and technical formulation of several model forms that are later used in the location and transport models.

In this chapter another central aspect is the data collection methodology, which provides data for the stated and revealed office location choice models. These two models then form the building blocks of a combined SC/RC model of office locations.

In chapter 4 the methodology of spatial interaction models for business travel and commuting are described. Besides a section discusses the overall model structure a separate section specifically focuses on the impedance functions, which is the part of the model that is crucial in how the model responses to a change in a travel impedance attribute. In the final section of chapter 4 potential accessibility indicators are elaborated on. These indicators are derived from the spatial interaction models and especially the impedance function plays a major role in the calculated accessibility values.

3.2 Discrete choice theory

Location choices, whether stated or revealed, can at a micro or meso scale be analysed by methodologies from discrete choice theory. As discussed in the previous section, in discrete choice theory actors are assumed to make choices out of a set of mutually exclusive alternatives. For making these choices actors evaluate the choice alternatives on the basis of their perception or belief of the alternatives' attributes (see Figure 3.3), which are the determinant decision criteria that decision makers use to evaluate the alternatives (Louviere, 1988). Attribute perceptions are dependant on some 'real' value of the attribute level. This real value is strictly unknown to the researcher, because decision makers might not be fully informed and other data sources are subjective to measurement errors.

Discrete choice modelling replicates this process (see Figure 3.3). Firstly, in RC studies attribute values are collected, usually from measurements but also perceptions can be collected through

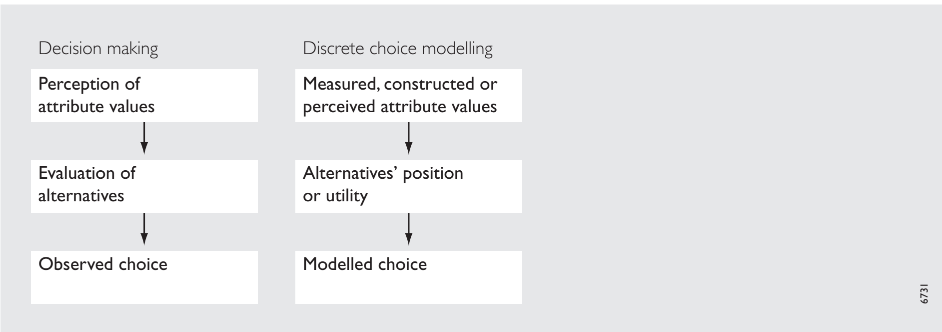

Figure 3.3 Conceptual model of decision making process and discrete choice modelling (based on Louviere, 1988; Adamowicz et al., 1997).

questionnaires (see e.g. Adamowicz *et al.*, 1997). From all alternatives in the data set a choice set is constructed whereby selection often takes place on the basis of the attribute values (see Cantillo and Ortúzar, 2005) or through a sampling process (see Ben-Akiva and Lerman, 1985). SC studies differ from RC studies in this respect, because the choice set and the alternatives' attribute values are set by the researcher; hence Adamowicz *et al.* (1997) classify SC attributes as 'constructed' attribute values. As respondents base their choices on these attributes, the attributes can be seen to be equivalent to perceived values.

Once the choice set and the alternatives' attributes are determined a decision rule (or a combination of decision rules) determines how the decision maker chooses an option from the choice set. Ben-Akiva and Lerman (1985) distinguish between the following types of decision rules:

- Dominance of one option's attribute levels: an option is chosen if none of its attributes has a level worse than any other option and at least one of its attributes has a level better than all other options,
- Choice of satisfactory options: an option is chosen if all of its attributes have a level better than a threshold level,
- Lexicographic rules: an option is chosen if it has the best level for the most important attribute; if more options have an equally high level then these options are compared on the basis of the second-important attribute, etcetera,
- Utility maximisation: an option is chosen if it has the highest value for a function of attributes.

In the model described in this thesis decision-making is based on utility maximisation. Utility maximisation differs from the other decision rules by being (essentially) compensatory, i.e. a dissatisfactory value for one attribute can be compensated by better values for other attributes. Important for this thesis is that random utility theory enables to take account of heterogeneity in taste with still having modest data requirements. Especially since the development of random utility theory the framework of utility maximisation is most extensively used in predictive models of decision-making. For the current thesis this is beneficial because many modelling techniques and software packages have been developed for analyses like those presented in this thesis, including techniques to assess the relevance of innovative location attributes such as high-speed rail.

This section gives a concise description of random utility theory and the modelling techniques that are used in discrete choice modelling; more extensive discussions on various aspects concerning discrete choice theory can e.g. be found in Louviere (1988) and Train (2002). The section first discusses the general principles of random utility theory and then three model prototypes for discrete choice modelling: the multinomial logit model, the nested logit model and the random parameter logit model.

3.2.1 Theory of random utility maximisation

Random utility theory is based on the work of McFadden (1974; 1978) and is predominantly used in transport modelling and related fields. Consistent with micro-economic theory random utility theory assumes decision makers to maximise their utility when making a choice. The utility U_{kn} of a choice option is thereby seen as an additive function of a quantifiable utility component V_{kn} (the 'observed utility') and an unknown utility component ε_{kn} that is assumed to have a predefined statistical distribution (the 'random utility'). The utility for a decision maker *n* to choose option *k* out of a choice set *K* is thus:

$$U_{kn} = V_{kn} + \varepsilon_{kn} \qquad [3.1]$$

The observed utility component for the alternatives is seen as a function of a set of quantifiable and measurable attributes. Observed utility functions can be additive, multiplicative or dual-distributive (i.e. a combination of additive and multiplicative terms, Louviere, 1988). In multiplicative terms an attribute's effect on utility is dependent on the level of one or more other attributes in the utility function. These attributes interact with each other, therefore multiplicative terms are often called interaction effects in the context of a primarily additive utility function. Most applications of random utility theory use additive utility functions or functions with additive terms and first order interaction effects (i.e. the product of two attributes); the use of third or higher order interaction effects is rare or absent (Louviere *et al.*, 2000).

Applications also frequently use alternative specific constants to correct for systematic differences in utility between choice options that are not embedded in the attributes. One of the choice options should thereby be appointed to be the 'reference alternative' that has no alternative specific constant, since utility is not an absolute quantity but only refers to the difference in attractiveness between choice options. Alternative specific constants can be seen as a way to take account of a choice option's attributes that are not accounted for explicitly in the model.

The observed utility function of a choice option *k* for a decision maker *n*, including first-order interaction effects, can then be specified dependant on *q* of the choice option's attributes X_{kq} as:

$$V_{kn} = \alpha_{kn} + \sum_{q} \left(\beta_{knq} X_{kq} \right) + \sum_{q_1} \sum_{q_2 \neq q_1} \left(\beta_{knq_1q_2} X_{kq_i} X_{kq_2} \right) \qquad [3.2]$$

where α is an alternative specific constant and β's are taste parameters to be estimated.

On this basic utility function several variations are possible. Firstly, non-linear effects may be included for the attributes. For example, a specific attribute might be relatively less important for higher values of this attribute. Different options for non-linear effects are further discussed in the sections 3.3.4 and 3.5.

Secondly, variations are possible for the taste parameters and alternative specific constants. These can be single parameters to be estimated, but are also often seen as a function of a set of respondent characteristics W_{ns} (typically in the form of 0/1 dummy variables), to express taste heterogeneity:

$$\beta_{knq} = \beta_{kq,0} + \sum_{s} \left(\beta_{kq,s} W_{ns} \right) \qquad [3.3]$$

The random utility component is assumed to be independent from the observed utility component. It is further assumed that it represents a number of aspects not embedded in the observed utility component. Interpretations of this random coefficient can include among others to account for (see e.g. Echenique, 2004):

- Attributes not in the observed utility function,
- Measurement errors in the observed attributes,
- Individual taste variations for the attributes in the observed utility function, as far as this is not taken into account explicitly in the observed utility component,
- The general finding that decision makers are often utility satisfiers rather than utility maximisers, and
- Aggregation errors with regard to the choice options.

Different statistical distributions are possible for the random component. On the basis of the assumption for this distribution, in general two types of models are most commonly used:

- Probit models, where the random utility component has a normal distribution.
- Logit models, where the random utility component has an extreme value distribution (an approximation of the normal distribution, as is described in the next subsection or see Ben-Akiva and Lerman, 1985; Train, 2002),

In general, probit models have some theoretical advantages, but are more difficult to apply since (unlike the extreme value distribution) the normal distribution does not allow for a simplification of the model specification (see Bhat, 2000). In the current research where the location choice and transport models deal with a large (and varying) number of choice alternatives the use of a probit model did not proof to be feasible; attempts with this type of model did either not show benefits over an alternative logit model (in the case of the SC location choice model), or had estimation problems caused by the large number of alternatives used in this application since estimating this type of model is computationally complex. Therefore the main focus here is on the logit models. Many types of logit models exist, which differ depending on the underlying assumptions. The description following subsections is limited to three common types of logit models that are relevant for the current research: the multinomial logit model, the nested logit model and the random parameter logit model.

Despite the wide use of random utility maximisation in modelling transport and location choices, some comments should be made about the framework described above. Firstly, the use of utility maximisation with a simple additive utility function implies that choices are based on compensatory rules, i.e. for being chosen an unfavourable characteristic of a choice option can be compensated by favourable values for other characteristics (e.g. Witlox, 1998). Even though studies have indicated that threshold effects may exist (i.e. choice options may not be chosen if an attribute has a value below some minimum acceptable limit). Extensions of the discrete choice framework (e.g. Cantillo and Ortúzar, 2005) would allow for choice options having an unacceptable value for an attribute to be excluded from the choice set. Furthermore, thresholds may be partly corrected for by introducing non-linear effects for attributes.

Many applications of discrete choice models use measured values for attributes in the utility functions. It are, however, not the measured values that determine the choices being made but the perception or belief of the attribute values by the decision maker (Louviere, 1988; Adamowicz *et al.*, 1997). Measured values may differ from perceived values, because (1) measurement errors can cause measured values to differ from the real values, and (2) misperceptions can cause perceived values to differ from the real values. Therefore, the type of data that is used should be considered when evaluating model results.

Despite of these considerations the current research still adopts a random utility framework. The main reasons for this are:

- The field of random utility modelling is well developed and has gained much experience in applications in the recent past,
- Most transport models and LUTI models rely on random utility theory, which makes the current research theoretically better compatible with additional or comparable models,
- Techniques have been developed to assess the relevance of new products or attribute levels and to relate these to choices that have actually been made in the past (and can therefore provide realistic prognoses),
- Random utility maximising models require data that is relatively straightforward and generally available, and
- Software to estimate random utility models is widely available in commercial software packages, even for some of the more advanced model versions.

3.2.2 The multinomial logit model

The multinomial logit (MNL) model is the simplest model in the logit family and most often used in empirical discrete choice studies (see Ben-Akiva and Lerman, 1985). It is based on a number of rigid assumptions, which can be summarised as:

- The unobserved utility component of a choice option is distributed following a Gumbel distribution (or type I extreme value distribution, see below),
- The unobserved utility is independently and identically distributed (called the IID condition), in other words: the unobserved utility component is not correlated across choice alternatives and has the same standard error for all alternatives,
- The observed utility of a choice option is independent of irrelevant alternatives (called the IIA condition), which means that the relative probability of choosing an option over another does not depend on what other alternatives are available in the choice set.

These assumptions make the parameters in the MNL model to be estimated relatively easily (see e.g. Train, 2002).

The probability of choosing an option k^* out of a choice set K when maximising utility can be formulated as:

$$\begin{aligned} P_n(k^* \mid K) &= P_n\left(V_{k^*n} + \varepsilon_{k^*n} \geq V_{kn} + \varepsilon_{kn} \; \forall k \neq k^* \in K\right) \\ &= P_n\left(\varepsilon_{kn} \leq \varepsilon_{k^*n} + V_{k^*n} - V_{kn} \; \forall k \neq k^* \in K\right) \end{aligned} \quad [3.4]$$

The Gumbel distribution is a bell-shaped distribution that roughly resembles the normal distribution. Following this type of distribution the probability of choosing one alternative over another is specified as:

$$P_n\left(\varepsilon_{kn} \leq \varepsilon_{k^*n} + V_{k^*n} - V_{kn}\right) = \exp\left[-\exp\left[-\sigma\left(\varepsilon_{k^*n} + V_{k^*n} - V_{kn}\right)\right]\right] \qquad [3.5]$$

Hereby σ is the so-called scale parameter of the model, which expresses how well the model explains the choices that have been made in reality. It is inversely related to the variance of the random utility component (the IID assumption implies equal variance for all choice options):

$$\sigma = \pi / \left(\sqrt{6}\ \mathrm{var}\left[\varepsilon_{kn}\right]\right) \qquad [3.6]$$

Using equation 3.5 to solve equation 3.4 gives a relatively straightforward solution (for more detail on the derivation of the MNL model, see e.g. Ben-Akiva and Lerman, 1985; Train, 2002):

$$P_n\left(k^* \mid K\right) = \frac{\exp\left[\sigma V_{k^*n}\right]}{\sum_k \exp\left[\sigma V_{kn}\right]} \qquad [3.7]$$

As a drawback of equation 3.7, however, the scale parameter σ cannot be explicitly known. Instead it is implicitly embedded in the model's taste parameters. In applications using a single data set this is no problem after all, but it makes results from different data sets not directly comparable. For most applications the scale parameter is thus not especially relevant and therefore omitted from equation 3.7. For combining SC and RC data scale differences are important (Swait and Louviere, 1993), which is why it is addressed explicitly here.

The taste parameters in random utility models are estimated using likelihood maximisation. Through iterations the maximum is determined of the log-likelihood function:

$$L = \sum_n \sum_k p_{kn} \ln\left[P_n(k)\right] \qquad [3.8]$$

Hereby p_{kn} equals one if option k is chosen by actor n and zero otherwise.

The log-likelihood function always has a negative value, which (besides on the prediction performance of the model) depends on the number of choices in the data set and on the size of the choice set. The maximum log-likelihood value is therefore not very suitable to give an indication of the model's prediction performance. Instead, a ρ^2 or pseudo-r^2 statistic is calculated:

$$\rho^2 = \frac{L_0 - L}{L_0} \qquad [3.9]$$

Hereby L_0 is the maximum log-likelihood of some reference model based on the same data; usually a model with an observed utility set to zero or to an alternative specific constant. The values for ρ^2 lie in the zero to one interval, in analogy to the correlation coefficient (r^2) in linear regression, although its values are not directly comparable to r^2 for determining the model fit. Models with a ρ^2 between 0.2 and 0.4 can be seen to have a very good model fit (this would be comparable with an r^2 of between 0.7 and 0.9 for linear functions, Louviere *et al.*, 2000).

There are two criteria on which it can be determined to include or exclude attributes or to restrict or release parameters in the observed utility function. The first is a t-test for parameters, which determines to what statistical level an individual parameter or a function of parameters differs from zero. If a parameter shows a low significance according to its t-value then it can be excluded from the model. Ortúzar and Willumsen (1994) thereby make distinction between parameters for policy attributes (attributes that are relevant for the main focus of the model) and parameters for other attributes. Policy attributes can be included as long as their parameters have the correct sign (an incorrect sign would be a considerable problem here). For other attributes a lower boundary for the significance is imposed, which is typically 80 percent in case of RC data. Parameters in SC models in most cases have higher significances then corresponding parameters in RC models, thus allowing for a higher boundary.

The second criterion is a likelihood ratio test, based on the difference in maximum log-likelihood between the models with and without an attribute or parameter restriction. This difference approximately has a chi-square distribution (Louviere, 2000), from which a significance level can be obtained. Where t-tests can only be used on single parameters, likelihood ratio tests have the capability to deal with multiple changes at a time, as long as one model version is a special case of the other model version. In the current research t-tests are used to choose which attributes to include in an observed utility function, and likelihood ratio tests for more complicated choices.

After all, the main advantage of the MNL model is clearly its ease to use, which makes software to estimate the MNL model parameters to be widely available. The underlying IID and IIA assumptions of the model, however, make the MNL model to be strictly inappropriate in many discrete choice situations. Therefore more extensive random utility model types have emerged to relieve these assumptions.

3.2.3 The nested logit model

One of these more advanced models is the nested logit (NL) model. This model type partially relaxes the IIA assumption of the multinomial logit model. The problem of the IIA assumption reveals itself in the so-called red-bus/blue-bus problem (e.g. Ben-Akiva and Lerman, 1985; Train, 2002): if for travel between two places someone can choose between a (blue) bus service and taking the car, then adding a second (red) bus service will most likely attract relatively more travellers who previously took the blue bus service than who previously went by car. For the MNL model, however, the IIA assumption implies that the model would predict the share of travellers changing their choice to the red bus to be equal for car and blue bus.

In an NL model a hierarchical nesting lay-out is used to specify that some choice options are more similar to each other than to other choice options (e.g. Daly, 1987; Train, 2002). ‘More similar’ thereby means that the choice options are more competing to each other and therefore a change in their observed utility level would affect each other’s probability more than the probability of other choice options. In a tree-like structure choice options are grouped into branches or nests on the basis of their similarity. These nests can themselves then be grouped further into higher level nests, and so on. For example, in the blue bus/red bus problem the two bus services might be grouped into one nest and car into another.

The NL model is in structure identical to the conditional logit model, where every level in the hierarchy is seen as a new choice. For example, travellers will first make a choice between car and bus, and then between blue bus and red bus conditional on bus being chosen over car. The difference between the NL and conditional logit models is in the estimation of the parameter. For the conditional logit model parameters are estimated for each choice consecutively, maximising log-likelihood for each level separately (called limited-information maximum likelihood, or LIML). In an NL model parameters are estimated in a single procedure, maximising log-likelihood for the whole model at once (full-information maximum likelihood, or FIML). In general, NL is preferred over conditional logit, but the complex functions makes FIML more difficult than LIML, which may cause estimation problems.

In case of a simple two-level NL model with Q nests, then the probability that an option k in nest Q is chosen can be formulated as:

$$P_n\left(k \middle| k \in K_q\right) = \frac{\exp\left[\sigma_q V_{kn}\right]}{\sum_{k \in K_q} \exp\left[\sigma_q V_{kn}\right]} \times \frac{\exp\left[\frac{\tau_q}{\sigma_q} I_{qn}\right]}{\sum_{q \in Q} \exp\left[\frac{\tau_q}{\sigma_q} I_{qn}\right]} \qquad [3.10]$$

Hereby the attractiveness of a nest q as a whole is determined by its inclusive value:

$$I_{qn} = \ln\left[\sum_{k \in K_q} \exp\left[\sigma_q V_{kn}\right]\right] \qquad [3.11]$$

In equation 3.10 there are two sets of scale parameters: the scale parameters σ for the elemental alternatives and the scale parameters τ for the branch level. To be consistent with random utility theory all scale parameters should be positive and the scale parameters for the alternatives within a branch should not be smaller than the scale parameter of their branch: $\tau \leq \sigma$, although in practice applications easily yield results that violate this condition (see Daly, 1987).

The two sets of scale parameters cannot both be estimated within the same model. One set should be fixed to unity, or in other words the model should be normalised to one set of scale parameters. The choice which set is used for normalisation is often made arbitrarily, but can under certain conditions lead to differences in model results (for more details on the consequences of normalisation see Hunt, 2000; Hensher and Greene, 2002). For the application of the spatial interaction models and accessibility in the next chapter it is more convenient to fix the elemental scale parameters σ. This results in the model:

$$P_n(k) = \frac{\exp\left[V_{kn} + \left(\tau_q - 1\right) I_{qn}\right]}{\sum_q \sum_{k \in K_q} \exp\left[V_{kn} + \left(\tau_q - 1\right) I_{qn}\right]}, \quad I_{qn} = \ln\left[\sum_{k \in K_q} \exp\left[V_{kn}\right]\right] \qquad [3.12]$$

The inclusive value parameter τ determines the strength of the nesting structure; lower values of τ mean a stronger nesting. Following random utility theory the inclusive value parameter should lie on the interval $0 < \tau \leq 1$ for the NL model to be internally consistent. From equation 3.12 it can be seen that the NL model has the MNL model as a special case if τ equals one.

For the application to location choices it is necessary to explicitly determine the elemental scale parameters, since these are used to compare SC and RC data. This model is formulated as:

$$P_n(k) = \frac{\exp\left[\sigma_q V_{kn} + \left(\frac{1}{\sigma_q} - 1\right) I_{qn}\right]}{\sum_q \sum_{k \in K_q} \exp\left[\sigma_q V_{kn} + \left(\frac{1}{\sigma_q} - 1\right) I_{qn}\right]}, \quad I_{qn} = \ln\left[\sum_{k \in K_q} \exp\left[\sigma_q V_{kn}\right]\right] \qquad [3.13]$$

The NL model has some advantages over the MNL model, as it partially relaxes the IIA and IID assumptions. With the NL model the IIA assumption applies to choice options that are within the same nest, but not to options in different nests (McFadden, 1978; Train, 2002). Furthermore, IIA applies on the level of the nests: omitting a whole nest does not affect the relative probability of the other nests being chosen. The IID assumption is also partially relieved in the NL model. Random utility components of choice options within nests are still correlated to each other (these are not independently distributed) and have an identical standard error. On the other hand, Random utility components of choice options in different nests are not fully correlated to each other, but have independent standard errors. Also the model allows the scale parameter (and thus the standard error) to differ among nests.

Despite the favourable properties with regard to partially relieving the assumptions from the MNL model, NL models have a number of limitations. Firstly, the nesting structure should be determined exogenously. In many applications more than one nesting structure seems theoretically plausible a priori. In that case a choice should be made which nesting scheme to adopt e.g. on the basis of the maximum likelihood estimations The more advanced cross-nested logit models offer more possibilities, since these allow a choice option to be part of multiple nests and to some nests more than to other, but these are computationally more difficult than the simpler NL model and therefore not feasible in the current thesis. As another limitation of the NL model the IIA and IID assumptions partially remain imposed, especially within nests and on the top level of the nesting structure. In particular, the use of multiple observations per respondent would violate the IID assumption in the NL model, since taste can be expected to be constant over these observations. With the increased use of multiple observations per respondent, e.g. in SC research, the need has arisen for more flexibility to model individual taste differences.

3.2.4 The random parameter logit model

A type of model that does offer more flexibility is the random parameter logit (RPL) model. The RPL model is a version of the mixed logit class of models (Hensher and Greene, 2003). Where the NL model primarily aims at relieving the IIA assumption, the mixed logit models explicitly relaxes the IID assumption by adding randomised coefficients to the model. (Mixed logit models are called like this since their random utility component is a mixture of logit and other distributions, Brownstone *et al.*, 2000). The RPL model differs from the MNL model by enhancing the taste parameters in equation 3.3 with an individual-specific coefficient μ_{knq} to model unexplained taste heterogeneity:

$$\beta_{knq} = \beta_{kq,0} + \sum_{s} \left(\beta_{kq,s} W_{ns} \right) + \mu_{knq} \qquad [3.14]$$

This coefficient is assumed to be randomly distributed across the decision makers, following an exogenously determined type of statistical distribution. Hence every actor in the data set is assigned a unique set of taste parameters. The random parameters are part of the unexplained variation of the model, but offer the opportunity to take account of several aspects of this variation. As a most relevant feature for the current research, the RPL model accommodates for multiple responses per respondent, which is common in SC studies. If a data set contains multiple observations of a respondent then the unexplained utility components of these observations are likely to be correlated, thereby violating the IID assumption of the MNL model. In the RPL model this issue can be solved by holding the random parameters equal across observations from the same respondent (see Revelt and Train, 1998).

It is to be determined exogenously which taste parameters receive a random coefficient and which type of statistical distribution is assigned to these random parameters. Indications for the first question can be derived from observing the unexplained variation (or residual) of an MNL model on the same data. If a positive relation exist between the value of an attribute and the unexplained variation then a random parameter is likely to be relevant. For the eventual choice of random parameters t-tests can be used.

Common distributions for the random parameters are the uniform, normal, lognormal and triangular distributions. Typical applications use uniform distributions for discrete variables (dummy codes or effect codes), lognormal or triangular distributions for taste variables that are theoretically restricted to a certain sign (e.g. the taste parameter for prices is often restricted to be negative), and normal distributions otherwise (see Hensher and Greene, 2003). The choice of random parameters can thus be based on theoretical grounds and on a comparison of maximum log-likelihood estimations. Further possibilities are to allow the random parameters to be correlated to each other or to include parameters that explain the heterogeneity of the random parameters' standard deviation (Greene *et al.*, 2006).

Estimation of RPL models is usually based on simulation techniques. Since it is relatively complex it will not be discussed here any further. Estimation techniques and other technical aspects of the application of mixed logit models are described by Bhat (2000) and Hensher and Greene (2003).

To conclude, RPL models are a way to relieve the IID assumption of the MNL model by introducing individual variation in the taste parameters. This has the advantage of giving more flexibility for analysing the structure of individual preferences. It also facilitates multiple observations per respondent. As a drawback of the supposed individual taste heterogeneity, however, contrary to the MNL and NL models the RPL model can only be applied to disaggregate data, i.e. data that is explicitly specified as individual choice situations instead of aggregated market shares.

3.3 Methodology for the data collection

Data is collected in this research to apply a discrete choice model on office location choices. With regard to this data collection three stages of interviews and questionnaires can be identified:

1. A small number of in-depth face-to-face interviews of an explorative nature,
2. Telephone interviews to yield RC data, respondent characteristics and other statistics,
3. An SC questionnaire for attaining SC data, distributed among the RC respondents.

The first of these stages primarily aims to support the design of the latter two questionnaires and would therefore be discussed shortly in this section. The main emphasis here lays on the telephone interviews and SC data collection. This section first focuses on the orientation stage of the empirical research that aimed to identify possible location factors. The second subsection discusses the results of the explorative interviews that are used as a basis for the questionnaire design. Then the sampling strategy is discussed; most notably the issue of categorisation of companies and institutions is raised in order to demarcate the research population and to come to stratification and segmentation criteria. In the fourth subsection the procedure of the telephone interviews is detailed further. And finally, the distribution of SC questionnaires is shortly discussed.

3.3.1 Identification of location factors

For the design of the telephone interview questionnaires and especially for the design of the SC experiment it is necessary to have an a priori insight into which location factors are most relevant for office location decisions. Hereby, for the current research accessibility-related aspects require extra attention, especially those related to railway accessibility.

General economic-geographical surveys typically take account of a large number of location factors and are therefore very well suitable to attain an overview of the field. For the Netherlands a great number of researches of this type have been conducted (see e.g. Pellenbarg, 1985; Jansen and Hanemaayer, 1991; Sloterdijk and Van Steen, 1994; and see Healey & Baker, 1996 for an international study that includes the Netherlands). However, because of differences in methodology and in the specification of location factors it is difficult to compare or aggregate the results of these studies. In general, it appears that the most important location factors can be categorised as follows:

- Accessibility (including proximity to actors or infrastructure, and the availability of personnel),
- Price of real estate,
- Properties of the building (availability, representativeness, possibilities for expansion),
- Quality of the surroundings,
- Regional factors (working mentality, quality of life).

Accessibility-related aspects are among the most important location factors. These are both connectivity aspects (e.g. connectivity to the motorway network), and potential accessibility aspects (e.g. availability of personnel). On average, accessibility by car can be seen to be more important than accessibility by public transport (e.g. Jansen and Hanemaayer, 1991). However, typically for this type of economic-geographical surveys, the concept of accessibility is not analysed in much detail.

Applications of SC models mostly take account of much less location factors. An SC experiment on firm location choices has been carried out in the Netherlands by Rietveld and Bruinsma (2000), an international example is Leitham *et al.* (2000). Berkhout and Hop (2002) used a related technique to analyse location attractiveness: stated preference with scoring or alternatives. These applications use six or seven attributes but differ in the location factors that are taken into account. Thereby, SC experiments can include soft location factors (i.e. qualitative location factors such as the image or representativeness of the building or surroundings) by using dummy variables.

Discrete choice models using RC data for firm location choices can for example be found in McQuaid *et al.* (1996) and Waddell and Ulfarsson (2003). These models typically hold more attributes than SC models, but due to exogenous influences the parameter estimations show lower significance levels. Furthermore, RC models are restricted by data availability, which makes it usually impossible to include soft location factors. In addition, in RC applications supply-side characteristics, such as the type of land-use at a site become important. It can be difficult to assess to which degree the location of a firm is due to the preferences of a firm or is influenced by supply-side characteristics (e.g. government policy or the availability of space). Therefore also these supply-side characteristics are relevant to embed in an RC model.

3.3.2 Orientating interviews

The studies described above give indications for what location factors to include in the SC experiment and the RC location choice model. None of the studies found in literature, however, deal with railway accessibility in a detailed way. To gain more insight into what aspects of railway accessibility are important to location choices a series of nine in-dept face-to-face interviews were held among decision makers of offices. Offices were selected that had relocated between mid-1998 and mid-2003; with this criterion the respondents were supposed to have the (re)location process still clear in mind. Because of the specific focus on (high-speed) railway accessibility six offices were selected that chosen a location within 500 metres of a large railway station with high-speed train connection, while the three other offices had located further away from such a station and thereby function as a control group.

The interview questions particularly focussed on the role of accessibility by (high-speed) train in their location choices, but also questions about accessibility in general and related location factors were asked. The interviews yielded qualitative information on which accessibility and non-accessibility factors are likely to be important for the location choices of offices. Besides of identifying rail-accessibility related location factors, the interviews provided insight into what questions could be asked to respondents of the telephone interviews and how these questions should be formulated.

In general, accessibility had been an important location factor to the respondents, but the exact elaboration differed greatly among the offices. Especially variation occurred in the relative importance of the transport modes (notably car and conventional train) and in the role of different trip purposes. The latter is likely to be explained by the activities that take place in the office, especially whether or not the location is regularly visited by customers. For the accessibility by train, the frequency and number of connections on a station seemed to be important to the firms. Five out of six respondents located in a station area did mention that the location choice had been largely influenced by the convenience of these level-of-service factors for employees and visitors. High-speed rail did not appear to have played an important role in any of the cases. This was not unexpected, as none of the respondents did have a predominantly international orientation. By the time of these interviews the two high-speed rail connections in the Netherlands did still provide a rather infrequent service and offered hardly any travel time advantages over conventional trains for domestic journeys.

To conclude, the in-dept interviews showed that various railway-related accessibility factors are likely to be relevant for the location choices of at least part of the offices. The importance of different accessibility factors, relative to each other and to non-accessibility factors, varies strongly between different types of firms. Apart from the accessibility factors, especially the appearance of the building and its surroundings seemed to be relevant.

3.3.3 Sampling strategy

For obtaining a sample of potential respondents, first the issue of categorisation of firms and institutions is examined. Categorisation is relevant not only for setting selection criteria for the sampling of possible respondents, but also for stratification and the further segmentation of respondents in the resulting models. For the current research a proper segmentation can be seen to be especially important. The explorative in-depth interviews raised the suggestion that there is a large variety among offices not only in the importance of railway accessibility for their location choices but also in the factors that determine this importance. Following the aim of this research, the data collection focuses on office locations; however, hereby several selection criteria are possible.

Most studies on the location of economic activities use economic sectors or branches of industry as segmentation or stratification criteria. This has the advantage that these data are usually readily available in data sets of e.g. the chambers of commerce. Using branches of industry furthermore makes a study more compatible with similar studies and with possible additional data and model sources. Examples of the latter are economic input-output data and macro- and meso-level forecasts on economic developments.

However, several studies suggest that the activities that are performed at a firm or institution department are a more important factor for explaining taste heterogeneity among employment location (Jansen and Hanemaayer, 1991; Stec Groep, 2002). A segmentation solely based on branch of industry did therefore not seem appropriate for the current application. By specifically focussing on offices taste heterogeneity within the sample would be reduced considerably, but also several additional office characteristics influencing taste heterogeneity towards accessibility are considered. The orientating interviews discussed in the previous sub-section made clear that travel-related aspects could be of great importance to location choices. A priori expectations existed that the importance of accessibility by the different transport modes depends on the distance of incoming and outgoing business trips (the 'spatial orientation' of the office with regard to its business partners) and the number of business trips made per employee. For example, car accessibility can be expected to be especially relevant to offices that have employees regularly visit business partners and that provide the employees therefore with a company-funded car. Furthermore, intercity services are more likely to be relevant to offices that have business contacts more dispersed throughout the country, resulting in intercity services being often used (or optional) for business trips.

As no database exists that includes all relevant office establishments in the Netherlands in combination with their functional characteristics, it was decided to use a sample containing all types of firm and institution establishments within the study area and then manually select offices from this sample. To acquire addresses of firms and institutions, a sample was taken from the LISA database (National Information System on Employment, in Dutch: Landelijk Informatie Systeem Arbeidsvoorziening), which contains practically all firm and government establishments in the Netherlands ordered by branch of industry, number of employees and geographical location. The sample comprises establishments that have at least 20 employees and are located within the study area (the provinces of North Holland, South Holland and Utrecht). The reason for the selection on establishment size is that this is supposed to increase the probability that the establishment has an international orientation, which is relevant for high-speed rail.

The sample was two-dimensionally stratified, with respect to the number of employees and the branch of industry. The number of employees was used as a stratification criterion because otherwise larger firms would be insufficiently present in the sample, while these firms have a relatively large share in the location of employment. A distinction was made between firms with 20 up to 100 employees and firms with more than 100 employees.

The branch of industry was used as a stratification factor to have an acceptable proportion of offices in the business and financial services industries and other industries. It seems reasonable to assume that in the business and financial services industries a relatively high proportion of the establishments have an office function, as many of these industries' main operational activities take place in office locations. In other industries (aggregated at the sector level) many of a firm's or institution's main activities take place in non-office locations. Furthermore, branches of industry from the database that are unlikely to contain office locations, and would therefore have a negative influence on the efficiency of the experiment, were excluded from the sample in advance.

To select offices from the sample selection procedures were applied in two stages. Firstly a manual pre-selection took place before contacting potential respondents. Selection was based on the description from the LISA database (e.g. to exclude local government services and banks) and on additional information from the company's internet site. A second selection took place after contacting the selected firms and institutions, when it was verified that office activities are the dominant activities on the respondent's location.

3.3.4 Telephone interview approach

In September-October 2003, after the first selection, the potential respondents in the sample were contacted by telephone. Telephone was used as a communication intermediary for the interviews as a trade off between efficiency to attain a large enough sample within a reasonable effort (given the spatial dispersion of the potential respondents face-to-face interviews would be too time-consuming) and the ability of an interviewer to guide the respondent through the questionnaire (a questionnaire by post or e-mail would lack this guidance, possibly resulting in a lower quality of the data and/or a lower response rate). The interviewers were mostly university students that were employed by an external agency. Beforehand these interviewers had received a detailed instruction on the questionnaire and its purpose. Computer aided telephone interview (CATI) software was used to manage the interview process. A series of test interviews were held to try out the interview set-up and the formulation of the survey questions. This did not reveal any significant problems.

In the first telephone contact with the establishment it was first verified that the location is an office location. Subsequently, an appropriate respondent within the office was searched. This is an important stage in the research as the reliability of the results as well as the response rate on individual questions depend on this. The respondent should have a function that implies (joint) responsibility for or otherwise close involvement in location decisions. In case the office directed to a decision maker in another office, this was accepted under the condition that the latter office itself was in the research area. After an appropriate respondent was found, this respondent was sent a letter introducing the research and announcing a telephone call in which the main interview took place (for a more extensive reflection on the aspects relevant for contacting potential respondents, see e.g. Curran and Blackburn, 2001). However, if a respondent was willing to participate in the research right away, as frequently occurred, the introduction letter was skipped.

In the second telephone call the main interview took place. Hereby questions were asked for three purposes:

a. Questions related to categorisation of the offices,
b. Questions from which additional statistics can be derived, and
c. Questions about the perceptions of the location factors.

Ad a: An important purpose of the interviews was obtaining information on the characteristics of the office, its employees and customers and on contacts with other business partners and other offices of the same firm or institution. These data were used for segmentation of the offices in the discrete choice models.

Ad b: Closely related to the previous point are questions from which some additional statistics can be derived about the respondents' perception of the travel behaviour of the offices' employees and visitors. Furthermore, although not the main purpose of these interviews, the opportunity was taken to include some questions on past location choices for offices that had recently made a (re)location decision.

Ad c: The respondents' perceptions of the location factors of their office can be used to compare with the calculated location attributes. This comparison may yield information on how well the calculated indicators represent the perceptions of the respondents and on how well the respondents are informed about the various location factors.

3.3.1 Stated choice questionnaires

The SC questionnaires were not part of this telephone interview itself, since it would be difficult to explain the different choice alternatives by telephone. Instead, at the end of the telephone call the respondents were asked if they were willing to fill in an SC questionnaire that could be sent to them by e-mail or post. Sending the questionnaire by e-mail has the advantage that the respondent receives the questionnaire shortly after the interview, when (s)he has the interview still clear in mind. However, some respondents might not have e-mailing facilities or might have a negative attitude towards electronic forms. Sending the questionnaire by post has the advantage that due to the official university writing paper the letter might appear more impressive to the respondent than an e-mail and thus might accommodate a higher response-rate. To compensate for the lower response rate and for possible technical problems with the e-mail or the electronic form, the respondents receiving the questionnaire by e-mail were send a reminder with a paper questionnaire by post about a month after the initial e-mail. The contents and structure of the SC questionnaire is described in the following section.

3.4 Design of the stated choice experiment

SC experiments are nowadays commonly used in several research fields, including transport studies. Also in research on location choices stated preference techniques are increasingly applied (recent examples are e.g. Rietveld and Bruinsma, 1998; Leitham *et al.*, 2000; Earnhart, 2002). Still, SC experiments are only limitedly used in studies on the impact of transport infrastructure on the location of economic activities (Rietveld, 1994; Leitham *et al.*, 2000), especially in the case of offices. As discussed in section 3.1, in this research an SC experiment is used to determine the effect of high-speed rail connectivity and other station level-of-service characteristics on the attractiveness of locations. In SC research much work goes into carefully designing the questionnaire. The following subsection shortly describes the setting-up of this experiment; for more information on the design of SC experiments see Louviere *et al.* (2000). Thereafter the analysis methodology of the SC data is described.

3.4.1 Design of choice sets

An advantage of SC studies is the possibility to attain multiple observations per respondent, which makes it possible to attain a reasonably large data set with a relatively small number of respondents. However, the number of choices per respondent should be limited because respondent fatigue may cause non-response and a lower quality of the response. The SC questionnaire discussed in this thesis consisted of eight binary choice scenarios preceded by a short introduction. The introduction firstly dealt with an instruction to the questionnaire form. This is kept straightforward, avoiding unnecessary details to keep the instructions easily understandable (for a discussion on issues involved in stated choice questionnaire design, see Louviere, 1988). Secondly, a brief description was given of current high-speed railway developments in the Netherlands. Although introductions like this can have an impact on the results, it was considered necessary for the unambiguousness of the questionnaire. A considerable part of the respondents is assumed to be unfamiliar with high-speed trains and/or the governments' (infrastructure) policy in this field. Therefore, omitting a description might lead to differences in interpretation of the alternatives.

The SC experiment studies the relevance of nine location attributes. This includes attributes related to the accessibility by train, attributes representing the accessibility by car, as well as attributes having no direct relationship with accessibility (although indirect relationships might be possible). The accessibility indicators taken into account are all connectivity indicators. The experiment is mostly aiming at choosing locations within the same city (most firms relocate over a small distance); centrality indicators typically have less variance for these choice situations and are thus less relevant for the experiment. Furthermore, centrality indicators from a RC model can be difficult to interpret by the respondents. Therefore, even if the availability of staff is relevant to an office decision maker then still the value of the potential accessibility indicator that represents this availability might appear meaningless to the respondent. Three out of four train-related attributes are varied between four levels (see Table 3.1): for the station access time and the frequency of trains this allows for estimation of non-linear effects; the type of train services encompasses the presence of four types of train services, including domestic high-speed train (HST) services and international HST services. The six other attributes can adopt two levels.

An issue still under debate is the number of attributes from which choice option can be constructed. Nine attributes might be too complicated for respondents to take account of in a single choice situation. For example Green and Srinivasan (1990) recommend a maximum of (about) six attributes per choice situation. However, for example Hensher (2004) argues that complexity is not to be avoided, since it is part of the natural process of decision making. Nevertheless, in practice decision makers would have much more time and benefit to tackle these complex issues carefully than is likely in the case of a SC questionnaire. In this experiment

Table 3.1 Attributes and levels in the stated choice experiment

Attributes	Levels	Sub-design
Accessibility by train		
Travel time to a station	5, 10, 15 or 20 minutes	Both
Transport mode to this station	Walk or bus	1
Total frequency of trains departing from this station	4, 16, 28 or 40 trains per hour	Both
Type of train services departing from this station	Only regional trains, also intercity trains, also domestic HST, also international HST	Both
Accessibility by car		
Travel time to a motorway access	5 or 15 minutes	1
Number of parking places per 100 employees	75 or 100	2
Non-accessibility factors		
Type of building	"Nice but not extraordinary" or "architectonic remarkable"	2
Type of environment	"In a city centre" or "in a city-rim office park"	1
Price of real estate	€ 150 or € 200 per m^2 per year	2

it is therefore decided to reduce complexity. Several methods exist to reduce choice complexity (see e.g. Green and Srinivasan, 1990; Oppewal *et al.*, 1994; Wang *et al.*, 2000). With the total of nine attributes so-called a bridging design seems most appropriate, because most more complex methods only become advantageous for larger attribute sets (Green and Srinivasan, 1990 mention a minimum number of ten attributes in this context) and a bridging design would allow to estimate some interaction effects (see below). With the bridging the total set of nine attributes in total is split into two designs of six attributes each, thus having three attributes in common. The three attributes not explicitly mentioned in the description of the choice alternatives were stated to be equal across the alternatives and at an acceptable level[7]. Table 3.1 above denotes for each of the attributes the level between which they vary and the sub-design in which they occur.

For each of the two designs the attributes were arranged into choice alternatives according to an orthogonal fractional factorial design. In contrary to a full factorial design in a fractional factorial design not all combinations of attribute levels are included. Therefore fewer observations are needed for the model. However, as a counterfeit, not all possible interaction effects can be estimated (and are thus controlled for) in the discrete choice model. The estimation of interaction effects shows whether or not and how the presence of an attribute influences the valuation of other attributes. Interaction effects can be estimated for combinations of two or more attributes, but in practice estimation is limited to two-way and three-way interaction (Louviere, 1988). With a bridging design interaction effects can only be estimated if both attributes are present within the same sub-design. Furthermore, the orthogonal set-up of the design aims at reducing correlation between the attributes at interest.

Given the number of respondents only a limited number of interaction effects can be taken account of. In the design of the SC questionnaires attention is given to the possibility of estimating some two-way interaction effects that are considered most relevant to the current research:

1. Complementarity of train-related accessibility factors: attributes expressing the accessibility by train might have mutual reinforcing effect. A special case for this is the non-linear interaction between station access time and station access mode.
2. Substitution of train- and car-related accessibility factors: a good accessibility by car might reduce the urge for a good accessibility by train and vice versa.
3. The image effect of high-speed train services: a location with a good accessibility, for example near a high-speed railway station, might have a high status and therefore attract offices even when these do not actually make use of high-speed train services on a regular basis. To study this hypothesis an interaction is tested between the availability of high-speed train services and the type of office building: an architectonic outstanding building and a prestigious environment might strengthen each other.

For each sub-design an orthogonal fraction consisting of 32 choice alternatives was constructed. The choice alternatives were presented to the respondents in the form of binary choice scenarios. Pairs of choice alternatives were created by randomly coupling the 32 alternatives per sub-design to an alternative out of a duplicate of the design, while avoiding the coupling of identical alternatives. The choice options presented to the respondents are unlabeled, that is to say the two alternatives do not have a meaningful name but are just assigned an indicator 'Location A' and 'Location B'. Labelling the choice options, e.g. with the names of existing locations, would add little value to the experiment but can greatly influence the respondents' stated choices.

Each of the respondents was sent one out of eight versions of questionnaire forms. Each form version contains eight choice scenarios, four out of each sub-design. Choice situations of the two sub-designs were to be assessed alternately, as a way to avoid patterned responses. The questionnaires were sent out by post or e-mail, according to the respondent's preference. As non-response is considerable (see Table 6.1) it was of importance to monitor the number of responses per questionnaire version that is returned. The relatively large time-span over which questionnaires were sent, allowed for correction by sending a higher proportion of questionnaire versions that had a relatively lower response rate.

3.4.2 Analysis of stated choice data

The results of the SC experiment are analysed an RPL model to take account of multiple responses per respondent and by an MNL model as a reference model to evaluate the relevance of the random parameter specification. For the estimation of the model parameters the commercial software package NLogit[8] was used. Since the experiment is unlabeled (i.e. no name other than a meaningless 'Location A' and 'Location B' is given to the choice alternatives) no alternative specific constants are included in the model; there is no theoretical reason why a respondent would choose Location A over Location B (or the other way around) other than based on the location's attributes.

For parameter estimation the attributes are coded as orthogonal codes (see Louviere, 1988), thereby retaining the original unit scale. For the station access time attribute the possibility of non-linear effects is determined by using quadratic and cubic polynomial codes. Together with the linear effect these quadratic and cubic codes make up a third-order polynomial function[9]. As a variation on Equation 3.2 the observed utility function is then:

$$V_{kn} = \beta_{knq,1} X_k + \beta_{knq,2} X_k^2 + \beta_{knq,3} X_k^3 + \ldots \qquad [3.15]$$

Beforehand, the valuation of the station access time is expected to decrease when access time increases and is also expected to depend on the distance that is maximally acceptable to walk. These aspects can be clarified by examining the polynomial representation. For the train frequency at a station non-linear effects are accounted for by testing the natural logarithm of the frequency apart from the linear effect. Non-linear effects are expected to be relevant because an increase in train frequency may be very beneficial for stations with a poor frequency but might add less value for stations that had already a high frequency. The type of train services attribute is represented by effect codes instead of orthogonal codes. Interaction effects are constructed by multiplication of the relevant orthogonal and/or effect codes. By using orthogonal codes and effect codes the correlations among the attributes and their interaction effects are minimized.

In the model estimation also account is taken of taste heterogeneity: the valuation of attributes can be different between distinct types of offices. Several indicators were derived from the information collected through the telephone interviews to represent the office characteristics.

These indicators are in the form of 0/1 dummy variables (specified in Table 6.2) and are interacted with the main effects. In this way, additional parameters are estimated in the discrete choice models that represent how the main effect changes when an office shows certain characteristics.

The heterogeneity indicators include office characteristics regarding commuting and business travels. These characteristics can be used to determine how the importance of accessibility depends on the frequency and properties of trips (most notably trip purpose and the spatial dispersion of origins/destinations). No research is known to the author were these characteristics are studied in relation to location choices. Several different specifications of heterogeneity characteristics were tested in the SC model to find the indicators that provided the most significant results. The following heterogeneity indicators appeared to perform best and were therefore used in the final version of the model:

The branch of industry: For the branch of industry a distinction was made between the business and financial services industries and other industries, consistent with the stratification applied by the data collection. The branch of industry is used for segmentation in most researches on firm locations. In the current research the relevance of the branch of industry for both accessibility and non-accessibility attributes was tested.

Reception of customers: If an office is visited by many customers then the accessibility is assumed to be more important. The number of customers visiting an office location is represented by the percentage of employees receiving customers at the office at least once a month. For the dummy variable a share of 50% was used as the boundary; this and following boundaries are based on the requirement that sufficient observations are present for each of the two categories.

Employees visiting customers: If many employees are visiting customers then accessibility is assumed to be more important for an office. However, for the accessibility by train also a reverse effect may occur: as employees who visit customers may be provided with a car by their employers the accessibility by train can become less important. The amount of employees of an establishment who visit customers is represented by the percentage of employees visiting customers at the office at least once a week. As with the reception of customers, for the dummy variable a share of 50% was used as the boundary.

Spatial orientation with respect to customers: The geographic extent of an office's market is related to the transport mode that is used for business trips. A distinction is made between offices that serve customers at a local or regional level and offices that serve customers nationwide or internationally. The spatial orientation is seen as relevant only for offices that have at least 50% of their employees visiting and/or have at least 50% of their employees receiving employees.

Spatial orientation with respect to employees: The geographic extent of an office's labour market is related to the transport mode that is used for commuting. A distinction is made between offices that have their employees living throughout the whole country (or even abroad) and offices with employees living within a smaller area.

International business trips: If frequently international business trips are made from an office the importance of international accessibility can increase. Especially relevant for high-speed trains are business trips to Belgium, Germany and France, which have direct high-speed train connections with the Netherlands. The heterogeneity indicator is therefore the presence at an office of employees making international business trips at least once a month, under the condition that their destinations include at least one of the aforementioned countries.

Apart from the main effects and the non-linear interaction between station access mode and station access time, in the final model only linear interaction effects and heterogeneity effects with a significance level of at least 80% were included. No further non-linear interactions or preference heterogeneities were tested because of the size of the data set that is available.

To better reflect the spatial distribution of employment rather than offices, the observations were weighted on the basis of the offices' number of employees. However, to retain the orthogonal properties of the survey design the weight of the eight form versions was set to be equal within each segment. Thus, the weighing was applied within each segment/version combination and between distinct segments (based on the average size of the offices in the segment).

Regarding the random parameters in the RPL model for dummy variables a uniform distribution is assumed and for other variables a normal distribution. These distributions are the most straightforward choices for the random parameters (see Hensher and Greene, 2003). For the price of real estate the random parameter is thus not a priori restricted to be negative since price could also be perceived as an indicator for the image of a site. A lognormal distribution, where the sign of the parameter is restricted, can also be tested.

3.5 Design of the revealed choice model

Compared to the SC model the RC model is more suitable for practical applications such as in the scenario study, because it better represents the uncertainty and variance in locations that are chosen in reality and because it is based on the same data sources that are available for the scenario study. The RC model is particularly used to test the calculated accessibility indicators. Furthermore, it forms the basis of the combined SC/RC model discussed in the next section.

In the RC model offices are modelled to choose a location out of other locations available in the study area. Locations are thereby represented in a GIS by grid cells with a width of 250 meter. This high spatial resolution is needed to properly take account of the importance of walking distance to and from a station. Furthermore, this resolution fits well with other land-use data available.

A distinction is made between the location choice between cities and within a city by making use of a nested logit model with nesting based on a division of the study area in 14 COROP regions (henceforth also referred to as 'urban regions'). COROP regions are a spatial division of the Netherlands commonly used for spatial-economic statistics, which makes the model compatible with other studies and exogenous data. In this model the urban regions are thus assumed to be static, as the immediate ability of high-speed rail to change patterns of commuting or business travel is seen to be rather limited. If in the long term indirect effects may cause location and/or transport effects to be more substantial then linking the location choice model to an analysis of functional regions is possible.

The RC model is based on the current location of the offices in the data set, regardless of how long the office has been located at that location. It can be seen that estimation of the model is based on the assumption of a dynamic equilibrium (i.e. a situation where the inflow of a certain type of office employment at a location equals its outflow). In other words: given the status of the location attributes for all available locations at the model's base year the distribution of employment at an aggregated level is supposed to have reached its ultimate value. This assumption is necessary to use base year location attributes to model the current location of offices, including those who have made their location decision long ago. In theory, a possible violation of this assumption does not have major consequences for the model as long as the location attributes are relatively stable over time. An alternative to the above assumption would be to use data from recently relocated offices only. This would, however, require a much larger effort for data collection and leads to an under-representation of offices that do not often make location decisions. Offices not making a location choice are relevant, since these occupy space that could otherwise be used by other offices.

3.5.1 Revealed choice set formation

The choice set for the RC model consists of the chosen location and alternative locations within the study area. For model estimation, the grid cells within the study area are only considered to be an alternative if there is employment located in that cell. Since the number of alternative locations within the study area is very large it is practically impossible to estimate the model with all the alternatives. The model is therefore based on a sample of locations following the IIA property of the model within the 14 urban regions in the study area. Choice sets are generated following a methodology described by McFadden (1978), who showed that using a random or stratified sample of alternatives is consistent with random utility theory under the IIA assumption. Each of the choice sets in the RC model consists of the current location of the office (the chosen option), 6 randomly sampled alternatives from the same urban region and 7 randomly sampled alternatives out of each of the other regions, to make a total of 98 choice alternatives.

This methodology is commonly used in studies on location choices (for recent applications see e.g. Earnhart, 2002; Waddell and Ulfarsson, 2003), despite of the criticism towards its underlying IIA assumption. Omitting alternatives with non-IIA models would strictly be inconsistent. Also in case the IIA assumption is not strictly seen to be valid, then McFadden's (1978) method could be considered to approximate a non-IIA model provided that the sample is large enough to yield a representative sample of the choice alternatives.

A disadvantage of the approach for the current application is that it is difficult to distinguish between aspects of demand and aspects of supply. This is because the decision makers of offices are restricted in their choice due to the limited availability of space. Supply-related factors may therefore enter the model, and parameters may be influenced by the restricted capacity around stations. Local and regional governements typically have restrictive policies for building in or near historical inner cities. Office locations near large stations, which are often near city centres, are scarcer than city-edge locations. Therefore an office decision maker might be forced to accept a city-edge location although it prefers a station location, while the reverse would be less often the case. Although supply this availability of space is partially accommodated for by including a land-use typology, the interference with supply factors urges for caution when interpreting the results of this model.

3.5.2 Location attributes in the revealed choice model

Similar to the SC model the observed utility in the RC model is based on a number of location attributes with no alternative specific constant. Hereby several accessibility and non-accessibility location attributes are used. The accessibility attributes are the potential accessibility indicators described in the next chapter, and a number of connectivity indicators. As connectivity indicators for the railway network the distance to the nearest station, the presence of intercity services at the nearest station and the total frequency of trains departing at the nearest station are used. The connectivity indicators are based on a catchment area analysis, whereby the locations are assigned to a station on the basis of road distance. Although distance is not always an optimal criterion for determining which station has the largest impact on a location's attractiveness, this is not seen as a problem since the influence of a station is most notable in the immediate surroundings of a station.

In a similar way as distance to a station, for motorway connectivity the free-flow car travel time to the nearest motorway ramp is taken into account. For the distance to a station and the travel time to a motorway ramp the effect on observed utility is considered to be non-linear. The shape of the function is thereby determined with a Box-Cox conversion (Box and Cox, 1964):

$$\left.\begin{array}{ll} X_{kq}^{(\lambda_q)} = \left(X_{kq}^{\lambda_q} - 1\right)/\lambda_q & \left|\lambda_q \neq 0\right. \\ X_{kq}^{(\lambda_q)} = \ln\left[X_{kq}\right] & \left|\lambda_q = 0\right. \end{array}\right\} \quad [3.16]$$

Box-Cox conversions have been used especially in transport related applications of random utility theory, such as for determining the shape of an impedance function in a spatial interaction model. The attractive property of a Box-Cox conversion is that it has a linear function and a logarithmic function as special cases, and that it has a single shape parameter that determines the shape of the function.

Besides these accessibility indicators also non-accessibility attributes are taken into account. A typology of urban land-use (Maat *et al.*, 2005) is used to represent both the function of the zone (residential areas, industrial sites, city centres, other) and the density of land-use in the zone. A total of ten types are distinguished. These types are quantified as -1/0/1 effect codes, using the left-over category as a reference. Apart from expressing the preferences of the office decision makers for these characteristics per se, the parameters of these attributes are also influenced by other factors. For example, government policy restricts building in historical city centres, thus limiting the possibilities for offices to choose a location in such a city centre. Also 'competition' for space with other land-uses plays a role here.

The price of real estate is not modelled explicitly in the RC model, although attempts have been made in this study to include real estate prices derived from a hedonic price regression (e.g. Rosen, 1974) in the model. Taking account of real estate prices can be complex in discrete choice models that are based on RC data, because real estate prices are often highly correlated with other location attributes. Therefore, applications could result in parameter estimations being insignificant or having a theoretically unexpected sign, as was also the case in the current application. However, under the assumption that real estate price is linearly dependant on the other attributes in the model, the price can be taken into account implicitly, incorporated into the other attributes.

3.5.3 Revealed choice model formulation

For the RC location choice model an NL model is assumed, with nesting based on the 14 urban regions. In this model it is assumed that locations within the same urban region are perceived to be more similar than locations in different urban regions. The inclusive-value parameters that determine the degree of similarity can be different across regions, since the regions are different in size and other characteristics. Having parameters fixed across regions of different size is subject to the modifiable areal unit problem (e.g. Paelinck, 2000). Still, in the interview sample not for all regions sufficient observations might be present to estimate a distinct scale parameter, since by far most offices are located in or near one of the four largest Dutch cities: Amsterdam, Rotterdam, The Hague and Utrecht. For the smaller regions therefore a joint scale parameter is estimated. The probability of an office q choosing a location z from the sample of region r is then expressed as:

$$P_q(z) = \frac{\frac{N_r}{n_r}\exp\left[\sigma_r V_{qz} + \left(\frac{1}{\sigma_r} - 1\right)\ln\left[\sum_{z \in Z'_r} \exp\left[\sigma_r V_{qz}\right]\right]\right]}{\sum_r \sum_z \frac{N_r}{n_r}\exp\left[\sigma_r V_{qz} + \left(\frac{1}{\sigma_r} - 1\right)\ln\left[\sum_{z \in Z'_r} \exp\left[\sigma_r V_{qz}\right]\right]\right]} \quad \left| Z'_r \subseteq Z_r \right. \qquad [3.17]$$

Hereby, N_r/n_r is a factor that corrects for the under-sampling of zones in larger regions (i.e. regions with more zones) as choice alternatives relative to the number of location choices that would ceteris paribus be made in larger regions. However, this application of this so-called size-variable is not fully consistent whith random-utility theory (Ben-Akiva and Lerman, 1985). As a result the modal can become (somewhat) dependant on the size of a regions if its scale parameter differs from one.

For simplicity the location choice can be divided into the choice of an urban region, based on the sample of zones:

$$P_q(r) = \frac{\frac{N_r}{n_r}\exp\left[\frac{1}{\sigma_r}\ln\left[\sum_{z \in Z_r} \exp\left[\sigma_r V_{qz}\right]\right]\right]}{\sum_r \frac{N_r}{n_r}\exp\left[\frac{1}{\sigma_r}\ln\left[\sum_{z \in Z_r} \exp\left[\sigma_r V_{qz}\right]\right]\right]} \qquad [3.18]$$

and the choice of a location within an urban region:

$$P_q(z|r) = \frac{\exp[\sigma_r V_{qz}]}{\sum_{z \in Z_r} \exp[\sigma_r V_{qz}]} \qquad [3.19]$$

3.6 Methodology for combined models of stated and revealed choice data

The combined model of stated and RC data aims to yield a single model that combines the advantages of the SC and RC models: a good valuation of station level-of-service attributes and a realistic representation of the explanatory capabilities of the observed utility component respectively. Two versions of such a model will be discussed in this section, one of which is later chosen for application in the scenario study. This section discusses these approaches.

In the combined SC/RC location choice models single taste parameters are estimated for attributes that are similar in the two data sets. A known problem in combining data sets in a logit model, however is that the scale parameters of the models to be combined can differ substantially and should therefore be corrected for (Swait and Louviere, 1993). Although the absolute value of the scale parameters cannot be known from logit models, the ratio between the scale parameters can be determined when combining multiple data sets through data fusion. In literature, several methods of estimating this relative scale parameter have been developed: methods using different types of logit models (for different approaches, see e.g. Hensher *et al.*, 1999; Brownstone *et al.*, 2000; Louviere *et al.*, 2000) or requiring 'manual' calculations (e.g. Swait and Louviere, 1993; Swait *et al.*, 1994). In this paper two different methods are used: one using an NL structure with full-information maximum likelihood (FIML) estimation (following Louviere *et al.*, 2000) and one using a sequential estimation procedure (following Swait *et al.*, 1994). In the subsections below these approaches are discussed in more detail, as well as a third alternative method that uses mixed logit techniques that has theoretical advantages but is not practically feasible in the current study.

For application of the methods described below it is important on which attributes data fusion is to take place. In other words, which attributes are assumed to have identical taste parameters in the two models to be combined. In order to use an attribute for combining data sources it is important that the attribute in both data sets is measuring the same feature and is expressed in the same unit. Furthermore, several aspects may cause two similar attributes not to be suitable for grounding data fusion, most notably measurement errors in observed data and respondent's perceptions differing from real values. Since the main purpose of the data fusion is to determine the effect of station level-of-service characteristics on location choices in the current paper solely the train frequency and the type of train services are used as merging attributes. The rather limited number of merging attributes may make the scale parameter less accurate for other attributes than station level-of-service, but seems most suitable for the purpose of this application.

3.6.1 The full-information approach

The FIML approach makes use of the ability of the NL model to estimate scale differences between nests. To do so, the SC options are treated as if it were additional options in the RC model. The RC options are therefore replicated eight times to match the number of SC observations per respondent. The RC options are retained as in the RC model: with nesting on the basis of the urban regions. The two SC options are virtually added to the choice set; separate SC branch. One choice situation would then appear in the model as is shown in Figure 3.4.

The full data set is then duplicated, whereby once the RC option is given as chosen and once the SC option. In this model set-up the relative scale parameter of the SC data with respect to the RC data then equals the inclusive-value parameter of the SC branch. The taste parameters and inclusive value parameters are then estimated to maximise likelihood for the whole model together.

3.6.2 The sequential approach

An alternative to full-information approach is the sequential approach proposed by Swait *et al.* (1994). In the sequential approach first an MNL model with SC data is estimated and its results are then used in a model with RC data. This model is therefore easier to estimate than the full-information combined SC/RC model.

The sequential approach not only differs from the FIML approach in the complexity and type of the estimation method, but the two approaches are also grounded in different assumptions with regard to the characteristics of the SC and RC data. In the FIML approach SC data is seen as a way to improve the RC parameter estimations by adding observations with lower correlation among attributes and to identify attributes that could not be distinguished on the basis of RC data only (Louviere *et al.*, 2000). The sequential approach goes a step further by stating that SC data is superior to RC data for the estimation of attribute parameters. Following the sequential

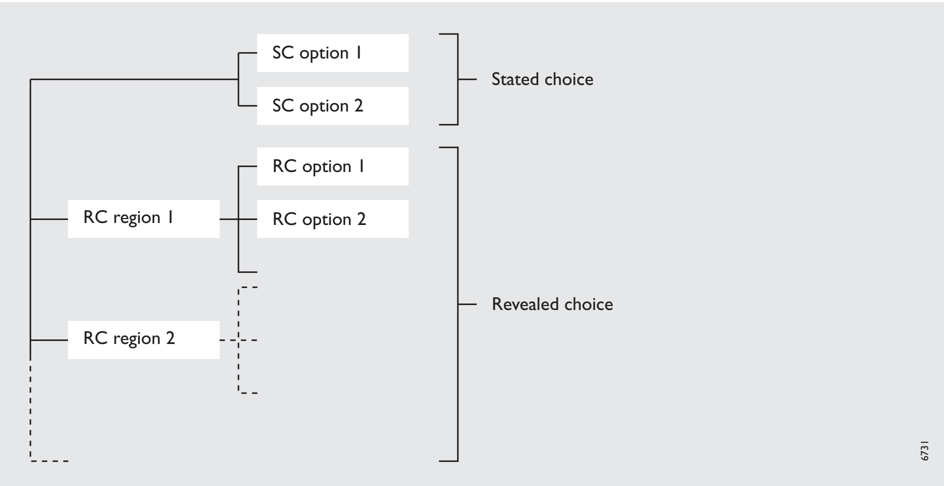

Figure 3.4 Nesting structure of the full-information maximum likelihood method.

approach, attribute taste parameters should therefore only be estimated on the basis of SC data and the purpose of the RC data is to ground these parameters in reality by estimating the relative scale parameter and alternative specific constants (Swait *et al.*, 1994). The current application differs from this view as no alternative specific constants are estimated; instead additional attributes (e.g. on land-use type) are taken into account for the RC data.

In the sequential estimation procedure first an MNL model for the SC data is estimated. For the attributes similar to the two models the SC estimates are then assumed to be the right values for the taste parameters. By using these taste parameters in an NL model to the RC data the relative scale parameter can be estimated. With this method the SC data are used to determine how the model reacts to an attribute change and the RC data to establish a realistic magnitude of this reaction.

Beforehand, it is not to say which of these approaches suits best for this particular application. Both methods have the advantage that the NL of the RC model is retained. Furthermore, both have the disadvantage that no account is taken of multiple observations per respondent. A major difference between these two approaches is that the taste parameters for station level-of-service are optimised for SC data and are therefore expected to show less declarative power when used on RC data. This would be accompanied by a higher scale parameter of SC data relative to RC data for the sequential approach compared to the FIML approach.

3.6.3 The mixed logit approach

An alternative approach that overcomes the disadvantage of the methods describe above is using mixed logit to take account of multiple observations per respondent. With mixed logit it is possible to approximate the nested logit structure from the FIML approach by specifying the utility function for a person *n* in the case of an SC observation as:

$$U_{kn} = V_{kn} + \varepsilon_{kn} + \mu_{sc,n} \quad [3.20]$$

And for RC data as:

$$U_{kn} = V_{kn} + \varepsilon_{kn} + \mu_{rc,n} \quad [3.21]$$

Hereby the ε_{kn} is the alternative-specific extreme value error term for option k with a standard deviation of one, as usual in a logit model, and $\mu_{sc,n}$ and $\mu_{rc,n}$ are normally distributed random parameters[10] with a standard deviation specific for the SC data or the RC region nest respectively. The normally distributed nesting parameters are equal for observations from the same respondent to account for multiple observations per respondent.

Although theoretically superior to the two methods discussed above, it has the disadvantage that mixed logit is very demanding with regard to the computational effort to estimate the model's random parameters. A model with all 100 choice alternatives per observation for all 297 respondents with 16 choice observations[11] per respondent would be far too complex to model. To simplify model estimation it is possible to use only intra-regional choice alternatives, reducing the number of choice alternatives to nine. This would also reduce the number of random parameters by one, since the nest with the lowest error term is to be used as a reference case for the nesting parameters. A disadvantage of this method is that only intrazonal location choices are modelled; the extent to which interzonal employment shifts are possible cannot be known from this model version. Furthermore the complexity of the model remains considerably. It is therefore concluded that it is not possible to use a mixed logit approach in the framework of this thesis.

4. Methodology for the design and estimation of spatial interaction models and potential accessibility indicators

In this chapter the methodology is described for analysing patterns of commuting and business travel and for specifying potential accessibility indicators. Firstly, spatial interaction models for commuting and business travel are presented. The term 'spatial interaction' here refers to the number of employment-household relationships (for commuting) or the number of business relationships (for business travel) between two geographical zones. It is not the purpose of the spatial interaction models to be used for assessing the transport effects of high-speed rail. Although some rude indicators of spatial interaction can be derived from the models, their task is primarily to serve as a basis for spatial interaction models. The models are therefore less extensive than state-of-the-art transport models. Because of the specific focus on a long-distance transport model also the required spatial level-of-detail is less high than is possible in transport models.

The first section of this chapter deals with the overall structure of the spatial interaction models. Subsequently, the second section focuses on a particular aspect of these models: the formulation of the impedance functions. Thereafter, in the third section methodologies and concepts are described to analyse the spatial interaction patterns resulting from the spatial interaction models. The fourth section gives attention to the formulation of potential accessibility indicators, which are derived from the spatial interaction models. Two types of potential accessibility indicators are discussed: gravity-type of indicators and contour indicators. The firmer are most commonly used in accessibility studies within the context of location choices, while the latter are more often used for specifically analysing long-distance accessibility. In chapter 5 the results of the spatial interaction models and potential accessibility indicators are discussed. The accessibility indicators are then used in the revealed choice model of office location choices in chapter 6.

4.1 Spatial interaction models

Spatial interaction models aim to model flows between areas (e.g. transport flows or communication intensities) in an aggregated way[12]. These models do thus generally not aim to describe individual choice behaviour but focus on overall patterns of flows. This makes this type of models suitable to study the impact of high-speed rail on patterns of commuting and business travel, although it does not model aspects on the level of individual transport users and is therefore less accurate in modelling specific transport processes than more extensive disaggregate transport models. Spatial interaction models can also be used to derive accessibility indicators. These potential accessibility indicators are especially suitable to represent accessibility's contribution to a location's attractiveness for activities (e.g. Geurs and Van Wee, 2004).

Gravity-type of spatial interaction models had first been used following analogies to the physics law of gravitation. Thereafter attempts were made to 'fill' the model specification with economic theory. Wilson (1970; 1971; 1974) used entropy theory to derive a family of gravity models. Entropy theory is a statistics-based approach to derive 'meso-states' (e.g. transport flows between areas) from 'macro-states' (e.g. trip production, trip attraction, average trip length), if the 'micro-states' (the travel behaviour of individuals) are unknown. Entropy can be seen as the total degree of randomness (i.e. the unavailability of information at the micro level) in the model, which is assumed to be maximal given the variation observed at the macro-states.

Around the same time McFadden (1974) introduced random utility theory to analyse travel behaviour, mostly based on individual observations. Analogies between the two approaches were obvious, but it took about a decade before Anas (1983) showed that the aggregated spatial interaction model is theoretically consistent with random utility theory and that (if based on the same data) likelihood maximisation (see chapter 3) and entropy minimisation yield identical parameter estimations. To be consistent with the location choice models described in the previous chapter the current research examines spatial interaction theory from a utility maximising perspective.

The spatial interaction model described in this chapter is applied to commuting and business travel in the Netherlands. The study area for the transport part of this research is thus larger than for the land-use part. The reasons for using this study area are: (1) this avoids biases in accessibility and travel patterns at the border area of the Randstad[13], and (2) travel data is available from the Dutch National Travel Survey for the whole of the Netherlands, but limiting the study area to the Randstad would give less accurate results for the analysis of especially business travel because then less observations are available of long-distance trips.

The next subsections consecutively give an overview of the spatial interaction model components, describe the data that is used, and give more technical details on the model specification and the accessibility indicators used.

4.1.1 Overview of the model

For the spatial interaction model distinction can be made between the four components described in subsection 2.2.3: trip generation, trip distribution, modal split and traffic assignment. The current subsection briefly describes how these four aspects are implemented in this research. The next subsection then focuses on the data that is used for achieving this model and the final subsection of this section gives a more technically detailed description of the spatial interaction model components.

Trip generation determines the importance of each zone in the accessibility indicators. For gravity-type spatial interaction models, such as is specified in this paper, the total amount of spatial interaction to and from a zone is determined exogenously. The aggregated spatial interaction per zone is thereby derived from a separate 'trip generation' function (see e.g. Ortúzar and Willumsen, 1994), which is typically only dependant on the characteristics of the zones and not on the ease of travel. In this paper we adopt this assumption, because a possible generative transport effect of high-speed rail is expected to be small and not worth the effort of developing a complex model with mutually dependant trip generation, distribution and modal split modules. As an implication, the accessibility indicators that are derived form the spatial interaction model will not be able to consider an increase in the total (i.e. nation-wide) number of business or commuting trip opportunities, but this is not seen as a serious shortcoming; such a feature is rather uncommon in accessibility studies.

In this application trip distribution and modal split are taken into account in combination with each other. Although many applications use spatial interaction models or potential accessibility indicators for a single transport mode without considering competing modes, in the current study combination of destination choice with mode choice is necessary. Estimation of parameters in the impedance function can be biased when mode choice is not included in the model estimation. This is especially the case for applications of train travel, because the long distance of a typical train journey can result in parameter estimations with a theoretically incorrect sign. An evaluation of all origin-destination relations possible by train shows that most trips are made on relations that have an above-average travel distance. In a destination choice model for train travel without mode choice this would be interpreted as if train travellers prefer long journeys over short journeys and thus have a positive taste parameter for train travel impedance. In reality the long average train travel distance is more likely caused by travellers choosing other modes over the train when making short trips, instead of travellers preferring long travel distances. Just like for other transport modes, train travellers have a negative taste parameter for travel impedance. This is modelled better in a model with mode choice embedded.

For the current research the main relevance of route choice or traffic assignment for a spatial interaction model is to provide impedance data. Route choice can be of interest, for example, when considering the market share of high-speed rail relative to conventional rail. But in general the exact way route choice is modelled does not have a large impact on the resulting interaction patterns or accessibility indicators. In the current research route choice is modelled using the shortest path algorithm, thereby assuming that travellers always choose the route with the lowest impedance (this can be seen to be a lexicographic rule from a discrete choice point of view). Also, no congestion is modelled on the road network or capacity constraints on the public transport network. This would require a more complicated travel model which demands a much larger computational and organisational effort, but is not likely to add much to the eventual results because firstly long-distance travel that is directly influenced by high-speed rail accounts only for a small part of all trips and secondly local congestion due to increased concentration of activities around high-speed railway stations is modelled less accurately in nation-wide travel models.

4.1.2 Data used for the model

For achieving the model described above three types of data are needed. Firstly, land-use related data is used for the production and attraction factors of the model. Travel impedance data are part of the utility function for the combined destination and mode choice. Finally, travel data is used for estimating the models' parameters. These data sources are further specified below.

Land-use data
For spatial interaction models land-use related data primarily concerns the amount of activities per zone. These are the main determinants for the zones' trip production and attraction. In some transport models other land-use characteristics are included in trip generation models as well, such as the type of land-use. These aspects can increase modal fit, although the relationship can mostly be seen as a substitute for segmentation of travellers rather than a direct causal relationship (see e.g. Wegener and Fürst, 1999).

In the current research for commuting, trip production and attraction are seen to be straightforward: the production factor is assumed to be the size of the working population living in the origin zone and the attraction factor is the number of jobs in the destination zone. For business travel, however, trip generation is more complicated. An important aspect of business trips is that these often occur in trips chains, where multiple destinations are visited before returning to one's work or home location. Of all business trips in the Dutch National Travel Survey about half of all trips is part of a chain of business trips. Furthermore, business trip chains can start and end at the employee's home location as well as at the work location or possible other locations for possible private activities. Trip production and attraction can thus theoretically depend on the location of economic activities as well as residential activities. To the author's knowledge spatial interaction models thus far do not accommodate chaining of trips. Models that do enable modelling trip chaining, such as activity-based models, are much more complex and require a large research effort. For the current application for studying high-speed rail, trip chaining is also less relevant because the train is only rarely an option for trip chaining. It is therefore chosen to deal with the trips within a chain independently of each other, by applying a regular spatial interaction model. Trip chaining is merely expressed in the model as a high alternative-specific constant for car and (to a lesser extent) for the leftover category, which results in the train being less often a viable option for business trips.

Impedance data
Impedance data function as the attributes of the choice options in transport choices. Table 4.1 gives an overview of the impedance attributes used in the model. For train travel data from the Dutch railway company NS is used in combination with station access and egress road distances from the Dutch national road database (AVV transport research centre, Ministry of transport, public works and water management). For other public transport and for car, travel times from

Table 4.1 Travel impedance data

Transport mode	Impedance attribute	Unit	Source
Bus/tram/underground	Travel time	Seconds	National model system 1995, AVV
Car	Morning rush hour travel time	Seconds	National model system 1995, AVV
	Rest-of-day travel time	Seconds	National model system 1995, AVV
Train	Station-to-station time	Minutes	NS (Dutch railways)
	Train fare	Euros 2000	NS (Dutch railways)
	Station access road distance	Meters	National road database 2000, AVV
	Station egress road distance	Meters	National road database 2000, AVV
Other	Road distance	Meters	National road database 2000, AVV

the Dutch national model system (AVV transport research centre, Ministry of transport, public works and water management) are used. Travel impedance for the leftover category, which mainly consists of slow modes, is also represented by road distances from the Dutch national road database. As can be seen from Table 4.1, not all impedance data are available for the year 2000. Particularly the travel time data from the Dutch national model system is only available for 1995. However, we assume travel times on most origin-destination relations have not changed much between 1995 and the year of analysis, 2000.

Because high correlation exists between the several impedance attributes for a single origin-destination relationship, only one impedance attribute is used for every mode (except for the train, as is discussed in section 4.2). For car morning rush hour travel time is used in the commuting model, because most commuting takes place during rush hours, and rest-of-day travel time in the business travel model, because more business trips take place in off-peak times than in rush hours. Furthermore, mode specific constants are included in the utility functions besides of the impedance attributes; hereby train is used as a reference mode, which has no alternative specific constant.

For road distance a distance matrix between zones from the Dutch National Travel Survey (in Dutch: 'Onderzoek Verplaatsingsgedrag', henceforth abbreviated as OVG[14]) is calculated from the national road database. Hereby the calculation of intrazonal distances is important. Typically intrazonal distances are calculated as being proportional to the radius of a circle with similar area (see Frost and Spence, 1995). Zones are thus assumed to be circular. However, as is illustrated by Frost and Spence (1995) controversy exist about the ratio of intrazonal distance and circle radius. An often-used ratio is 0.67; which is the average distance from all points in the circle to the centre of the circle. Hereby it is thus assumed that the origins are equally distributed over the circle and all destinations are located in the centre of the circle. The assumption that all destinations are located in the centre of the sphere underestimates the average intrazonal trip length (for illustration: assuming that destinations are also equally distributed over the circle leads to a ratio of 0.905; Frost and Spence, 1995). On the other hand, assuming an equal distribution would overestimate intrazonal distances, because cities are typically denser towards the centre and these can be surrounded by a rural zone. In addition to this, also within a zone distance decay is present, resulting in relatively much short trips. Another aspect is that the above figures are based on arithmetic approaches that assume airline distances, while for road travel also a detour factor applies. A detour factor commonly used is 1.2 (see e.g. Bonsall *et al.*, 1977). Therefore a ratio of 0.80 seems reasonable for use in this thesis; this is the 0.67 value multiplied by a 1.2 detour factor.

Travel data

Travel data are RC or SC data on transport choices being made by travellers. It was chosen to use secondary data. Having a dedicated data collection on travel choices would have some advantages, such as the possibility to use SC data for better determining the travel effects of high-speed rail (e.g. Hensher, 1997). But it was not expected to lead to considerable different accessibility effects and would therefore not enhance the overall model enough to justify the large effort required for attaining these data. Instead, it was chosen to use data from the Dutch National Travel Survey for the year 2000, because:

a. It contains data for the entire Randstad area (and even for the whole of the Netherlands), and
b. It contains data for all available transport modes.

Ad a: The large area of the OVG data is a prerequisite for two reasons. Firstly, a large study area ensures that for enough (medium-) long-distance journeys both origin and destination locations are known. For train travel volumes especially intercity journeys within the Netherlands are relevant. Secondly, having the Randstad area totally within the study makes the parameter estimations in the model valid for the whole of the study area. Although alternative data sets might give more information about the routing of a train journey, these detailed studies cover a smaller research area. An example of this is the Amadeus data set (see Krygsman, 2004).

Ad b: Having a single data-set with all available transport modes is necessary for this study, because estimation of parameters in the impedance function can be biased when mode choice is not included in the model estimation. As discussed above, this is especially the case for applications of train travel.

The year 2000 is used as a base year, because for this year much data is available (including the land-use data described above) and because the year is close to the time of the location choice interviews, so slow processes like land-use changes can be ignored.

The OVG, however, also has some limitations. A first notable disadvantage for the current application is that little detail is given on business travel. Where for trips it is indicated whether or not a location is a person's home location, no information is given on a person's regular work location. Furthermore, no detail is given on the purpose of a business trip (e.g. selling products, buying products or internal contacts). These aspects limit the possibilities for the analysis of business travel.

Another limitation of the OVG data set for this study is the spatial level-of-detail on which the origins and destinations of trips are known. These determine the spatial resolution of the accessibility indicators. The OVG uses 552 zones within the Netherlands as origins and destinations. This results on average in a surface of 63 km^2 per zone, although the zones are smaller in more densely populated areas. For the current application this spatial level of detail is seen to be large enough, because the main emphasis of this research is on long-distance accessibility, which does not differ much on lower spatial scales than are used here.

4.1.3 Model specification

This subsection gives a technical description of the spatial interaction models that are used in this study, given the data that has been discussed above, but without going into detail about the travel impedance function that is more thoroughly dealt with in section 4.2. In this research the singly-constrained model from Wilson's (1971) family of spatial interaction models is used to derive accessibility indicators. These indicators do not account for competition effects. Although these competition effects can be relevant in the context of the current research, indicators with competition did not yield satisfactory results.

From a random utility perspective, a single constrained spatial interaction model can be seen as an MNL model of destination choice given the origin of a trip or of origin choice given the destination of a trip[15]. In case the model is constrained at the origin side, then the number of trips from one zone to another zone can be seen as the trip production of the firmer zone multiplied by the probability of a traveller choosing the latter zone as the destination of the trip:

$$T_{ij} = O_i P(j|i) = O_i \frac{D_j \exp[V_{ij}]}{\sum_j D_j \exp[V_{ij}]} \quad [4.1]$$

In the tradition of the original gravity models equation 4.1 is commonly written as:

$$T_{ij} = a_i O_i D_j f_{ij} \quad [4.2]$$

Hereby a_i is a so-called balancing factor: a factor used in spatial-interaction modelling techniques to satisfy the condition $\sum_j T_{ij} = O_i$ in the model. It is defined as:

$$a_i = \left(\sum_j D_j f_{ij} \right)^{-1} \quad [4.3]$$

And f_{ij} is an impedance function that represents the ease of travelling between two zones. It expresses how and to what extent the intensity of spatial interaction is dependant on the impedance attributes presented in the previous sub-section. The formulation of this function determines how the model results for spatial interaction and potential accessibility indicators react to a change in one of the impedance attributes. In literature several functional forms for the impedance function can be found, which are discussed in more detail in the next section.

For introducing mode choice into the spatial interaction model, an NL form can be used. For the origin-constrained model the number of trips from one zone to another zone by a specific model can be expressed as an NL model of combined destination and mode choice with nesting based on the origin zone (e.g. Ortúzar and Willumsen, 1994):

$$T_{ijm} = O_i P(j \cap m|i) = O_i \frac{D_j \exp\left[V_{ijm} + (\tau - 1)\ln\left[\sum_m \exp[V_{ijm}]\right]\right]}{\sum_j D_j \exp\left[\tau \ln\left[\sum_m \exp[V_{ijm}]\right]\right]} \quad [4.4]$$

An alternative structure would be nesting based on transport modes[16] (see e.g. Anderstig and Mattsson, 1991). Hereby, options are regarded to be more similar than other options if made by the same transport mode, so that spatial interaction is calculated as:

$$T_{ijm} = O_i P(j \cap m|i) = O_i \frac{D_j \exp\left[V_{ijm} + (\tau_m - 1)\ln\left[\sum_j D_j \exp[V_{ijm}]\right]\right]}{\sum_m \exp\left[\tau_m \ln\left[\sum_j D_j \exp[V_{ijm}]\right]\right]} \quad [4.5]$$

A possibility for this model is to use different scale parameters for each transport mode, to reflect the differences in explanatory capabilities of the transport modes' observed utility functions. This is an advantage of this version over the structure in Equation 4.4.

In the current thesis both nesting alternatives are evaluated and compared with the basic model without nesting. Evaluation takes place on the basis of theoretical consistency (the inclusive value parameters should lie on the 0-1 interval, see Daly, 1987) and maximum likelihood values. Both nesting alternatives also have different consequences for accessibility analyses. Nesting on destinations would better represent a modal split effect of accessibility: the absolute change of the impedance on an origin-destination relation if an impedance attribute changes depends on the competitiveness of this transport between these origin and destination. As a consequence, as would theoretically be expected decreasing travel time by train between two places has little effect on accessibility if the train is hardly used on this link. Nesting on transport modes would better represent a network effect for the transport modes: if a transport mode's network is poorly developed then an additional link does have a larger effect on mode choice than if this transport network is further developed. Note that from a theoretical point of view a cross-nested logit model would be superior, since it could embed both of these effects; this type of model would, however, be too computationally demanding for the current application.

In this application of the spatial interaction model, 'mode choice' refers to the choice of the main means of transport of a trip, following the rationale of the OVG travel survey. This is a hierarchical system of transport modes to determine the main mode of a trip. A trip's main mode is the mode with the highest position in the hierarchy of all modes that are used in the trip. Hereby (in short) train has a higher position than bus/tram/underground, which have itself a higher position than the car; cycling and walking have a still lower position. As a result, if a trip is made partially by train and by car then the mode chosen is 'train'; the car part is in this case seen as access and/or egress to/from the train network. The main mode of travel is thus determined regardless of the distances travelled by each of the transport modes.

In this study the transport modes are grouped into four categories: car, bus/tram/underground, train and a leftover category comprising most notably walking and cycling. Each of these categories is assumed to have a different utility function, consisting of a mode specific constant and one or more of the impedance attributes from Table 4.1. The impedance functions are discussed in more detail in section 4.2.

The impedance parameters are estimated following the origin-constrained model described above, i.e. an NL model of combined mode and destination choice. The 'zones' in the OVG are identical to municipalities with the exception of the four largest cities in the Netherlands, which are subdivided into a number of smaller zones. This results in 552 possible destinations to be combined with the four mode choice options. Since the software package used (Limdep/NLogit) allows a maximum choice set size of 100 choice options per choice situation the total of 552 zones is split into 23 sets of 24 zones, which together with the four mode options result in 23 choice sets of 96 choice option per origin (provided that travel data for these choice sets is available within the OVG). Theoretically, using a sample of alternatives within a nest of the NL model would lead to unbiased parameter estimations if the IIA assumption holds within these nests. A practical test showed this bias to be small compared to the effect of having model choice embedded in the spatial interaction model.

4.2 Impedance functions

The most direct influence of high-speed rail is on the time and cost for travelling between two places. The formulation of the impedance function is therefore of great importance. Firstly, the shape of the impedance function determines how travel patterns and potential accessibility react on a change of the travel impedance between two locations. And secondly, the impedance attributes taken into account are of importance. These two aspects are subsequently discussed in the next two subsections.

4.2.1 Shape of the impedance function

Since the introduction of the spatial interaction model a variety of impedance functions have appeared that describe how transport volumes react on a change in an impedance attribute between two places. Several possible functional forms are discussed below. The random utility framework for the spatial interaction model allows for the most common impedance functions to be estimated. Table 4.2 gives more detail on these functions and Figure 4.1 illustrates the Box-Cox generalised impedance function with the exponential and power functions as special cases. The exponential form of the impedance function corresponds with a linear utility function. Different shapes for the impedance function imply a non-linear effect of an attribute on the utility of travelling (or rather the 'disutility' of travelling, since most travel has no net positive effect on its own). Non-linear effects can have behavioural explanations, such as travellers perceiving a certain amount of additional travel time to be more severe for shorter than for longer trips. Furthermore, a non-linear effect may also (partly) be a substitute for segmentation (Mandel *et al.*, 1997), because it focuses on the thin equal tails problem of the MNL model (the observation that the MNL model systematically tends to underestimate the probability that a very unattractive alternative is chosen, Gaudry, 1981) which may be caused by unexplained taste variation.

Table 4.2 Impedance functions and corresponding utility functions

Type	Impedance function	Utility function
Exponential function	$f_{ijm} = \exp\left[\beta X_{ijm}\right]$	$V_{ijm} = \beta X_{ijm}$
Power function	$f_{ijm} = X_{ijn}^{\beta}$	$V_{ijm} = \beta \ln\left[X_{ijm}\right]$
Tanner function	$f_{ijm} = X_{ijm}^{\beta_1} \exp\left[\beta_2 X_{ijm}\right]$	$V_{ijm} = \beta_1 \ln\left[X_{ijm}\right] + \beta_2 X_{ijm}$
Box-Cox function	$f_{ijm} = \begin{cases} \exp\left[\beta \dfrac{X_{ijm}^{\lambda} - 1}{\lambda}\right] & \lambda \neq 0 \\ X_{ijm}^{\beta} & \lambda = 0 \end{cases}$	$V_{ijm} = \begin{cases} \beta \dfrac{X_{ijm}^{\lambda} - 1}{\lambda} & \lambda \neq 0 \\ \beta \ln\left[X_{ijm}\right] & \lambda = 0 \end{cases}$

Following physical analogies the earliest applications predominantly used a version of what is now generally referred to as a power or inversed-power decay function. This function is the impedance attribute to the power of a negative impedance parameter (see Table 4.2). The impedance parameter can be statistically estimated, but especially in accessibility studies it is sometimes assumed to be equal to minus one (e.g. Frost and Spence, 1995). Anas (1983) shows this function to be consistent with random utility theory as being equivalent to a logistic conversion applied to the impedance attribute in a utility function. For large spatial scales a power function yields often good results. However, at small spatial scales this function's strong decay at short distances does not seem realistic (Geurs and Ritsema van Eck, 2001).

After the derivation of spatial interaction models from entropy theory and random utility theory an exponential form for the impedance function has become most common in applications. The exponential function is consistent with a linear utility function. Compared to the power function the exponential function declines less sharply at smaller distances and is therefore better suitable for smaller spatial scales. For larger spatial scales, however, the exponential function is commonly found to give a worse goodness-of-fit than the power decay function. This systematic bias for very unattractive choice options is a form of what Gaudry (1981) calls the 'thin equal tails problem' of the MNL model.

To combine the benefits of these two basic impedance functions, generalised and more flexible impedance functions have appeared. A first one is the Tanner function (or 'combined function', referring to the exponential and power components, Ortúzar and Willumsen, 1994), which is an exponential function multiplied by a power function. Despite its increased flexibility compared to the two basic forms, Tanner functions are not often used in scientific applications. An example of an application is the ITLUP model (Webster *et al.*, 1988; Putman, 1998). In random utility theory the Tanner function appears as two additive attribute terms in the utility function. A reason for the scarce use of the Tanner function probably is the theoretical difficulty to justify the structure of the function in a random utility context.

A second generalised function is the Box-Cox function, whereby a Box-Cox conversion is applied to the attributes in a utility function (Box and Cox, 1964, see also the description of the RC model in chapter 3). This function has two special cases. If the shape parameter λ equals one then the utility function is equivalent to a linear function[17] and thus to an exponential decay function. If the shape parameter equals zero then the utility function is identical to the logistic utility function, resulting in a power decay function. Therefore, the Box-Cox function can be seen as a generalisation of the exponential and power impedance functions. Furthermore an interesting feature of the function occurs if the shape parameter is larger than one, in which case the function produces an S-shaped curve (see Figure 4.1 below). For very large values of the shape parameter the Box-Cox function approximates a discrete impedance function, similar to the function used in the so-called 'daily accessibility' indicators (Spiekermann and Wegener, 1996; Gutiérrez, 2001); also called 'proximity count' (Geurs and Ritsema van Eck, 2001) or 'cumulative opportunity' indicators (Handy and Niemeier, 1997).

Scientific applications of the Box-Cox functions are in transport modelling more common than Tanner functions. Box-Cox conversions have been especially applied in disaggregated mode

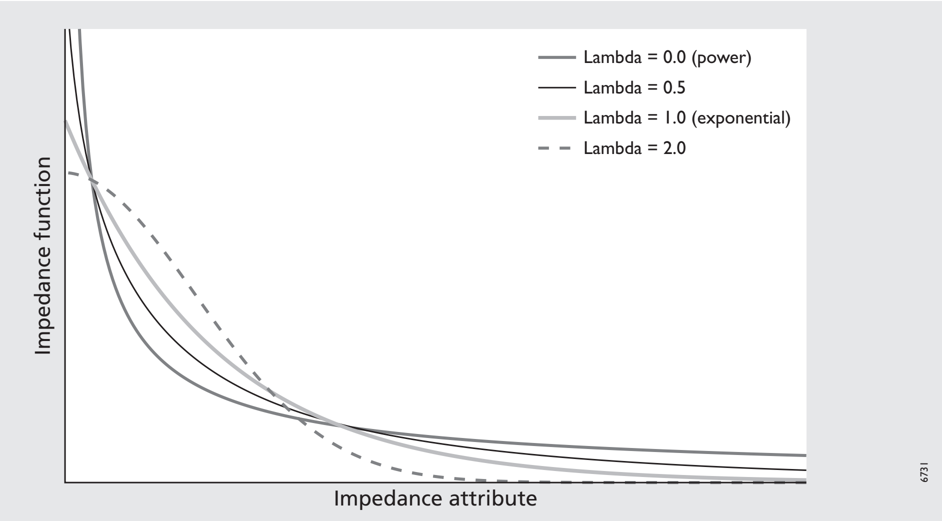

Figure 4.1 Examples of Box-Cox impedance functions with different values for the shape parameter λ, including the power and exponential functions as special cases.

choice models (Gaudry, 1981; Gaudry *et al.*, 1989; Postorino, 1993; Mandel *et al.*, 1997). These applications have reported good results for this impedance function compared to alternative forms. Applications in spatial interaction models are less common. One example of a Box-Cox conversion in a trip distribution model is Blum (1991), who used a gravity model for forecasting aggregated interregional transport demand in Germany. Finally, Tiefelsdorf (2003) applied a Box-Cox conversion to a spatial interaction model of migration and focussed in his article especially on its methodological advantages.

Similar to a Box-Cox function with shape parameter larger than one, several applications have been focussing on S-shaped impedance functions. Further examples of S-shaped impedance functions are log-logistic and Gaussian functions. Especially for intra-urban it has been argued that S-shaped functions can be better than concave functions because for very short trips the impedance the relevance of impedance declines (Hilbers and Verroen, 1993; Geurs and Ritsema van Eck, 2003). Furthermore, S-shaped curves may interfere with threshold effects. These effects occur when individuals regard alternatives as irrelevant for their choice set when an attribute exceeds a certain threshold level (see e.g. Cantillo and Ortúzar, 2005). Such a threshold effect can also be approximated by a higher marginal utility for higher levels of an attribute.

The current application is restricted to the four impedance functions in Table 4.2, which are consistent with random utility theory and can therefore be implemented in an NL model of combined destination and mode choice. The two generalised functions can be evaluated to see if these perform significantly better than the two basic forms (the generalisations will perform at least as good as either of the two basic functions, since the basic functions are special cases of these). This is done by means of a likelihood ratio test. In a likelihood ratio test it is tested if a generalised function is performing significantly better in terms of log-likelihood than its special case, given the difference in the degrees of freedom between the two models (for more details on this test, see e.g. Ben-Akiva and Lerman, 1985).

As impedance attributes for the train a generalised cost component is estimated, as discussed in the following sub-section. For the other transport modes impedance is based on a single attribute along with an alternative-specific constant.

4.2.2 Generalized transport costs for train travel

The generalized transport costs for train travel between places is input to the combined mode and destination choice model. High-speed rail directly affects (in-vehicle) travel time and travel fare, but indirectly network effects can lead to a more complex effect on generalized transport costs for train travel between two sites. For example, train travellers might change the route they travel. And also, the impact of the change in generalized transport costs on a link might depend on the trip length. To take account of these effects the different aspects that make up train travel impedance should be considered.

In literature several impedance components are distinguished for train travel. An overview of rail travel impedance attributes is for example given by Wardman (2001) in a meta-analysis of British studies. In general five stages of a train trip can be distinguished, each of which has specific impedance attributes associated:

1. Access to the departure station,
2. Waiting at the departure station,
3. In-vehicle impedance,
4. Train transfers,
5. Egress from the arrival station.

Access and egress impedances are important aspects of rail travel. Wardman (2001; 2004) found the valuation of station access time by travellers to be on average about 1.8 times the in-vehicle travel time. Access and egress can also be seen to determine the availability of the train as an option for travel (see Cantillo and Ortúzar, 2005). Wardman and Tyler (2000), however, did not found access to the railway network to be more important in this context compared to journey length and cost.

Station access and egress impedances are usually measured by access/egress time or distance, sometimes in combination with access-related impedances of the access station. For example, Wardman (2001) distinguishes besides station access time per se also the searching time for parking space and car congestion delays. For the Netherlands access and egress is rather specific because slow modes (bicycle and walking) account for about 60 percent of all access modes (Rietveld, 2000), which is high compared to for example the figure of Wardman and Tyler (2000) of 26 percent for the north of England.

Time spent at the departure station and transfer stations is also rated higher by travellers than the in-vehicle travel time. Hereby a distinction can be made between walking and waiting time. As a rule of thumb walking and waiting time is often rated as twice the in-vehicle time for non-business trips and equal to the in-vehicle time for business trips (Wardman, 2001). For business trips it is relevant that distinction can be made between the employer's valuation of waiting/walking time and the valuation by the employee who actually makes the journey. The equal valuation of waiting, walking and in-vehicle time stems from the employer's point of view, based on the assumption that employers aim to increase productivity by reducing overall travel time (Wardman, 2001).

In a meta-analysis of empirical studies Wardman (2004) found values of on average 1.7 times in-vehicle time for walking and 1.8 for waiting. Very relevant for the topic of this thesis is the valuation of waiting time for interurban business travel that was found to be 1.8 times the in-vehicle time, thus much higher than the rule-of-thumb value of one (for walking time values are missing). In the Netherlands a recent study (Bovy and Hoogendoorn-Lanser, 2005) calculated higher values (2.0 for walking and 2.2 for waiting) for route choice in the Rotterdam/Dordrecht area. For bus, tram and rapid transit Van der Waard (1988) found a similar value (2.3) for walking time, but lower values (1.5 for the access stop and 1.3 for transfer stops) for waiting time; although for this study it is relevant that waiting time was approximated by half of the service headway and might thus have overestimated the waiting time.

For the length of the waiting times several issues are of importance concerning the scheduling of the train services (for a more lengthy discussing see Wardman *et al.*, 2004). Depending on the frequency of the train services travellers can either come to the station at a random time or plan to come just before their train leaves. In the first case statistically expected waiting time is half of the interval (headway) between trains (assuming train departures are distributed evenly along time). In the second case waiting time will be shorter, but can be associated with a penalty for planning inconvenience. (Wardman *et al.*, 2004) On top of the waiting time fixed penalties for interchanges are often accounted for.

In-vehicle impedance here refers to the impedance components directly related to the length of the train trip: the in-vehicle train travel time and the train fare. These are the components that are most affected by the high-speed railway implementation. Since in a spatial interaction model the in-vehicle train travel time and the train fare are often highly correlated, a generalised cost or generalised time component can be calculated where an external value of time source is used to convert time into monetary units or cost into time units respectively. In this case value of time is assumed to be constant regardless of the length of the journey (even though e.g. Gunn, 2001, found evidence that value of time rises with trip duration). Other model specifications, e.g. with Box-Cox transformations on separate time and cost components (Gaudry *et al.*, 1989), allow the value of time to different across trip lengths. In the absence of a more extensive route-choice model this is not possible in the current application.

For the current application the use of a simple shortest-path route assignment model limits the possibilities for the impedance components that can be taken account of. Essential for high-speed rail is the combination of in-vehicle time and travel fare, since the travel time reduction due to the high-speed train services is compensated by a fare supplement. This fare supplement makes the model more complicated, because unlike the base fare it also affects route choice given the access and egress stations. An exogenous value of time (based on Gunn, 2001) was used to compute a station-to-station generalized cost attribute, excluding possible transfer penalties. Hereby the average value of time for commuting and for business travel respectively was used. Although Gunn (2001) also reports a value of time for train specific, the average values where preferred because mode-specific values of time do not only capture mode characteristics but also personal characteristics (Wardman, 2004). Thus, on the one hand being able to work during a train travel might lower train-specific value of time compared to, for example, the car. But on the other hand train travellers might from themselves have a different value of time than e.g. car drivers, possibly even when corrected for personal characteristics such as income. Furthermore, Wardman (2004) showed that travellers also have a structurally lower value of time for the transport mode they had chosen (e.g. if correcting for other factors car users still have a lower value of time for car travel than other travellers), although Wardman (2004) noted this may (partly) be due to a justification bias (i.e. in an SC survey respondents might choose the same option as their RC observation to justify the choice they have made in practice).

To summarise the above: using the average value of time only per trip purpose would ignore differences in value of time between transport modes as perceived by a traveller, but using the mode-specific value per trip purpose in an aggregated model would wrongly assign person-specific variation in value of time to be mode-specific. In this study it is chosen to use the average values of time, because in this aggregated application person-specific variation (e.g. due to income differences) is assumed to be much more extensive than mode-specific variation.

For the valuation of train trip time elements a value of transfer time (thus half the headway) of 2.0 times the value of in-vehicle time is adopted for both commuting and business travel. This value corresponds to the rule of thumb described above and the value found by Bovy and Hoogendoorn-Lanser (2005). Furthermore, the results of Wardman (2004) suggest there are no large differences in this value between trip purposes. Table 4.3 gives an overview of the values of time used in the model. For these figures to be used in a scenario study it should be noted that the 2004 supplement to the OEI guideline for the evaluation of transport investments (AVV and CPB, 2004) prescribe the value of time to evolve over time along with real income.

For the base year 2000 this setup of station-to-station generalised cost practically means that the route with the smallest travel time is chosen, because train fares for conventional trains are independent of the route and the current high-speed train services[18] do not offer benefits for travel time yet. For years after the high-speed railway implementation the all-or-nothing assignment assigns all traffic between two zones either to the high-speed train services or not. This is not seen as a major problem, because the mode is not meant to determine the market share for high-speed rail. Another consequence is that for the year 2000 the use of the current international high-

Table 4.3 Values of time for base year used for train travel in-vehicle generalised costs.

Value of time (year 2000 euros per hour)	Commuting	Business travel
In-vehicle time	€ 7.00	€ 23.46
Transfer time (half the headway)	€ 14.00	€ 46.93

Source: based on Gunn (2001), Bovy and Hoogendoorn-Lanser (2005) and Wardman (2004) speed train services for domestic trips is assumed not to contribute to accessibility, since these do not offer travel time gains over conventional trains until the dedicated infrastructure becomes available. Beneficial aspects for high-speed rail, such as a higher comfort, or overcrowding in conventional trains are not included in the model, because no suitable data is available on these attributes. Taking account of these factors would let high-speed rail have a larger influence on accessibility, both in the base year 2000 and in scenarios for future developments, although the extent of this is not certain.

The calculation of transfer times is based on the assumptions of random station access of travellers and even departure intervals of train services, in which case the statistically expected transfer time is twice the inverse of the service headway (Wardman *et al.*, 2004). As explained above in this sub-section these assumptions could imply a bias for low frequency services. Transfer times might be overestimated because travellers could plan their arrival time at the departure station and the railway company's service schedule is optimised for the most important transfer possibilities. However, uncertainty exists for values of planning penalties in the Netherlands.

For access/egress to the railway network distance to the nearest station is taken into account. Because of the high share of slow modes in accessing stations in the Netherlands, distance seems a more appropriate attribute than for example car travel time. In the train impedance functions the shape of the impedance attributes are assumed to be independent of one another (for the Box-Cox conversion this implies that the parameters λ differ per attribute), which is necessary because impedance of different stages in a train trip are measured in different units. Independent shape parameters also enable to study how the influence of access distance differs from the egress distance. Interaction effects between the impedance attributes can be tested to see if the importance of access and egress distances depend on the length of the total journey.

4.3 Potential accessibility indicators

The spatial interaction models are used to derive indicators of potential accessibility. These accessibility indicators are related to location attractiveness in the location choice model for offices described in the previous chapter. Furthermore the indicators as such can give information on the possible spatial effects of high-speed railway infrastructure. This section discusses the derivation of potential accessibility indicators from spatial interaction models, thereby raising several theoretical issues regarding the use of these indicators.

Accessibility is a concept used for a wide range of purposes in different disciplines (for an overview, see Geurs and Van Wee, 2004). This section thus specifically focuses on the formulation of *potential accessibility* indicators, which are especially suitable to represent the location attractiveness to activities (e.g. Geurs and Van Wee, 2004). Potential accessibility is a form of 'place accessibility', i.e. it refers to attractiveness of a location for a certain type of activities on the basis of the possibilities for spatial interactions at that site. As the specific actors of these possible future interactions are not known beforehand potential accessibility treats these actors aggregately, without reference to person-specific characteristics or constraints. This is opposed to the 'personal accessibility' (Kwan *et al.*, 2003), which focuses on the interaction possibilities of predefined individuals, and to accessibility for measuring network performance (e.g. Gutiérrez *et al.*, 1998). As a result of the diversity in underlying purposes and meanings of accessibility a large variety of indicators to quantify accessibility has appeared. Overviews of indicators are among others given by Bruinsma and Rietveld (1998) and Geurs and Van Wee (2004).

In studies on high-speed rail different types of indicators are used. In this research two types of potential accessibility indicators are tested: gravity-type of indicators that are directly derived from the spatial interaction models, and contour indicators that are better suitable for studying long-distance accessibility. The methodology of these indicators is consecutively discussed below.

4.3.1 Gravity-type indicators

As is already discussed in chapter 2, with regard to the potential accessibility indicators several variations are possible of the attraction function and impedance function in Equation 2.1. A common practice is to derive these functions from a transport model or another spatial interaction model. Wilson (1971) remarked that the Hansen (1959) type of accessibility indicator is equal to the inverse of the balancing factor of a singly-constrained spatial-interaction model, following equation 4.3:

$$A_i = \sum_j D_j f_{ij} = a_i^{-1} \qquad [4.6]$$

In case of an NL model that combines destination choice with mode choice the balancing factors are somewhat more complicated. For the nesting structure that is expressed in equation 4.6, potential accessibility is formulated as:

$$A_i = \sum_j D_j \left(\sum_m \exp\left[V_{ijm}\right] \right)^{\tau} \qquad [4.7]$$

If the alternative nesting structure of equation 4.7 is adopted then the potential accessibility indicator can be seen to be:

$$A_i = \sum_m \left(\sum_j D_j \exp\left[V_{ijm}\right] \right)^{\tau_m} \qquad [4.8]$$

These two accessibility indicators have the properties that have already been described in section 4.1.3. In the special case where the inclusive value parameters τ are one, the potential accessibility indicator is derived from a non-nested MNL model:

$$A_i = \sum_m \sum_j D_j \exp\left[V_{ijm}\right] \qquad [4.9]$$

The potential accessibility indicators can be interpreted as the size of the market at a location (e.g. a labour market for commuting), although criticism stresses the ability of these indicators to represent the complex economic relations of a market (Frost and Spence, 1995). With regard to this interpretation three aspects require special attention:

1. Trip purpose
2. The qualitative match between supply and demand, and
3. Competition within this market.

Trip purpose is relevant for the question which market is focussed on: for the size of the labour market commuting is relevant, whereas a business-to-business product market depends on business travel. Different trip purposes have different attraction and impedance characteristics, even for the same travellers and if the underlying land-use and impedance data are the same. Reasons for this are the allocation of the travel cost (does the employee or the employer pay the travel costs) and differences in trip frequencies (some employees make much more business trips than others, but for commuting these differences are less extensive).

Once the trip purpose is determined the qualitative match between supply and demand concerns whether the potential interactions are of an appropriate type for the location attractiveness. For example in case of a labour market not all actors in a labour market have appropriate education and labour skills for a certain type of employment. Differences in characteristics of the supply/demand that is relevant for a location decision (in case of the labour market the potential employees' income level among others) make these actor categories have different location preferences and impedance functions. Taking account of the characteristics of supply and demand is thus important, but data on land-use and travel data often show less detail in these aspects. For the current application it is not possible to distinguish between qualitative aspects of the production and attraction, firstly because this would require more detailed data of especially the nature of activities in the land-use data and secondly because this would result in a large variety of highly correlated accessibility indicators that would not be reasonable to test in the RC location choice model. Accessibility indicators in this application can be seen to be based on the assumption that all types of supply and demand are equally distributed over the total supply and demand respectively.

The level of competition refers to how many other actors are aiming for the same resources. For the example of the labour market it might not be the total number of potential employees that is relevant for the attractiveness of a site but the number of employees relative to the number of competing employment places (e.g. Van Wee *et al.*, 2001). In this case the number of competitors aiming at the same potential employees reduces accessibility for employees, since it becomes harder to actually attract the employees that are within reach of the office. Similarly, for business travel the competition effect embeds the reduction of a firm's economic potential at a site if more competitors are in the same geographical product market.

For the current thesis attempts have been made to use potential accessibility indicators derived from a doubly-constrained spatial interaction model (see e.g. Geurs and Ritsema van Eck, 2003). These analyses did not yield satisfactory results, both for the accessibility indicators and for the location choice model. Competition is therefore not included in the accessibility indicators that have been used in this thesis.

Most studies on the effect of transport on location choices use gravity-type of indicators or the related logsum indicators. With these indicators the main emphasis lays on short-distance travel; the self-potential (i.e. the contributions of a zone to its own accessibility) can be substantial (see Frost and Spence, 1995, for a discussion on the self-potential), which limits the impact of long-distance transport infrastructures such as high-speed railway connections on the accessibility indicator. Previous applications of gravity-type indicators to high-speed rail (e.g. Spiekermann and Wegener, 1996; Gutiérrez, 2001) base their impedance parameters on theoretical considerations instead of on empirical analysis. For example Gutiérrez (2001) mentions choosing a low impedance parameter specifically to avoid the self-potential being dominant. In an analytical application impedance parameters can be expected to be higher, thus resulting in a sharper declining impedance function, because a majority of trips take place on small distance connections.

Previous applications also do not consider competing transport modes (some accessibility studies do make use of multimodal indicators, see e.g. Bruinsma and Rietveld, 1998, but these indicators are not used for evaluating high-speed rail projects). Train only accounts for part of a zone's overall accessibility; other transport modes such as the car, air transport and slow transport modes often contribute more to overall accessibility. Therefore an increase in train accessibility always results in a relatively smaller increase in overall accessibility, all else being equal.

In the current application of gravity-type indicators, with an empirical determined impedance function and with mode choice, the effect of a new high-speed rail link on accessibility can be relatively small. Accessibility by short-distance connections are expected to be dominant. For a second type of indicator, the contour indicator, long-distance connections can have a larger influence.

4.3.2 Contour indicators

Contour indicators are based on the assumption that a maximally acceptable transport impedance exists. The indicator is the weighted sum of all possible destinations that can be reached at an impedance below this maximum. Potential destinations further away than the maximum impedance do thus not contribute to a zone's impedance; destinations more proximate than the maximum impedance add their attraction factor to the indicator value.

Of crucial importance for contour indicators is the choice which impedance is taken as the maximally acceptable. A new transport infrastructure or service can have a large impact on the accessibility indicator for a particular zone if it lowers impedance to a destination with a large attraction factor to below the critical boundary, and can at the same time have a negligible impact on other zones that experience a similar decrease in impedance but for which this boundary is not crossed. This effect is larger if a lower boundary is assumed or if larger zones are used. Contour indicators are therefore more suitable for studying long-distance travel than short-distance travel. Previous applications on high-speed rail that use this indicator (e.g. Spiekermann and Wegener, 1996; Gutiérrez, 2001) have adopted the concept of daily accessibility. This concept suggests that it is important for businesses to travel to a destination, have a certain time for a meeting or other activity, and return to their original location all within the same day. Travel time is thus the solely determining factor in these studies. The time limit in these applications is several hours; this makes the concept unsuitable for the current application, because of the small distances within the study area. Furthermore, because of the analytical nature of the current study a more empirical approach is preferred.

In this study contour indicators are based on the results of the spatial interaction model that have been described above. Travel disutility from these models can be seen to be an impedance factor for travelling. The advantage of disutility as an impedance factor over train travel time is that all transport modes are considered and that for high-speed train travel a trade-off is made between a possible travel time decrease and a fare supplement. However, it makes the indicator less easily comprehensible.

The critical value of disutility is determined empirically, based on the RC model for location choices. A range of values is tested as a boundary and the value is chosen that results in the lowest value for log-likelihood. This method suits best within this study's approach of likelihood maximization. Train impedance is expected to have its most dominant influence on this indicator if the critical value is relatively large, because it has its highest share in travel utility for longer distances.

The following chapter presents the results of the estimation of the commuting and business travel spatial interaction models and of calculation of the potential accessibility indicators. Both types of potential accessibility indicators are subsequently tested in the RC office location choice models, the results of which are discussed in chapter 6.

5. Estimation of spatial interaction models and calculation of potential accessibility indicators

In Chapter 4 the methodology of spatial interaction modelling has been described. This chapter focuses on the results of parameter estimations for this model's application to commuting and business travel in the Netherlands and the calculation of potential accessibility indicators that are derived from this model. The first section of this chapter presents the results of the parameter estimation of the commuting and business travel spatial interaction models. In the second section potential accessibility indicators and spatial interaction indicators are discussed that are based on these spatial interaction models. The accessibility indicators are used in the RC office location choice model, the parameter estimation of which is discussed in Chapter 6. The spatial interaction indicators are later used in the scenario study of Chapter 7. The third section of this chapter, finally, presents and discusses a ceteris paribus accessibility analysis of domestic high-speed train services in the Netherlands. The purpose of this section is to evaluate the reaction of the accessibility indicators to a change in an impedance attribute and to explore the effect of high-speed train services on accessibility in the Netherlands.

5.1 Results for the estimation of impedance functions

As described in Chapter 4, spatial interaction models for business travel and commuting were estimated on the basis of travel data from the Dutch national travel survey (OVG) for the year 2000. The impedance parameters are estimated following origin-constrained models: NL models of combined mode and destination choice. The next two subsections describe the parameter estimation results of the commuting and business travel models respectively. Hereby the first subsection focuses on the comparison of the different nesting structures and shapes of the impedance function that were tested in this research. One type of impedance function is chosen and its parameter estimation results are presented in more detail in the second subsection.

5.1.1 Comparison of impedance functions

The impedance function is of importance for the outcome of the spatial interaction models and accessibility analyses, as discussed in chapter 4. Two aspects of the impedance functions are examined more closely: a nesting structure for the combined mode and destination choice models and the shape of the impedance functions.

An NL model is tested with two different nesting structures to distinguish mode choice from destination choice. However, the inclusive value parameters for both nesting structures lay above

Table 5.1 Estimated maximum log-likelihoods (MLL) and corresponding pseudo-r²s (ρ²) for different impedance functions in non-nested commuting and business travel spatial interaction models.

Impedance function	Commuting MLL	ρ^2	Business travel MLL	ρ^2
Exponential function	-4582.48	0.613	-2402.97	0.560
Power function	-4467.15	0.623	-2283.39	0.581
Tanner function	-4385.65	0.630	-2259.93	0.586
Box-Cox function	-4357.06	0.632	-2257.26	0.586

the theoretical upper boundary for the model to be consistent with random utility theory (as described in chapter 3, or see Daly, 1987). This is not uncommon for this type of models (see e.g. Anderstig and Mattsson, 1991). To keep the model consistent with random utility theory the inclusive value parameters were restricted to one in this application. This yields a model that is equivalent to a non-nested MNL model. These model results can thus confirm neither a mode competition effect where modes with a low market share have less influence on travel impedance and thus on accessibility, nor a network effect where the influence of a new link in a poorly developed network is larger than a similar link in a more extensive network.

Furthermore, four types of impedance functions were tested for the spatial interaction models: the well-known power and exponential functions and two generalised functions (Tanner function and Box-Cox function). Table 5.1 gives an overview of the maximum log-likelihood values and ρ^2's for these model versions. For the ρ^2 values a model without impedance attributes but with the attraction factor is taken as a reference model. The attraction factor is included in the reference model because it can be seen as a way to aggregate choice options (in this case destinations), which is relevant to the reference model as well With values for ρ^2 of around 0.6 the model fit is good for this type of model (as discussed in chapter 3); however, the use of aggregate data (market shares) instead of individual observations plays a significant role here. Models based on aggregated data always show higher model fit statistics than their equivalent based on disaggregate data. Still, model fit is satisfactory for both applications.

The differences in model likelihood between the model versions are small in an absolute sense, but the dataset is sufficiently rich for likelihood ratio tests to reject the restricted exponential and power functions in favour of the generalized impedance functions with more than 99 percent certainty. Given the equal degrees of freedom of the two generalized functions, the Box-Cox function appears to perform slightly better than the Tanner function on the basis of likelihood maximization.

To summarize the above, the generalized Tanner and Box-Cox function fit significantly better than the restricted exponential and power impedance function, with the Box-Cox function having a somewhat better fit than the Tanner function. Therefore, the Box-Cox function was chosen for further application of the spatial interaction models and potential accessibility indicators. For the other impedance functions the results are not discussed in more detail here.

5.1.2 Parameter estimations

The previous subsection showed the Box-Cox impedance function without nesting structure to be the preferred impedance function for this application. This section elaborates on the results of the commuting and business travel models with this type of impedance function. Table 5.2 shows the results of the parameter estimations for the Box-Cox impedance functions. None of these parameters has a value that is theoretically unexpected. All impedance attributes correctly have a negative taste parameter, which makes an alternative less likely to be chosen the higher the value of the impedance attribute is. Alternative-specific constants interfere with the Box-Cox conversion and are therefore less straightforward to judge. It is also complicated to compare the taste parameters across the two trip purposes, because in most cases the taste parameters are conditional on different shape parameters for the Box-Cox conversion.

Of particular interest are the values of the Box-Cox shape parameters. Table 5.2 shows these parameters to differ considerably across modes, although this may be partly due to the use of different impedance attributes. The Box-Cox parameters also differ among trip purposes. For most impedance attributes this parameter is closer to the power-decay equivalent value of zero than to linear exponential decay value of one. These are thus consistent with the general practice that power decay functions perform better than exponential decay functions in spatial interaction models on large geographical scales. The low parameter values suggest that a change in the impedance attribute has a higher impact on travel disutility if the impedance attribute has a low value than in case this attribute has a higher value.

For train travel station-to-station generalized cost, however, the Box-Cox parameters have higher values. For commuting it even has a value above one, resulting in a utility function that reacts stronger on the generalized cost for higher values of generalized cost. Such a shape for a utility function can be explained by the annoyance of commuters with bottlenecks in the

Table 5.2 Parameter estimation results for the Box-Cox logit spatial interaction models.

Attribute	Commuting		Business travel	
	Coefficient	t-value[I]	Coefficient	t-value[I]
Car time (hours)	-2.95	-52.8	-2.80	-41.2
Car Box-Cox parameter	0.41		0.17	
Car constant	-2.21	-9.0	-2.01	-6.5
Bus/tram/underground time (hours)	-3.31	-23.5	-3.17	-17.3
Bus/tram/underground Box-Cox parameter	0.28		0.04	
Bus/tram/underground constant	-0.973	-3.7	-1.12	-3.3
Train access distance (km)	-0.954	-7.5	-0.395	-4.2
Train access Box-Cox parameter	0.21		0.64	
Train egress distance (km)	-1.10	-6.3	-0.759	-4.4
Train egress Box-Cox parameter	0.22		0.21	
Train station-to-station cost + time (€)	-0.0687	-13.7	-0.0769	-11.1
Train station-to-station Box-Cox parameter	1.31		0.89	
Other transport distance (km)	-1.61	-42.6	-1.14	-15.2
Other transport Box-Cox parameter	0.29		0.59	
Other transport constant	4.05	15.1	3.05	8.5

I: All parameters are significant at the 99.9 percent level.

network. Another possible explanation for large Box-Cox parameter values is the occurrence of threshold values for attributes. Very large values produce a discrete impedance function, similar to the function used in the so-called 'daily accessibility' indicators applied by Spiekermann and Wegener (1996) and Gutiérrez (2001); see also Geurs and Ritsema van Eck (2003) for a discussion on S-shaped impedance functions.

Access and egress distances to/from a station are important impedance attributes for the train. For these attributes, however, it is important to recognize that causality can go in both directions: if an office's employees or visitors frequently use the train then it can be reasoned that this office has a higher probability to choose a location near a railway station. The spatial interaction model does not correct for this kind of mutual dependency, since it would require travel and location choice data to be related to each other, i.e. it must be known or estimated which type of office is the source of every observation in the travel data. Since this is not possible in the current application, access and egress distance attributes are necessarily treated as if it represents traveller preference alone.

In the train travel utility function also interaction effects between attributes have been tested. These interaction effects could for example indicate if access or egress distances become more or less important for longer train trips than for short train trips. Analyses of the above model with interaction effects did, however, not yield significant parameter estimations for two-way interaction effects, which is remarkable for a rich data set as the OVG travel survey.

5.2 Indicators for potential accessibility of business travel and commuting

The previous section has focussed specifically on the estimated parameters in the commuting and business travel spatial interaction models. This section elaborates further on the consequences of these estimation results by presenting and evaluating potential accessibility indicators for the base year 2000 and for an explorative analysis with a high-speed rail scenario. The accessibility indicators for the base year are used in the estimation of the RC office location choice model described in the next chapter. By using an alternative of the future Amsterdam-Rotterdam-Breda high-speed train service as an explorative example this section illustrates the effect of the impedance function on potential accessibility of locations.

5.2.1 Base year potential accessibility

Potential accessibility for the year 2000 is used as an explanatory variable in the RC location choice model, the results of which are discussed in the next chapter. Accessibility indicators with and without competition effect are presented, by using the inverse of the spatial interaction models' balancing factors as discussed in chapter 4. Chapter 5 assesses the relevance of each of these indicators, as well as a logarithmic conversion of the indicators, for office location choices.

Since potential accessibility does not have a meaningful measuring unit, in this thesis it is expressed as an accessibility score: the calculated values are normalised on the maximum value of all zones in the Netherlands. The best accessible zone in the year 2000 is given the score of 100. Changes in accessibility are expressed in the same scoring, so with the year 2000 normalisation factor.

For the evaluation of the accessibility results it is important that notice is made of the border effects that affect the accessibility indicator. Potential accessibility of zones near the border of a study area is underestimated, because relevant potential destinations are omitted (see Geurs

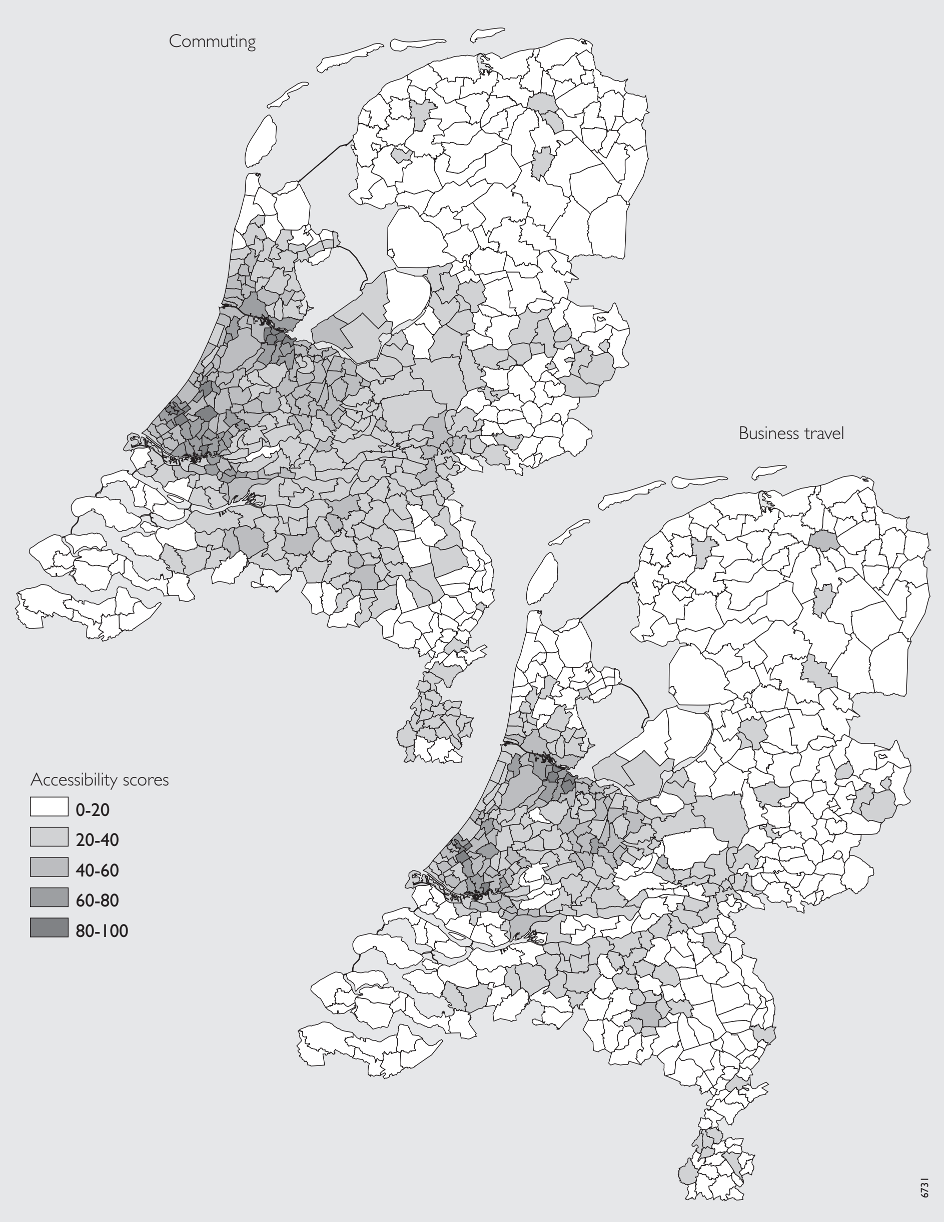

Figure 5.1 Calculated gravity-type potential accessibility towards potential employees and potential business partners for the year 2000 (scaled on maximum=100).

and Ritsema van Eck, 2003). In the current application the border effect is most relevant for the contour indicator, because the large role of long-distance trip opportunities makes the border effect to extend much further from the border than for the gravity-type indicators. However, the Randstad area, which is the main subject of this study, does not suffer from the border effect because it is not located near the national border.

The results of the accessibility analyses for commuting and business travel in the Netherlands are shown in Figure 5.1 for the gravity-type of indicators. No unusual results are found for the potential accessibility scores in Figure 5.1 (for a comparable image of potential accessibility see e.g. Geurs and Ritsema van Eck, 2003). The highest accessibility scores for commuting are assigned to the cities of Amsterdam, The Hague and Rotterdam. Utrecht, the fourth urban core in the region has a somewhat lower accessibility because of its own smaller size and because it is less proximate to other cities. Outside of the Randstad area accessibility scores are modest, with several larger cities across the Netherlands having a somewhat higher score than their surroundings. The accessibility scores for business travel are in general rather similar to those for commuting, although accessibility to employees seems somewhat less concentrated to the main urban cores in the Netherlands than accessibility to business partners.

In general, the contribution of train accessibility to the overall potential accessibility scores is only moderate. On average for commuting train accessibility is only 4.4 percent of car accessibility, which is the main contributor to the potential accessibility scores. For business travel this percentage is only slightly higher: 6.1 percent. More variation can be seen at the level of individual zones: train accessibility can be as high as 57 percent of car accessibility for commuting and 23 percent for business travel. These higher percentages can especially be found in zones within or near the Randstad area.

An important issue for gravity-type potential accessibility indicators is the contribution of the self-potential in a zone's accessibility score. The self-potential of a zone is the part of potential accessibility that is caused by the attraction of the zone itself. Frost and Spence (1995) showed that the impact of the self-potential can be substantial and that it is highly dependant on the way intrazonal impedance is measured. For the accessibility indicators in Figure 5.1 self-potential is on average 22 percent, for commuting as well as for business travel. Frost and Spence (1995) found values in the same order of magnitude, with for London the highest value of 60.5 percent. The current application of the Netherlands has smaller zones, especially for densely populated areas, which leads to lower self-potentials for the main cities. For peripheral towns self-potential in this application can be much higher, more than 70 percent of the accessibility score.

The contour accessibility indicators depend on the critical boundary that is chosen for disutility (see chapter 4). The optimal critical boundary is determined empirically in the RC model of location choices, the results of which are described in more detail in the next chapter. Here the eventual chosen accessibility indicator for business travel is presented. For business travel a critical boundary is found optimal that corresponds with the 90th percentile of trip observations in the business travel data set without the leftover category, i.e. 90 percent of all business travellers who use the car, train or other public transport has a travel disutility lower than this boundary. The resulting accessibility indicator is shown in Figure 5.2.

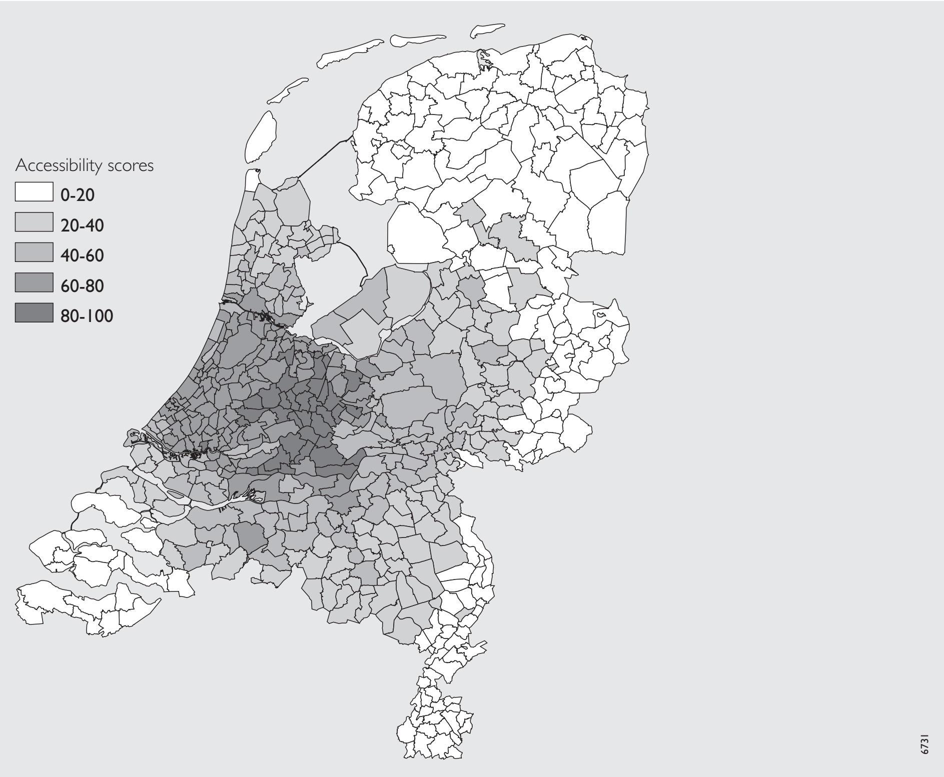

Figure 5.2 Calculated contour accessibility indicator towards potential business partners for the year 2000 (scaled on maximum=100).

For commuting the contour indicators that are used in the model did not yield statistically significant results with a correct sign. Even though a full range of different critical travel disutilities have been tried (see subsection 4.3.2) all estimated parameters were either not significant or negative. Accessibility is assumed to increase location attractiveness and not to have a negative influence. However, the contour indicator for commuting yields especially high values for the area called the 'green heart of Holland', a sparsely populated area in the centre of the Randstad conurbation. Although it seems quite reasonable to assume that this area has a high potential accessibility, the low number of offices located there results in a negative taste parameter for this indicator in the location choice model. Since this relation is not theoretically justifiable it is not included in the location choice model.

This contour indicator assigns the highest accessibility score to an area in the centre of the Netherlands. Compared to the gravity-type indicators the high accessibility scores are much more spread out over an area instead of concentrated at the cities in the Randstad. The region around Utrecht has the highest accessibility, because from there not only cities in the Randstad can be reached but also places in the south of the Netherlands (e.g. Eindhoven and Tilburg) and east of the Netherlands (Arnhem and Nijmegen) are within reach. It can thus be seen that this indicator is indeed particularly representing accessibility on medium-long distances. However, an interesting question remains how this and the other indicators react on a change in train travel time and cost. This is the subject of the next subsection.

5.2.2 Explorative accessibility analysis of domestic high-speed railway services

This section describes the results of an accessibility analysis of domestic high-speed railway services on the HSL South. The purpose of this analysis is firstly to explore the accessibility effects of high-speed rail in the Netherlands, but also to evaluate the performance of the different accessibility indicators. This section anticipates on the scenario study that is the topic of chapter 7, but has the specific aim to examine the methodological aspects of the accessibility indicators. Chapter 7 focuses more on the practical results with regard to the case study of the Amsterdam South Axis.

The accessibility analysis in this section is a ceteris paribus study of the HSL South, i.e. all data other than travel times and cost on the HSL South are held constant compared to the base year. In this way the reaction of the accessibility indicators on the change is train impedance is more comprehensive to oversee. The HSL South is a suitable example, because it is to be implemented relatively soon (and is therefore a realistic example) and by linking some of the major nodes in the Randstad railway network it is expected to lead to the strongest accessibility effect for the Randstad region of all rail projects being planned or considered.

Domestic high-speed railway services on the HSL South track consists of two lines: (1) a frequent (four trains per direction per hour) Amsterdam-Rotterdam connection via Schiphol airport and for half of the services extended to Breda in the south of the Netherlands, and (2) an hourly The Hague-Breda service via Rotterdam. Travel times are expected to be reduced considerably: a train trip between Amsterdam and Rotterdam (currently taking over an hour) will be reduced to about 35 minutes. However, higher train fares will be charged for these services, limiting the effect on station-to-station generalized transport cost. In this analysis the fee supplement is assumed to be 10 percent of the basic train fare between the origin and destination of the high-speed train connection. This seems a realistic percentage that is similar to the supplement used by NEI

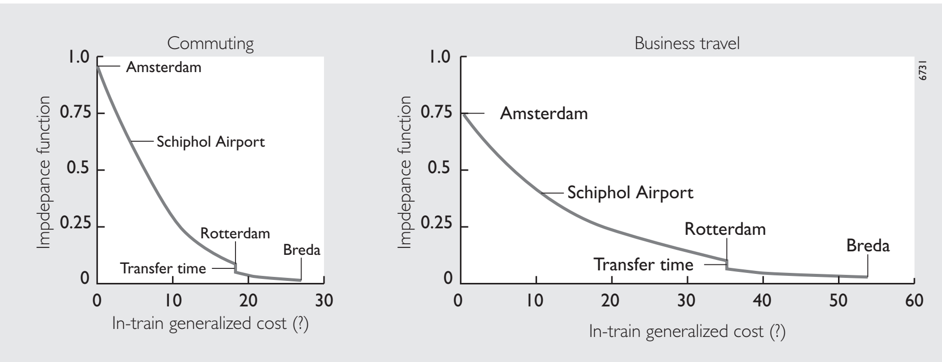

Figure 5.3 Commuting and business travel impedance for train travel along the Amsterdam-Rotterdam-Breda corridor in the base situation.

(2000b) in a study on the Zuiderzeelijn. However, a distance-dependant supplement is different from the current practice for domestic trips on the Amsterdam-Utrecht-Arnhem ICE service, which has a fixed supplement of € 2.00 to the (distance-dependant) basic fare.

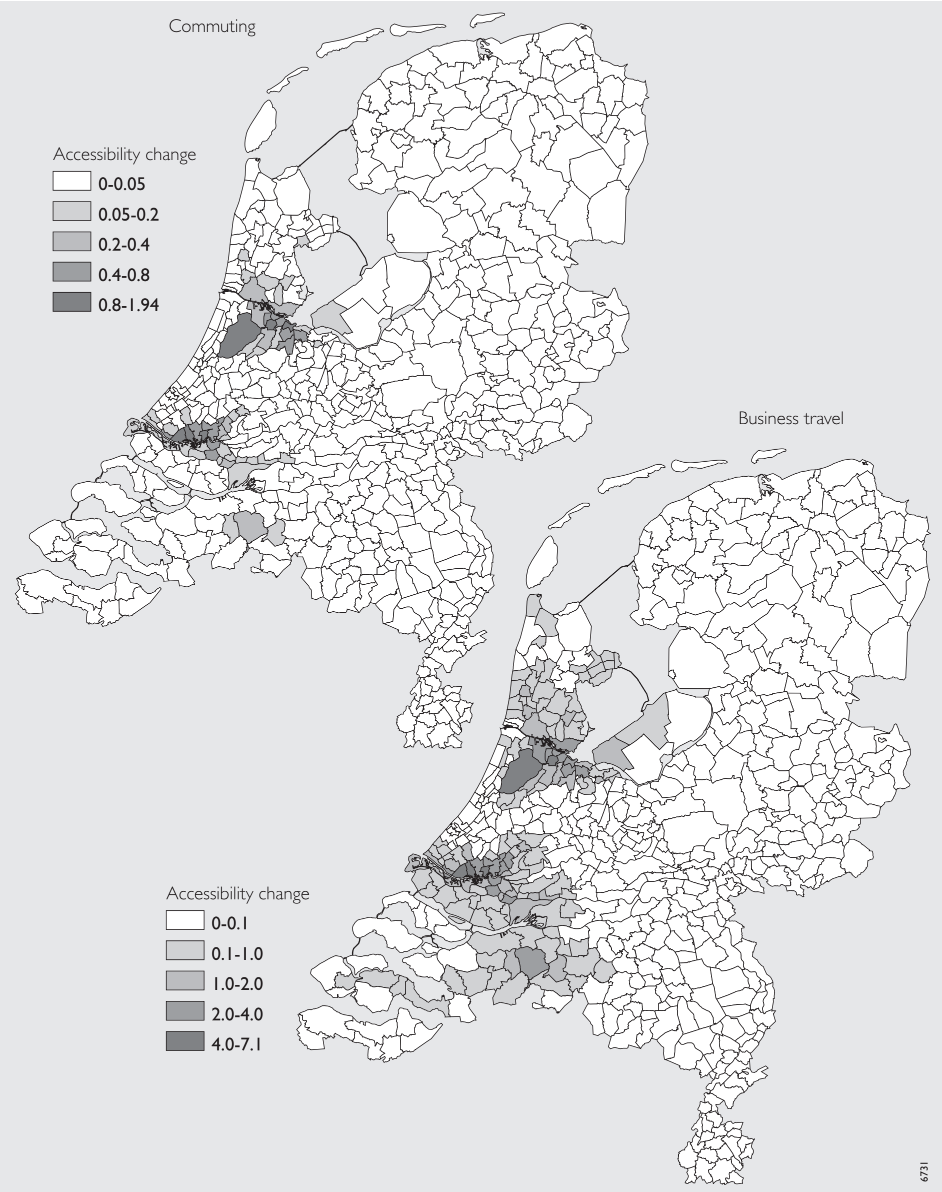

Figure 5.4 Increase in gravity-type potential accessibility towards potential employees and potential business partners due to domestic services on the HSL South (the maximum accessibility by train in 2000 is 100).

To gain insight on the behaviour of the potential accessibility indicators Figure 5.3 shows the impedance from stations along the future Amsterdam-Breda line. The figure gives an idea about the possibilities for the high-speed railway line to change commuting patterns between cities along this line. The HSL South will reduce in-train travel times between the stations in this corridor that are shown in Figure 5.3, and would therefore lead to a shift of these stations towards the left side of this graph. The steepness of the impedance curve at the range of those shifts is a major determinant for the accessibility effect of the HSL South. It can be seen that decreasing in-vehicle generalised costs can improve conditions for interaction between the Rotterdam and Amsterdam city centres and therefore also potential accessibility of these places. Breda is less likely to fall within a reasonable commuting range from Amsterdam after the HSL South is implemented, and also possibilities for business interaction is on the basis of this model not expected to increase much. Accessibility effects for these two cities are therefore mainly the consequence of their connection to Rotterdam.

Figure 5.4 shows the resulting effect on gravity-type potential accessibility, expressed as the accessibility score as explained in the previous subsection. As expected, the surroundings of the high-speed train station have the largest increase in potential accessibility. When regarding the relative accessibility changes (so as a change relative to the previous accessibility value, not as an accessibility score) train accessibility for commuting increases at maximum 4.0 percent for the city of Amsterdam and 4.3 percent for Rotterdam. However, when looking in more detail at the Amsterdam region a remarkable result is observed: within Amsterdam the South axis area has the highest absolute increase in potential accessibility, even in this scenario where it does not have direct high-speed train services from its station. The frequent train connection of the South axis with Schiphol is a likely explanation for this.

Other places within the Randstad region do hardly or not benefit from the high-speed railway for potential accessibility to employees. Cities and towns between Amsterdam and Rotterdam are bypassed by the high-speed trains (the so-called 'tunnel effect' of high-speed railway infrastructure, Plassard, 1991; Vickerman, 1997), whereas for places further north and south of the line the effort to get to the high-speed trains is often too large to have an advantage over conventional rail. For The Hague the impact on the accessibility score is also negligible because of the very low frequency of services that stop in this city. The level of the additional fee for high-speed trains is very important for accessibility to employees because of the relatively low average value of time for commuting.

For business travel, the potential accessibility effect is more extensive. Train accessibility increases at maximum 7.1 percent in the Amsterdam region and 8.9 percent in the Rotterdam region (outside the study area increases of up to 14.6 percent in the area around Breda can be seen, although here also cross-border accessibility can be expected to be relevant). In the business travel model high-speed railway implementation has an effect on accessibility in a larger area around Amsterdam and Rotterdam than for commuting and is thus less limited to the cities themselves.

Figure 5.5 shows the impact of the HSL South domestic services on the contour potential accessibility indicator. It can be seen from the figure that the accessibility effect for this indicator is much larger than for the gravity-type indicator. Accessibility increases are calculated of up to

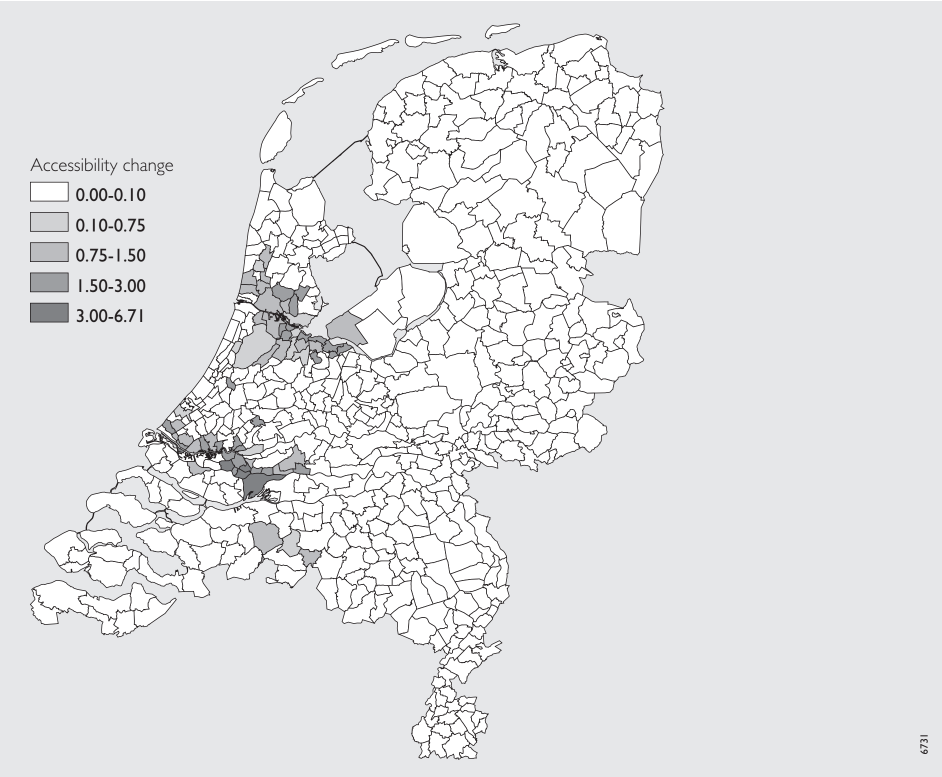

Figure 5.5 Increase in contour accessibility towards potential business partners due to domestic services on the HSL South (the maximum overall accessibility in 2000 is 100).

6.7 percent of the maximum accessibility in the reference situation. Some differences between the gravity-type and contour indicators can also be seen if regarding which areas benefit from the HSL South. Compared to the gravity indicator the area on which the high-speed railway line has at least a small influence is less extensive for the contour indicator. But on the other hand a high increase in accessibility is less restricted to the cities that have a high-speed train station; also several cities and towns with good train connections to the high-speed train stations are seen to gain accessibility. So according to the contour indicator a smaller area benefits from the HSL South, but this benefit is larger than followed from the gravity-type indicator.

This explorative analysis has shown that although the overall potential accessibility image for the reference situation showed little differences between commuting and business travel the effect of high-speed rail differs considerably between these transport motives. Still it must be noted that the overall accessibility effect of this scenario is limited also for business travel, because train accessibility accounts only for a small part of the total accessibility score in Figure 5.1.

5.3 Conclusions

Most findings of this accessibility analysis are consistent with those of the accessibility studies that have been described in chapter 2. Within the Netherlands the high-speed railway line leads to a more unequal distribution of accessibility and thus to wider differences between central and peripheral regions, which corresponds to the results of for example Bruinsma and Rietveld (1993) and Vickerman *et al.* (1999) on a European level. Furthermore, similar to Gutiérrez *et al.* (1996) a tunnel effect causes imbalances between on the one hand the main cities (Amsterdam and Rotterdam) and on the other hand the rest of the Randstad area. However, compared to other accessibility studies on single connections (e.g. Gutiérrez, 2001; Tira *et al.*, 2002, see chapter 2) the accessibility increases due to the high-speed train services are considerably smaller. The chosen type of indicators, impedance functions and impedance parameters are probably of great influence here, besides differences in spatial context (e.g. the distribution of population and the location of stations) and high-speed train level-of-service characteristics.

In this accessibility analysis two types of potential accessibility indicators are used: gravity indicators and contour indicators. When considering the difference between these two indicators, similarities can be found with other accessibility studies that use both indicators, notably Vickerman *et al.* (1999) and Gutiérrez (2001). The accessibility surfaces for the gravity indicator in Vickerman *et al.* (1999) show that both the absolute accessibility score and the increase of accessibility due to high-speed rail are rather dispersed on a large (international) spatial scale but much more concentrated on a small (regional) scale. For the contour indicator the opposite is true. Also the accessibility maps in Gutiérrez (2001) reveals the effect on the gravity indicator to be relatively smooth and the effect on the contour indicator to follow a more scattered pattern. These effects can all be found as well in the current accessibility study.

An aspect that the abovementioned studies do not cover is how these indicators differ if competing transport modes are taken into account. In the current study both types of indicators use the same travel disutilities that are based on spatial interaction models with mode choice. Still their outcomes differ considerably. For the gravity indicator short-distance transport modes are dominant, so high-speed rail has little effect on the overall accessibility score. On the other hand for the contour indicator distances within a certain range of travel disutility have no effect on the height of the indicator, but it are relatively long-distance travel opportunities that determine changes in the accessibility indicator. This leads to a higher increase in accessibility due to high-speed rail for the contour indicator. Contour indicators seem to yield more distinguishable results when used for studying high-speed train accessibility; though its relevance should be based on theoretical or empirical grounds.

The accessibility indicators that have been calculated can have different spatial-structuring effects. Their relevance for explaining spatial-economic processes is studied by focussing on office locations. The following chapter links potential accessibility to office location choices. Thereafter, in chapter 7 more scenarios are tested for their accessibility and location choice effects.

6. Accessibility influence on location choices of office establishments in the Randstad area

Accessibility is generally seen as having an influence on location choices, because (as discussed in chapter 2) it is a determinant for the economic potential and location quality of a site. The previous chapter has presented and evaluated potential accessibility indicators that are considered to represent the size of the market and labour market for an office. This chapter makes use of these accessibility indicators to estimate a revealed choice (RC) model on office location choices. Together with a stated choice (SC) model this model yields the building blocks for a combined SC/RC office location choice model that is used in the next chapter to evaluate different scenarios of railway network and land-use developments.

The outline of this chapter is as follows. Firstly, the responses on the office telephone questionnaires (see Chapter 3) are used to attain some explorative statistics on the response, the characteristics of participating offices and some aspects related to their location choices. The second section presents the estimation results of an RPL model of stated office location choices. Hereby the main focus is on the valuation of station level-of-service attributes. Subsequently the third section deals with the location choice models that use RC data. Attention is among others given to the distinction of intraregional and interregional shifts of office employment and the role of perceptions in location choices. Finally, in the fourth section of this chapter the SC and RC model results are used in a combined SC/RC model of office location choices.

6.1 Explorative statistics

This section presents some explorative statistics on the response, the offices' characteristics and the offices' location choices. The purpose of this section is to provide some easily interpretable statistics that can be used to evaluate the results of the discrete choice models presented in the following sections of this chapter. The first subsection focuses on the response characteristics of the telephone interviews and stated choice experiment; attention is given to the size of the total population that this data set applies to. The second subsection evaluates the characteristics of participating offices, divided into three categories: general/organisational characteristics, characteristics related to spatial orientation, commuting and business trips, and characteristics more specifically related to international business trips. Finally, the third subsection presents statistics related to the offices location choices: their previous location choices, their perception of their current location's attributes and more specific on the potential role of high-speed railway locations in their future location choices.

6.1.1 Response to the interviews and stated choice questionnaires

In the current research offices have been selected from a database containing all types of firms and institutions. Therefore the size of the total research population can only be approximately determined after all potential respondents have been contacted by telephone and do or do not have confirmed or that their establishment has an office function. The response characteristics of this research are important for the interpretation of the model results in the scenario study in Chapter 7. This subsection first presents details on the interview response and then focuses on the research population issue.

Response percentages

The response of the research is relevant for the representativeness of the results. Table 6.1 shows the response figures per stratum of the telephone interviews and stated choice questionnaires. The percentage of respondents that is in an office establishment is given, based on the two stages of selection in the interview procedure (see section 3.2). Furthermore, the table shows percentages for the response to the interviews and stated choice questionnaires. Since a part of the non-response occurred before verification of the relevance of an establishment the percentages for the RC data in Table 6.1 are estimates.

The percentage of respondents that is part of the relevant population for this study is higher for the business and financial services industries than for other economic sectors. Because of the nature of business and financial services the establishments in these industries are more often offices than establishments in other industries. Furthermore establishments with 100 or more employees are more often part of the relevant population than smaller establishments.

The response to the telephone interviews yields 297 valid observations of revealed location choices. Response is higher for the strata of offices in the business and financial services than for the strata of other branches of industry. The reason for this is not completely clear. It could be that offices from business and financial services have a higher incentive to respond to enquiries in general, due to the nature of these offices or their companies. Another possible explanation is that the willingness to respond can depend on how relevant the specific topic of the current study is to the potential respondents. Hypothetically, despite of the selection procedure the current topic might be more often relevant to an office in the business and financial services than to other offices. However, from the data available from the telephone interviews it is not

Table 6.1 Response characteristics per stratum

Branch of industry	Business and financial services		Other	
Number of employees	20-100	100 or more	20-100	100 or more
Telephone interviews				
Percentage relevant	68%	80%	47%	58%
Response percentage[19]	52%	46%	27%	33%
Revealed choice response	92	94	46	65
Stated choice questionnaires				
Response percentage[20]	49%	56%	54%	58%
Stated choice response	45	53	25	38

possible to confirm that the topic of the study has an effect on the response. The reasons given for non-response are for the large majority either 'having no time' or 'being not interested in participating', without explicit reference to the topic of the interview. There is therefore no indication from the data that the response is biased towards offices that are sensitive to railway accessibility.

For the stated choice questionnaire differences in response percentages between strata are not significant. Just over half of all telephone interview respondents also returned a completely filled-in stated choice questionnaire, resulting in 161 stated choice respondents which makes 1288 observations in total with eight observations per respondent.

The absolute response to the telephone interview is sufficient to derive basic statistics and to establish an RC model with a few segmentation criteria and that has the main explanatory variables for office location choices in general, without being able to focus on niche location criteria. For the SC questionnaires possibilities to estimate interaction effects in the model (i.e. the occurrence that the combination of two or more attributes has a positive or negative effect additional to these attributes separately) are limited and care should be taken to select indicators for taste heterogeneity.

Relevant population
The size of the relevant population in number of offices is estimated from the selection percentages in Table 6.1 and the total number of establishments per branch of industry in the study area derived from the chambers of commerce database (KvK, 2002). The relevant population is estimated to be approximately 7000 office establishments, which accounts for 1.7 percent of all firm and institution establishments within the study area.

The size of the relevant population in number of employees is estimated from the estimated number of offices per branch of industry in combination with the average number of employees per establishment in each of the branches of industry (from the LISA database). With this method the relevant population of office employment is estimated to be about 0.63 million employees, which is 20 percent of total employment in the study area. The models presented in this thesis are thus considered representative for one fifth of all employment in the study area.

Using the above population estimations, the approximate net sample percentages can be calculated. The 297 offices in the data set result in a sample percentage of 4.2 percent, but since offices with 100 or more employees are oversampled the participating offices account for 8.4 percent of the relevant employment in the study area. Sample percentages differ considerably between strata: for offices with 100 or more employees in business services this is as high as 14 percent, while for offices with 20 up to 100 employees in other industries this is 1.5 percent. However, the absolute response is seen to be large enough to represent the target population as a whole.

6.1.2 Characteristics of participating offices
The properties of the respondents are relevant firstly for exploring several accessibility-related aspects of the profile of offices and secondly because a number of office characteristics are used

to explain taste heterogeneity in the location choice models. Three categories of characteristics are distinguished and are subsequently discussed below: (1) general and organisational characteristics, (2) characteristics related to spatial orientation, commuting and business trips, and (3) characteristics more specifically related to international business trips. The results discussed in this subsection as well as those presented in the following subsection are corrected for the stratification applied and they are weighted for the number of employees, unless if it is explicitly stated otherwise. Because of this weighting the figures mentioned in this and following subsections should be interpreted as being aspects that can be relevant for the location of office employment, although these are for simplicity referred to as office characteristics. The differences between these weighted figures and their equivalents without weighing are generally small and omitting these weights would not lead to different conclusions.

General and organisational characteristics of offices

General and organisational statistics are presented here to examine the institutional context of the respondents. These characteristics may be of influence for an office's location preferences. The statistics are all based on the total data set of 297 respondents.

The branch of industry is commonly used as an explanatory factor for taste heterogeneity in office location choices. Figure 6.1 shows the branches of industry of the respondents in this data set. From the business and financial services strata the business services branch of industry is clearly dominant, accounting for 44 percent of office employment. Financial services have a moderate share in all respondents, as well as offices in manufacturing, construction, trade and government. Other branches of industry are negligible in this data set. In the location choice models the branch of industry is tested as a characteristic explaining taste heterogeneity. Thereby two segments are distinguished, following the stratification of the data set: one segment with business and financial services and one segment with other industries.

For business travel a relevant aspect can be the organisation in head and branch offices of the firm or institution that an office is part of. Business travel can among others serve to maintain internal contacts. In the data set 39 percent of the firms/institutions[21] has just one establishment, for these

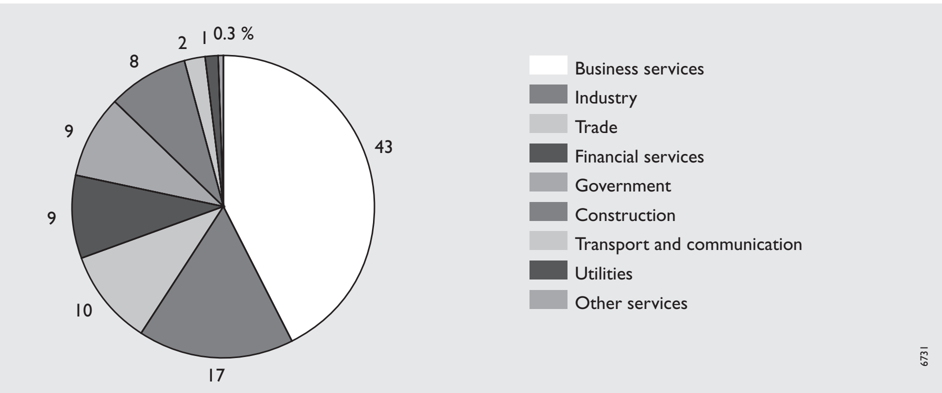

Figure 6.1 Branch of industry of office employment.

offices business travel to maintain internal contacts is not relevant. Of all firms/institutions with multiple establishments 46 percent has more than five establishments. Furthermore, 53 percent of all offices in the data set has a head office function (either for the whole firm/institution or for the Netherlands); other offices are branch offices. Since head offices might have specific accessibility requirements, having a head office function is tested as an explanatory variable for taste heterogeneity of accessibility attributes in the location choice models.

A final organisational aspect is whether an office has international internal linkages. This is possibly relevant for the international accessibility requirements of the office. Of all office employment 48 percent is part of an international company or alliance. According to a chi-square test (e.g. Rice, 1995) such an international linkage is more often present in the office establishments with at least 100 employees than in the smaller offices ($\chi^2 = 25.9$; $p=0.00$). This organisational aspect is further referred to below, when the focus is on the international travel behaviour of the offices' employees.

Spatial orientation and travel frequency
In the current research the relevance of several travel-related office characteristics for the valuation of accessibility attributes is tested. These travel-related aspects can be divided into the spatial orientation of the office, i.e. the spatial extent of the office's product and employment market, and the frequency with which business trips are made to and from the office.

Before going deeper into these two aspects, first it should be assessed what type of business trips are relevant to the offices. For firms/institutions with more than one establishment it is possible that the respondent's office does not directly have contact with customers[22], but that these contacts go via other offices within the same firm/institution. Of all office employment in the data set the large majority (94 percent) is in an office that has direct contacts with customers. Furthermore, business trips can also be made to other business partners than customers. In this data set (based on 295 observations) 58 percent of the office employment is in an office that has contact with other business partners than customers. However, it appears that these contacts generally produce less business trips for the offices than customers. And also from the initial explorative interviews the overall image was that customers were considered to be more important than other business contacts. Therefore, customer contacts are considered decisive for the spatial orientation and trip frequency of business travel in this study.

Indicators for trip frequency to customers used in this research are the number of employees of the office that regularly receive or visit customers. This indicator is chosen because most respondents are considered capable of giving a relatively accurate answer to this type of question. In general more employees are involved in visiting customers than in receiving customers: 33 percent of the offices has 40 percent or more of its employees visiting customers at least once a week, but only 27 percent of the offices has half or more of its employees receiving customers at least once a month (based on 269 en 261 observations respectively). Both these indicators are tested to explain taste heterogeneity in the location choice models, as explained in more detail in the sections 6.2 and 6.3.

The spatial orientation of an office refers to where most of the office's customers are located and determines the maximum distance of most regular business trips. In this study distinction is made between local/regional and national/international orientations. Hereby a correction is applied on the basis of trip frequency to ensure only offices that regularly make business trips[23] are assigned a spatial orientation indicator. Of the offices 61 percent has a national or international orientation, 16 percent has a local or regional orientation and 23 percent does not meet the trip frequency criterion (281 observations). Thereby, for some offices this orientation is more restrictive than for other. Firms/institutions may assign fixed territories to each of their branch offices or offices might otherwise be limited in their orientation, for example by administrative boundaries. Of all offices 28 percent indicated having a strictly demarcated market (278 observations).

Also the spatial orientation to employees differs among offices. Most offices have a local (43 percent) or regional (45 percent) orientation, only 12 percent has a national orientation (295 observations). This indicator is also tested in the location choice model.

International mobility
The international mobility characteristics of an office are expected to be an indication for the relevance of high-speed rail to the office. Of all offices in the data set 61 percent has employees who make international business trips (294 observations), although for 27 percent of these offices international business trips are not made at least once a month by (part of) its employees (157 observations). As is relevant within the context of high-speed rail, 81 percent of these internationally oriented offices make business trips to one of the countries that have a direct high-speed train connection with the Netherlands: Belgium, France and Germany.

The international orientation of an office for business travel is related to the international organisational aspect of the office. A chi-square test shows that there is a strong connection between being part of an international company or alliance and having employees making international business trips ($\chi^2 = 55.5$; $p=0.00$). Because of the relationship between the size of the office and having international linkages (see the organisational aspects above) international mobility is more frequently relevant for the larger office establishments. Since the relevance of international accessibility for office location choices is assumed to increase with international mobility of the offices' employees this supports the emphasis of this research on these larger office establishments.

The transport modes that are used for these trips depend of course on the destinations of the trips. Most respondents confirm the use of airplanes (95 percent) and/or the car (71 percent) for at least part of their employees' business trips (121 observations). Rail transport is less common for international business trips. According to the respondents high-speed trains are used by employees of 44 percent of the offices and conventional trains by 21 percent. The low percentage of high-speed train users can be explained by the small time gain that high-speed trains offer by the time of writing this thesis; this makes high-speed rail little competitive to car and air transport.

6.1.3 Explorative analyses of offices' location and travel behaviour
Besides the properties of the offices some other statistics derived from the telephone interview results give more information on the location choices of offices. These results are discussed in this

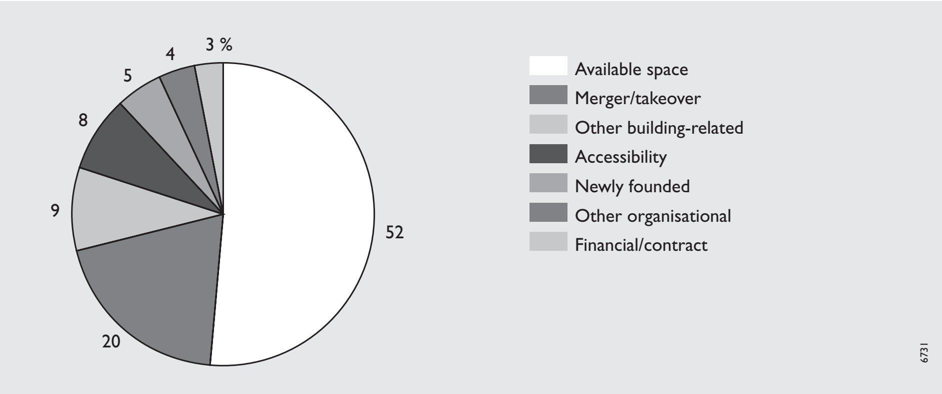

Figure 6.2 Motives to move for recently relocated respondents (98 observations).

subsection. Firstly, statistics are presented on the previous location choices, which are especially important for interpreting the results of the location choice models. Secondly, the perceptions of location attributes are discussed, since these perceptions are the aspects on which location choices are actually based. And finally the potential relevance of high-speed railway connectivity for the respondents' location choices is evaluated.

Previous location choices of respondents
Information on characteristics of the current location and on previous location choices can be used to better evaluate the results of the location choice models. Several sources of information are available for this. Firstly, offices that indicated having made a location choice in the last five years before the interviews were asked additional questions on their relocation incentives and their main location choice determinants. These questions were formulated as open questions; responses are categorised afterwards by the author.

The first question concerns the motives to move. Seven categories are distinguished for this question. The results are depicted in Figure 6.2. For the current research topic especially the category 'accessibility' is relevant. Here, the 'Accessibility' category comprises centrality (respondents' qualifications such as "centrally located within the country"), connectivity (e.g. "close to a station") and more general responses ("good accessibility"). As expected from literature (see chapter 2), accessibility is not often an incentive for an office to relocate. Building-related aspects account for a majority of all relocations; most dominant is the availability of sufficient office space. Also organisational aspects such as mergers and take-overs are more important than accessibility. Five percent of the location choices are caused by offices that were newly founded. This is a small number, because only offices with at least 20 employees were included in the research, so that older companies and institutions can be expected to be dominant in the data set.

Respondents that made a location decision were also asked about the dominant location factor for their recent location choice. Answers to this open question were assigned to eight categories, see Figure 6.3. Here accessibility is the most important category of location factors. Some respondents also mentioned access to Schiphol airport as being a dominant factor, which is

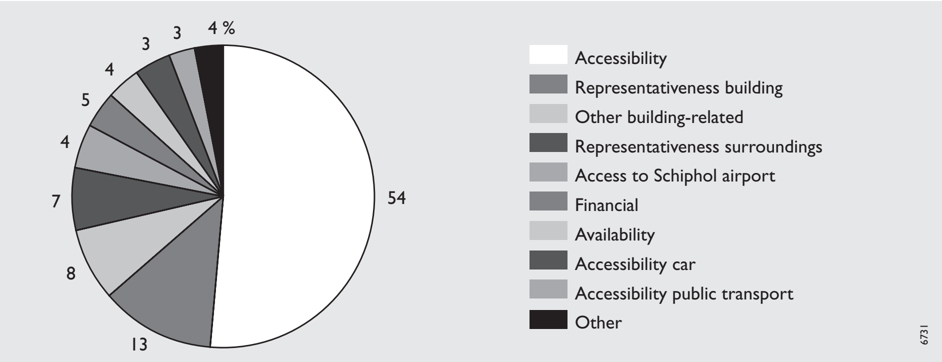

Figure 6.3 Dominant location factor as proclaimed by recently relocated respondents (68 observations).

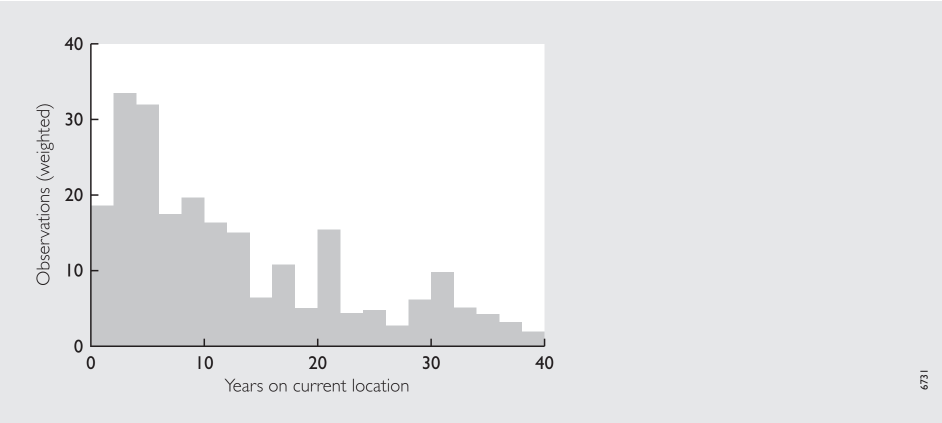

Figure 6.4 Histogram of the number of years respondents had been located on their location by the time of the interviews[24].

important for the current research in the context of international accessibility. Other important categories relate to (the representativeness of) the building and its immediate surroundings.

The results above confirm the general finding discussed in chapter 2 that accessibility is mainly relevant for the choice of a new location and not as an incentive for an office to relocate. However, it should be mentioned that although these questions were asked at the beginning of the interview, their results for the accessibility category could be coloured by the purpose of the interview, since the topic of accessibility was explicitly announced when introducing the interview. Still, the low score of accessibility on the first question does make such a bias not likely to be large. Railway developments can therefore be assumed to influence the spatial distribution of offices but to have little effect on the speed with which this distribution changes.

More can be said about the speed of change in office locations by examining the frequency with which offices relocate. Respondents were not selected on the basis of a recent relocation; therefore the sample also comprises respondents who had been at their location for a very long time. All respondents were asked since when their company or institution had been located at their location. Figure 6.4 shows a histogram of how many years before the interview the office's previous location choice had been made.

Of all office employment in the data set 18 percent has relocated in 2000 or later, and another 40 percent had their last relocation in the previous decade. As expected, office employment can be seen to be a type of activity that relocates easily. Furthermore, at this aggregated level of analysis macro-economic conditions can possibly play a role: the recent low in the number of location choices can be the lagged response to the low economic growth in the first years of this decade. Developments in the office market can also be relevant in this context.

As the RC models use the current location of the respondents' offices the characteristics of these offices can increase understanding of the model results. Figure 6.5 below shows the distribution of RC respondents over the urban regions within the study area. It can be seen that most of the respondents are located in or close to the four largest cities in the study area: Amsterdam (65 observations), Rotterdam (43), The Hague (38) and Utrecht (67). Business and financial services

Figure 6.5 Distribution of respondents over the study area: number of revealed choice observations per urban region.

are predominantly located in Amsterdam and Utrecht; in The Hague little offices of these sectors are found.

Furthermore, only six of the respondents' offices are located immediately near Schiphol airport. This is too few to yield a significant effect for airport connectivity in a location choice model. Also otherwise no clear structure is observed in the spatial distribution of internationally oriented offices.

Respondents were asked to classify the type of their current offices' surroundings. Four predefined types could be chosen, as well as a leftover category (for more detail on location types and a more extensive classification see Rietveld and Bruinsma, 1998). The participating offices are rather equally distributed over the four types (296 observations). Most offices (28 percent) are located in an office park outside of the city centre but which is not directly observable from a motorway. These sites are typically well connected by local public transport and can be adjacent to a (small) railway station. Furthermore, these locations in many cases have less parking issues than city centre locations. A second-large group (26 percent) is located in the centre of a large or medium-large city. These offices can generally be expected to be well accessible by public transport but can be suffering from poor car access. The third group are locations in a rim town or rural town; this type of location has 20 percent of the offices. Another 18 percent of the offices is located in an office park that is visible from a motorway. This type of location is typically oriented on car accessibility. Finally, 8 percent of the respondents did not see one of the above-mentioned categories to be an appropriate description of their office's location. From the figures above it can be concluded that there is much variety in the office locations in the data set at an intraregional scale.

Another indicator is the type of the office building itself. The respondents were asked to choose between three levels of building appearance (295 observations). Most of the respondents (45 percent) assigned their office building to be of the least decorative category: a sober but functional building. Slightly less respondents (36 percent) choose their office to have a good appearance without being exceptional in its surroundings. And finally 19 percent of the respondents has an office that is architectonic high-valued or very remarkable. It can thus be seen that the appearance of the building is a relevant location aspect, although given Figure 6.3 it is not often a decisive factor for location choices. Furthermore a chi-square test shows that a relationship exists between the type of building and the location type (χ^2 = 17.4; p=0.01, with six degrees of freedom if the left-over location type is omitted). Therefore, even though in the RC location model the subject is the choice of an office between geographical zones and not between particular buildings, these building characteristics are still implicitly taken into account via the land-use typology.

Perceived railway connectivity of locations
As discussed in Chapter 3 it are the perceptions of attribute values on which location choices are based. To explore these perceptions the respondents were asked questions about their beliefs of several railway connectivity indicators. To start, respondents were asked which station was most important to their office's accessibility. For about half of the offices this is the nearest station but especially if this nearest station does not have intercity services then another, usually larger station was mentioned. Subsequently, some questions were asked about this station to shed more light on the respondents' perceptions of railway connectivity.

Firstly, the respondents were asked whether or not their office is located within walking distance of the station that has been mentioned. About half (51 percent) of the respondents confirmed this question (290 observations). Subsequently, these respondents were asked about their perceived walking time to the station (138 observations). On the one hand walking times of up to 25 minutes were stated, but most these respondents (74 percent) mention walking times of 10 minutes or lower. This suggests that walking distance is not a strictly demarcated quantity.

A second aspect that is studied is the station's level-of-service. Respondents were asked about the presence of intercity and high-speed train services at the station they mentioned earlier. The respondents' perceptions are compared with level-of-service figures provided by the Dutch railway company NS. For intercity services this remarkably yielded a relatively large number of false positives (i.e. respondents claiming the presence of intercity services if this is not the case according to NS data[25]). Apparently, respondents overestimate the relevance of the station in the railway network. For high-speed train services on the other hand the number of false negatives was larger. This can be explained by the current high-speed train services being unknown to the respondents. As a result, high-speed train connectivity is not expected to have a large determining influence on location choices in the RC data, since decision makers will not take account of an aspect of which they are not aware.

On the total hourly frequency of train services at the station respondents appeared to have little information. This is expressed in a low response (41 percent) to this question and also in a low number of answers that were consistent with timetable data: even when a high tolerance of 20 percent is adopted 81 percent either underestimates or overestimates the train frequency. It can be concluded that awareness of this attribute is low. Still, this makes it not impossible to take account of total train frequency in a location choice model, since it is the relative position of choice options on an attribute that matters most. Decision makers might very well be able to judge a station's level-of-service without knowing the exact figures. However, the low response and low awareness of train frequency makes these perception data unsuitable for further use in a location choice model.

High-speed railway accessibility
To gain more insight into the role of high-speed railway accessibility in an office's location choice, two further questions were asked that relate to this topic. The first question is whether or not the respondent would consider choosing a location near a high-speed railway station if (s)he would have to relocate. A minority of 25 percent would regard such a location a viable option for their office establishment (291 observations).

High-speed rail is considered to affect location attractiveness mainly via two ways: firstly the accessibility effect of high-speed train services and secondly the image effect of high-speed railway stations. Respondents that would consider a high-speed railway station location were asked which of these or a possible other reason was most important for considering this type of location. Most respondents (62 percent) indicated the accessibility effect of high-speed rail to be most influential and 20 percent mentioned the image effect. Although not given as a predefined option the typically good regional accessibility of high-speed train stations was a reason for ten percent of the respondents.

These results confirm that high-speed rail is relevant to a very limited group of offices. Furthermore besides of accessibility also an image effect of high-speed rail can be of importance to a location decision maker.

6.2 Models based on the stated location choices of offices

This section focuses on the parameter estimation results of the SC office location model. The purpose of this model is to evaluate the valuation of different station level-of-service attributes in the location choices of offices. Hereby attention is given to how this valuation varies over the participating offices. It also enables to assess the relevance of high-speed railway connectivity for location choices, which is not possible on the basis of RC data. Furthermore, it is studied how station access time influences location attractiveness.

This section firstly describes differences between the populations of the SC and RC models. Then the parameter estimations for the RPL model with SC data are presented. Subsequently, several aspects of these results are dealt with consecutively: the influence of station access time, the relevance of station level-of-service and the relevance of car accessibility and non-accessibility aspects. Finally, some conclusions are drawn from this part of the research specifically.

6.2.1 Respondent characteristics

The SC model is based on a subset of the telephone interview respondents. Therefore, the respondent characteristics for the SC model are somewhat different from those for the RC model.

The SC experiment described in the previous section yielded a reply of 161 valid SC forms, which is about 2.4 percent of the target population. The respondents varied in their characteristics as shown in Table 6.2. This table only shows office characteristics that were statistically significant in the model. Other heterogeneity aspects that were tested, such as whether an office has a head office function, were rejected from inclusion in the location choice model. The dummy variables that represent heterogeneity among respondents (W_{mq}) show low mutual correlations, resulting in r^2 values of 0.30 or lower between heterogeneity attributes in the final model.

An aspect that is relevant for the interpretation of the SC model results is the possible occurrence of a selective response. Even if choice questions are formulated in a general way, the response might be lower for respondents who are indifferent about some of the attributes and higher for respondents who feel affected to some of the attributes. Because of the specific focus of this research on railway related location attributes respondents for whom railway accessibility in general and high-speed railway accessibility in particular is relevant might have a higher response rate than respondents who do less take account of the train in making location choices. A possible selective response can be identified by comparing the office characteristics of SC respondents to the figures of the RC respondents in section 6.1 above. In general the differences in office characteristics between the whole data set and the SC subset are small, and so is presumably the selective response. The largest difference exists for employees making international business trips. For the RC data 35 percent of the offices has employees who at least once a month make international business trips to destinations that include Belgium, Germany and/or France; for the

Table 6.2 Respondent characteristics to represent preference heterogeneity, with the dummy values used as covariates in the model.

Office characteristics	Levels	Heterogeneity dummy	Sample %
Branch of industry	Business/financial services	1	56
	Other	0	44
	Total		100
Employees receiving customers at least once a month	Less than half of employees	0	61
	Half or more	1	30
	Unknown	0	9
	Total		100
Employees visiting customers at least once a week	Less than half of employees	0	61
	Half or more	1	32
	Unknown	0	7
	Total		100
Spatial orientation customers	Local/regional	0	21
	National/international	1	48
	Not relevant/unknown	0	27
	Total		100
Spatial orientation employees	Local	0	42
	Regional/National	1	58
	Unknown	0	0.2
	Total		100
Destinations of employees making international business trips at least once a month	Include HST area[1]	1	38
	Exclude HST area	0	9
	Not relevant/unknown	0	53
	Total		100

1: Destination countries include at least one of the countries with a direct high-speed train connection from the Netherlands: Belgium, Germany and France.

SC questionnaire this is 39 percent. This is only a small difference; for other office characteristics differences are even smaller and given the sample size not statistically significant. Overall, the occurrence of this minor selective response is not expected to have serious consequences for the model results, also because it is corrected by estimating different parameter values on the basis of the office characteristics.

6.2.2 Results of the parameter estimations

The results of the random parameter logit model and multinomial logit model estimations are shown in Table 6.3. Both models have a satisfactory goodness-of-fit, with ρ^2 values of 0.300 and 0.350 respectively. The main effects account for the larger part of this goodness-of-fit; a model with only the main effect parameters has a ρ^2 of 0.259. Two interaction effects are included in the model. The interaction effects contribute little to the goodness-of-fit (a model with main effects and interaction effects has a ρ^2 of 0.261) but are important as they give information relevant to the scope of the research. Furthermore, a number of heterogeneity effects are significant. Relevant heterogeneity aspects are the branch of industry, the trip frequency and the spatial orientation of the office. For the type of train services the heterogeneity parameters are restricted to be equal

Table 6.3 Parameter estimation results for the stated choice logit models.

Attribute	Multinomial logit			Random parameter logit		
	Param.	t-value[1]	P-value	Param.	t-value[1]	P-value
Station access time (min) :						
Linear	-0.12	-10.8	0.000	-0.30	-6.3	0.000
Quadratic	$4.0\ 10^{-3}$	1.9	0.064	$8.0\ 10^{-3}$	1.5	0.134
Cubic	$9.8\ 10^{-4}$	2.5	0.012	$3.1\ 10^{-3}$	3.3	0.001
Random parameter (normal distribution)	n.a.			0.20	4.1	0.000
Train frequency (natural logarithm of trains per hour)						
Main effect	0.44	6.6	0.000	1.25	4.8	0.000
Random parameter (normal distribution)	n.a.			1.58	5.2	0.000
Train services: also intercity train services						
Main effect	-0.039	-0.38	0.703	0.37	1.6	0.120
Employees visiting customers	-0.15	-2.2	0.028	-0.37	-2.4	0.015
Spatial orientation to employees	0.14	2.4	0.017	×		
Trips to international HST destinations	-0.24	-2.5	0.012	-0.37	-1.7	0.085
Train services: also domestic HST						
Main effect	0.21	2.1	0.036	0.60	2.6	0.009
Employees visiting customers	-0.15	-2.2	0.028	-0.37	-2.4	0.015
Spatial orientation to employees	0.14	2.4	0.017	×		
Trips to international HST destinations	-0.24	-2.5	0.012	-0.37	-1.7	0.085
Train services: also international HST						
Main effect	0.12	0.11	0.269	0.24	0.86	0.391
Employees visiting customers	-0.15	-2.2	0.028	-0.37	-2.4	0.015
Spatial orientation to employees	0.14	2.4	0.017	×		
Trips to international HST destinations	0.68	4.2	0.000	2.15	4.0	0.000
Random param. (uniform distribution)	n.a.			2.28	4.2	0.000
Station access mode (bus = 1, walk = -1)						
Main effect	-0.59	-6.0	0.000	-1.35	-5.2	0.000
Branch of industry	0.35	2.6	0.008	0.76	2.6	0.008
Motorway access time (minutes)						
Main effect	-0.074	-3.4	0.001	-0.40	-5.9	0.000
Employees receiving customer visits	-0.068	-1.7	0.094	×		
Employees visiting customers	-0.085	-2.1	0.034	×		
Spatial orientation to customers	-0.065	-2.1	0.040	×	4.8	0.000
Random parameter (normal distribution)	n.a.			0.33		
Parking places (number per 100 employees)						
Main effect	0.016	2.2	0.029	0.044	2.5	0.014
Employees receiving customer visits	0.026	1.8	0.065	0.065	2.2	0.027
Price of real estate (€ per m per year)						
Main effect	-0.038	-12.2	0.000	-0.11	-6.3	0.000
Random parameter (normal distribution)	n.a.			0.067	4.8	0.000
Type of building						
Main effect	-0.18	-1.9	0.057	0.10	0.50	0.614
Branch of industry	0.35	2.7	0.008	×		
Random param. (uniform distribution)	n.a.			2.67	4.8	0.000

(Table 6.3 continued)

	Multinomial logit			Random parameter logit		
Attribute	Param.	t-value[I]	P-value	Param.	t-value[I]	P-value
Type of urban environment						
Main effect	-0.76	-6.4	0.000	-1.64	-3.4	0.000
Branch of industry	0.48	3.0	0.002	×		
Random param. (uniform distribution)	n.a.			3.99	5.2	0.000
Interaction effects						
Station acc time × acc mode (linear)	8.6 10^{-3}	0.70	0.484	0.047	1.5	0.130
(quadratic) (cubic)	2.0 10^{-3}	0.48	0.635	6.4 10^{-3}	0.73	0.465
	-7.1 10^{-4}	-1.3	0.200	-2.5 10^{-4}	0.21	0.831
Internat. HST service × type building	0.27	2.8	0.005	0.48	2.0	0.048
Number of observations	1288 (= 161 × 8)			1288 (= 161 × 8)		
Log-likelihood	-627.94			-583.07		
ρ^2	0.307			0.356		

n.a. = not applicable; x = not significant
I: According to a two-tailed t-test.
II: Effect code, "only regional trains" is reference value.
III: "Architectonic remarkable" = 1, "Average" = -1.
IV: "City centre" = 1, "City-rim office park" = -1.
V: Parameters for Intercity services, domestic HST services and international HST services are restricted to be equal.
VI Compensate effect code for International HST service. Intercity services and domestic HST services are restricted to be equal.

for different train services, because not enough data is available to estimate the model with the heterogeneity parameters of all types of train services treated separately.

The RPL model has a considerably higher goodness-of-fit than the MNL model[27]. Several random parameters are significant. The occurrence of random parameters with a larger effect than the heterogeneity parameters indicates that office characteristics used still have limited capability for explaining taste differences, although their influence is statistically significant. Furthermore, several heterogeneity indicators that are significant in the MNL model are not significant in the RPL model. This is in particular the case for characteristics referring to the spatial dispersion of the office's employees and customers. These heterogeneities appear to fall well within the standard deviation of the respective random parameter. In these cases a more continuous random distribution represent the diversity of offices better than the discrete categorisation by dummy variables, where the heterogeneity within each category is not taken into account.

6.2.3 Influence of access to stations on location attractiveness

Station access is seen as an important aspect of train connectivity. As the transport model results already show the distance to a station can be seen as a determinant for the availability of the train as a transport mode. Accordingly it is also very relevant for office location choices, since these determine the starting and ending points of commuting and business trips. In the SC model station access is dealt with in somewhat more detail than in the transport model and in the RC location choice models, by using travel time instead of distance and by taking account of the transport mode used to access the station. The results are thus not strictly comparable but can be seen as complementary to each other.

The station access time has, as expected, on average a significant negative influence on the valuation of a site. Furthermore, being situated within walking distance of a station adds extra value to the location. Because station access time and access mode are closely connected in the formulation of the choice alternatives, the interaction effect of these attributes is estimated in the model. The utility coefficients of this interaction are not significant, however the relevance of the interaction effect appears from Figure 6.6: the polynomial function for the station access time by bus shows a different shape than for station access time on foot.

The figure supports the hypothesis that the utility effect of the station access time is non-linear in case of access on foot. When a station is to be reached on foot a transition range seems to be present around 10 to 15 minutes walking time, where a change in walking time has the largest influence on location utility. Locations at a walking time below this range can be seen as being within an acceptable walking distance; then a moderate change in the walking time does not significantly influence the utility of the location. On the other hand, for walking times above the transition range the station access is poor and differences in walking time are less important as well. With these walking times other transport modes are more likely to be chosen. For access of the station by bus no such transition is present. Instead, the utility effect of station access time by bus seems to decrease more gradually when access time increases.

For the same access time, walking is preferred above taking the bus, as is shown by Figure 6.6. This preference is less extensive (but still statistically significant) for offices in the business and financial service industries compared to offices in other industries (the heterogeneity effect is omitted in Figure 6.6). For the station access time no heterogeneity effects were tested, as discussed in Chapter 3.

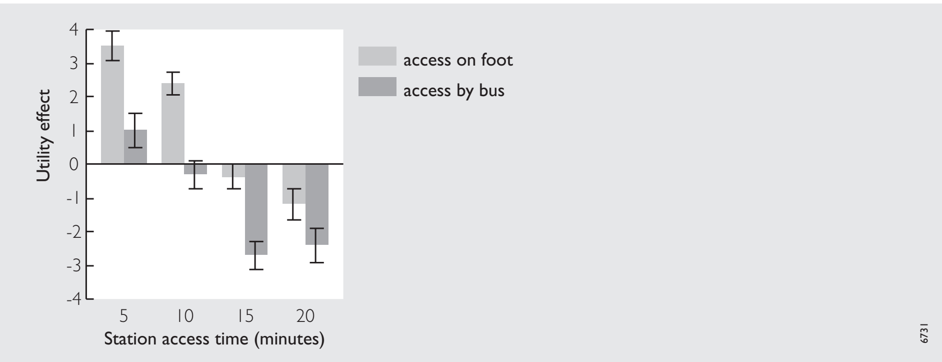

Figure 6.6 Effect of the station access time for access on foot and by bus on the total utility. The reference case is the situation with average parameter values in the experiment: station access time is 12.5 minutes, access transport mode is undetermined. Error bars indicate standard deviation. Bars include the constant utility effect of the access transport mode (but its standard deviation not included in the error bars).

From the above it can be concluded that for office location choices the influence area of a station is a not strictly demarcated, but is rather declining over space, with a main transition range at the boundary of what can be seen as a 'reasonable' walking distance. Assuming a walking speed of about 5 kilometres per hour then the centre of this transition can be localised at the order of magnitude of one kilometre from the station. Still uncertainty about this is large, because of the broad time classes in the model. Furthermore it cannot be assessed from this model how the extent of the station area depends on the level-of-service of a station.

6.2.4 Influence of the level-of-service at railway stations on location attractiveness

Besides station access the level-of-service of the station is a determinant for railway connectivity. In the SC study the influence of the total train frequency and the type of train services at a station were studied. For the train frequency the natural logarithm appeared to perform significantly better than the linear effect. This suggests that a change in train frequency is less important for higher train frequencies than for lower train frequencies, as was anticipated for in the design of the experiment. As discussed in Chapter 3 no heterogeneity effects were tested for the train frequency.

The presence of intercity services at a station the main effect is relevant compared to a station with only regional services. In the RPL model one heterogeneity effects is of importance (hereby domestic and international HST services are assumed to have no additional effect): if many of an office's employees regularly visit customers then the presence of intercity services is not beneficiary to a location's attractiveness. A possible explanation for this is that employees often get a company car from their employer if they regularly visit customers. This increased car availability can lower the need for a good accessibility by train. In the MNL model also the spatial orientation to employees is relevant: if an office's employees are more dispersed throughout the country then the presence of intercity services becomes more important. However, this influence is not significant in the RPL model.

The SC model determines the impact of high-speed train services at a station in addition to intercity services. In other European countries high-speed railway stations exist that do not have conventional train services or only have regional train services. In the Netherlands, however, no new stations exist or are being built/proposed to serve high-speed trains exclusively.

The utility impact of domestic high-speed train services is statistically significant but small in addition to the effect of intercity services. This is not surprisingly, since domestic travel distances in the Netherlands are relatively short. For the few connections on which a reasonable time gain might be expected (for example the Amsterdam-Groningen connection) the expected number of business and commuting trips is small relative to all trips to and from offices in the Randstad area. Because of the limited effect of domestic high-speed train services, no heterogeneity effects are estimated.

Two effects are observed for international high-speed train services. Firstly, the model provides evidence for an image effect, which is that the presence of high-speed train services at a nearby station can influence location choices by raising the status of a location. Because the architectonic style of the building also has an impact on the status, an interaction can occur between the architectonic style of the building and the presence of high-speed train services in case the image effect is true. As this interaction is actually found to be significant, this can be regarded as an indirect indication that image effect exists. Secondly, also the accessibility by high-speed train (so the actual use for travelling) is important but only for offices from which regularly international business trips are made. However, the large random parameter in the RPL model indicates that besides these two effects there still remains a substantial unexplained taste variance.

6.2.5 Role of car accessibility and non-accessibility attributes for location attractiveness

Although the main focus of the SC model is on station connectivity attributes, other attributes are necessary in the SC experiment to formulate realistic choice options and to assess the importance of station level-of-service relative to other attributes.

The two car accessibility attributes (motorway access time and the number of parking places) yield significant parameter estimation results for the main effects and several heterogeneity effects. As a first heterogeneity effect the number of employees receiving customer visits increases the importance of parking places in the MNL and RPL models. An office with many visitors has a relatively large need for parking places. In the MNL model three heterogeneity aspects are statistically significant for the motorway access time that are not significant in the RPL model. The number of employees receiving customer visits at the office, the number of employees visiting customers elsewhere and the spatial dispersion of customers all make being located near a motorway ramp more important. The number of employees visiting or receiving customers leads to a higher intensity of trips to and from the office and thus increases the importance of accessibility. The spatial orientation of an office can be relevant because motorway connectivity is generally more important for long-distance trips than for intra-urban trips.

The model estimation results show a large variance in the valuation of the non-accessibility attributes included: the price of real estate, the type of building and the type of urban environment. In the current model this variance remains unexplained. This is not surprising, since the model is optimized for explaining the taste variance for accessibility attributes but not for these non-accessibility attributes. However, it is important to notice that for part of the offices the non-accessibility attributes are more important than accessibility. This is especially the case for the price of real estate, which can be seen to be the attribute with the highest value in the model.

6.2.6 Conclusions

The SC model has the particular purpose to study how the level-of-service of railway stations, and in particular the presence of high-speed train services, has an effect on the attractiveness of locations for offices. This experiment has also given information on how the valuation of accessibility differs among types of offices and on the effect of station access on the attractiveness of locations.

The model results show that international high-speed train services can have a considerable impact on the attractiveness of an office location. There are, however, large differences in the valuation of high-speed train connectivity among offices, thus for some offices the influence of high-speed train connectivity is large but for others it is irrelevant. This taste heterogeneity can partly be explained by the regular occurrence of business trips to Belgium, Germany and/or France; these countries can be directly reached from the Netherlands by high-speed train. In spite of this, a substantial part of the heterogeneity remains unexplained.

Additionally to the accessibility effect, evidence for an image effect suggests that the impact of international high-speed rail can increase in combination with a representative building and environment, although this effect is considerably smaller than the accessibility effect. This is particularly relevant for the Netherlands because several Dutch cities with a high-speed train connection are restructuring their station area; a notably example is the Amsterdam South axis area.

Domestic high-speed train services are less important for location choices. This is not surprising, since the distances within the Netherlands are either too small to reach a considerable gain in travel time or are able to serve only a small portion of all business or commuting trips. The proposed domestic connections from Amsterdam to Groningen or from Rotterdam to Utrecht are therefore not likely to have a significant impact on location choices of offices in the Randstad region (for a more peripheral region like Groningen this might be different.)

The influence area of a station is not strictly demarcated, but is rather a complex combination of station access time and access transport mode, as shown in Figure 6.6 above. Walking times up to a range of around 10 and 15 minutes walking are generally seen to be reasonable walking times. For walking times above this range going on foot becomes unattractive relative to station access by bus, although in practice the actual use of local public transport for accessing a station would depend on its availability and travel speed. Due to the limited size of the data set, however, no information could be obtained from the model on if and how the level-of-service of a station affects the influence area of the station.

The estimation of heterogeneity attributes has resulted in more insight into what office characteristics determine the relevance of the different accessibility attributes. The model results show that the travel-related characteristics of the offices – especially the frequency of trips – are in general more suitable for explaining preference differences between offices for accessibility attributes than the branch of industry. Finally, the model estimation results show that large differences exist among offices in the Netherlands for the relevance of accessibility by high-speed train. This heterogeneity is partly explained by whether or not an office has employees making international business trips to countries directly linked to the Netherlands by high-speed train. But a substantial part of the taste heterogeneity remains unexplained by the office characteristics considered and might be ascribed to the individual preferences of the respondents.

6.3 Models based on the revealed location choices of offices

In this section the results of the RC models for office employment location are presented. Better than SC models, RC models take account of the external disturbances and uncertainties that offices are confronted by when making location choices in reality. Furthermore, in the current research the RC model is used to evaluate the relevance of the different potential accessibility

Table 6.4 Revealed choice nested logit parameter estimation results

	Parameter	t-value	P-value
Accessibility			
Gravity accessibility score commuting	0.0129	3.46	0.00
Contour accessibility score business	0.0221	3.18	0.00
Train frequency (log)	0.0301	0.28	0.78
Train frequency (log) * Branch of industry	0.348	2.38	0.02
Station access distance	-0.0957	-1.37	0.17
Box-Cox parameter	0.00		
Motorway freeflow access time	-0.190	-3.92	0.00
Box-Cox parameter	0.20		
Land-use typology			
City centre high density	0.641	3.54	0.00
City centre low density	0.0866	0.29	0.77
Town centre	-0.773	-2.02	0.04
City high density	-1.20	-4.33	0.00
City high density * Branch of industry	0.927	3.22	0.00
City average density	0.130	0.61	0.54
City low density	-0.290	-1.51	0.13
Town/village	-0.896	-2.39	0.02
Industrial/business in city	0.860	5.79	0.00
Other industrial/business	1.49	8.22	0.00
Other industrial/business * Branch of industry	-0.729	-3.96	0.00
Scale parameters			
Amsterdam	1.57	5.48	0.00
Rotterdam	1.33	6.27	0.00
The Hague	1.00	n.a.	
Utrecht	1.31	5.77	0.00
Other	1.54	6.21	0.00
Observations	297		
Maximum log-likelihood	-1052.11		
ρ^2 (pseudo-r^2)	0.227		

indicators presented in the previous section and of the application of a logarithmic conversion to these indicators.

Table 6.4 shows the parameter estimations for the revealed location choice model. In this model only attributes and heterogeneity characteristics are included that are also significant in the combined SC/RC model. With a ρ^2 of 0.24 the model has a good fit for this type of model. Many main effects as well as some of the interaction effects show statistically significant results. The parameter values reflect their direct influence on location attractiveness as well as their indirect influence via the price of real estate. An attempt to include the real estate price in the model yielded a positive taste parameter for price, where theoretically price is expected to have a negative influence on location attractiveness. The mutual relationship between price and location attractiveness is a likely cause for this model outcome. After all, real estate prices are seen to depend on the characteristics of a site, resulting in the highest prices for locations that are otherwise most attractive. Therefore, a positive correlation between real estate prices and location attractiveness might not only be interpreted as higher prices raising the utility of locations (which is theoretical unexpected) but can also be due to a causal relationship between the location characteristics that underlie the real estate price and the probability that a location is chosen. To avoid theoretical inconsistency, real estate prices are not retained in the model presented here.

The next subsections go deeper into the results for each of the attribute categories in the model separately. The first subsection discusses the results for the accessibility indicators. Thereafter, the second subsection focuses on the role of the land-use typology in the model. Finally, the third subsection goes deeper into the implications of the nested logit structure of the model, whereby locations within the same urban region are considered to be more similar to each other than to locations in other urban regions.

6.3.1 Role of accessibility for location choices

The potential accessibility indicators that were presented in the previous chapter have been tested in the RC model. This concerns the gravity-type indicators, with and without logarithmic conversion, and a series of contour indicators with different critical boundaries. These indicators are interpreted as representing the size of the labour market in case of the commuting indicators and as the size of the product market for the business travel model.

For gravity-type accessibility only the indicator for commuting has a significant influence on revealed location choices. But for business travel the gravity-type of indicator did not yield satisfactory parameter estimations and was therefore left out of the model. A logarithmic conversion of these indicators resulted in a lower maximum likelihood and was therefore rejected.

For the contour indicators only indicators derived from the business travel model yield satisfactory results; for commuting this type of indicator was not found to be appropriate. Contour indicators are compared to the gravity-type indicators focussing on accessibility over longer distances. Therefore it is assumed for the model that these accessibility indicators are only relevant for offices with a national or international orientation for customers. Different critical values for the travel disutility have been tested, in steps that correspond to one percentile of trip observations in the business travel data set (without the leftover category). An optimal value was found for a critical utility at the 90th percentile, i.e. 90 percent of all business travellers who use the car, train or other public transport has a travel disutility lower than the boundary used in this indicator.

Potential accessibility can be seen to have a considerable influence on location choices, especially for the choice between distinct cities. But in addition to potential accessibility also some connectivity indicators are important. For train connectivity the total train frequency at the nearest station is found to be significant, but only for offices in the business or financial services industry (this heterogeneity aspect was not found in the SC model, a difference that is discussed below). However, in the RC model train frequency and the availability of intercity services are highly correlated, which makes it difficult to distinguish between these aspects. The correlation causes the estimated parameter for intercity services at station to be negative, which is theoretically illogical and the parameter is therefore omitted from Table 6.4. Other connectivity parameters are kept in the table even when these are statistically insignificant, although it should be mentioned that the RC model is less suitable to represent connectivity than the SC model. Besides of correlations this is because of a presumed interference of demand with supply: a preference of an office for a location well-connected to the railway network cannot always be fulfilled because often a limited amount of office space is available around large stations. It is therefore difficult to draw conclusions from this model about connectivity for rail as being the result of demand. For potential accessibility this issue is seen to play a less important role, because its influence is mostly on a higher spatial scale.

Further high correlations are found between on the one hand potential accessibility to employees and on the other hand station access distance and motorway access time. This is a possible reason why station access distance is not statistically significant in this model. Motorway access time in contrary is a statistically significant attribute in the model. Optimal Box-Cox parameters for these access attributes are low, which indicates that the influence of the network access points is predominantly concentrated close to the nodes.

Data on revealed choices are susceptible to external influences and it is therefore a common finding that RC models yield less statistically significant results and can identify less heterogeneity characteristics. In addition possible mismatches between location preferences and the availability of suitable office space may exist. For example the relationship between the branch of industry and the train frequency, which is not found significant in the SC model, may be caused by a correlation of train frequency with another location attribute that could not fully be accounted for in the model. This would also mean that relatively little locations exist near a station with a high train frequency station that has a favourable level of this second attribute, i.e. a mismatch might exist between the supply and demand characteristics of locations for this category of offices.

6.3.2 Influence of the type of land use on the spatial distribution of offices

Table 6.4 also shows the results of a land-use typology that represents the type of urban environment. The land-use typology is a dominant location factor at a low spatial scale. For this location attribute also strong differences can be seen in preferences between branches of industry. Offices in the business and financial service industries have a preference for industrial/business sites in or immediate adjacent to cities. But also other industrial/business sites and high-density city centres have favourable characteristics. Only a small number of offices choose a location in a town or village, or in a low-density city environment. Other city environments are valued averagely. Preferences of offices from other branches of industry on average differ from those of business and financial service offices in two aspects. Firstly they have a much stronger preference for industrial/business sites outside of a city and secondly they do not prefer locations in a high-density city environment. These taste differences make offices in different branches of industry end up in different locations, also if their accessibility preferences are similar.

The land-use typology is also relevant in the view of the influence of supply characteristics on the location of office establishments. The availability of office space is closely related to the type of urban environment. Among other things for this reason it can be seen that high-density land-uses have higher parameter values than low-density land-use or the same type. Furthermore it explains why industrial/business sites are more often chosen; in these environments a larger part of the space is reserved for offices.

6.3.3 Evaluation of the spatially hierarchical nesting structure

A nested logit structure appears to be considerably better than a multinomial logit model. The scale parameters are above or around the theoretical lower boundary of one. For the urban region of The Hague the scale parameter is set to one to ensure consistency with random utility theory. Having a scale parameter larger than one means that locations within the same urban region are regarded as being more similar to each other than to a location in another urban region. 'Similar' in this context implies that those locations are more competing to each other, so if a location becomes more attractive then it will attract more offices that would otherwise have chosen another location in the same urban region than offices that would have chosen a location in another urban region, everything else being equal.

In the model different scale parameters are calculated for different cities. The value of these parameters reflects on the one hand the internal structure of a city (to what degree offices in a city are concentrated at highly-valued locations) but is on the other hand also influenced by the demarcation of the urban region (lager areas contain more distant locations, which can be regarded is less similar than locations near to each other). The urban regions of Utrecht and The Hague have scale parameters that are significantly higher than for other regions. For Utrecht the second explanation is most likely, since its urban region has a rather large surface with next to Utrecht itself many other urban centres. The urban region of The Hague in contrary is much smaller and almost entirely made up of built-up area, so that the first explanation is most probable.

The RC model thus reveals aspects of the office real estate market that are not possible to analyze by using SC data only: supply-side aspects concerning the availability of office space, the influence of a specific spatial configuration on location choices, and the more realistic setting of effects caused by exogenous influences. However, neither the RC model nor the SC model gives an overall picture of the possible spatial effects of high-speed rail. A combined model of SC and RC data is more suitable for this purpose. The next section gives the results of two alternative versions of such a model.

6.4 Combined stated/revealed choice models for office locations

The SC and RC models discussed in the previous sections are used to construct a combined SC/RC model of office location choices. The aim of this model is to give an overall image of the consequences of high-speed rail for location choices of office establishments, which can be used in the scenario study described in the next chapter. Two alternative versions of such a model are evaluated, based on different assumptions for the role of RC and SC data in the combined model: the sequential approach and the full-information maximum likelihood (FIML) approach, which are described in chapter 3. One of these alternatives is chosen for further use.

Table 6.5 Parameter estimation results for the combined SC/RC model alternatives.

	FIML approach			Sequential approach[28]		
	Parameter	t	P	Parameter	t	P
RC and SC common station level-of-service attributes						
Train frequency (natural logarithm)	0.0648	2.54	0.01	0.181	3.98	0.00
Train frequency (natural logarithm) * Branch of industry	0.297	2.04	0.04	0.0759	1.27	0.21
Intercity services	-0.0212	-0.83	0.41	0.0558	0.71	0.48
Intercity services * Spatial orientation customers	0.122	1.91	0.06	0.0661	1.71	0.09
RC-specific accessibility attributes						
Gravity accessibility score commuting	0.0128	3.36	0.00	0.0124	3.39	0.00
Contour accessibility score business	0.0225	3.20	0.00	0.0234	3.37	0.00
Station access distance	-0.0985	-1.42	0.16	-0.0983	-1.41	0.16
Box-Cox parameter	0.00			0.00		
Motorway freeflow access time	-0.191	-3.96	0.00	-0.190	-3.94	0.00
Box-Cox parameter	0.20			0.20		
RC land-use typology						
City centre high density	0.629	3.44	0.00	0.624	3.48	0.00
City centre low density	0.0898	0.33	0.74	0.0888	0.30	0.77
Town centre	-0.779	-2.03	0.04	-0.784	-2.04	0.04
City high density	-1.21	-4.45	0.00	-1.24	-4.47	0.00
City high density * Branch of industry	0.939	3.43	0.00	1.00	3.56	0.00
City average density	0.128	0.62	0.53	0.135	0.64	0.52
City low density	-0.290	-1.50	0.13	-0.291	-1.53	0.13
Town/village	-0.893	-2.38	0.02	-0.895	-2.40	0.02
Industrial/business in city	0.859	5.73	0.00	0.860	5.77	0.00
Other industrial/business	1.50	8.26	0.00	1.52	8.31	0.00
Other industrial/business * Branch of industry	-0.736	-4.10	0.00	-0.770	-4.20	0.00
SC-specific accessibility attributes						
Station access time (linear)	0.119	1.88	0.06	0.331	2.24	0.03
(quadratic)	-0.0134	-2.19	0.03	-0.0373	-2.83	0.00
(cubic)	0.00372	2.25	0.02	0.00104	2.96	0.00
Station access mode	-0.0738	-2.77	0.01	-0.208	-5.63	0.00
Domestic high-speed rail	0.0426	1.16	0.25	0.0819	0.96	0.34
International high-speed rail	-0.0870	-0.76	0.45	-0.0714	-0.83	0.41
International high-speed rail * International business trips	0.294	2.39	0.02	0.232	3.89	0.00
Motorway access time	-0.0719	-2.83	0.00	-0.0551	-5.45	0.00
Motorway access time * Employees visiting customers	-0.116	-2.64	0.01	-0.0754	-4.54	0.00
Parking places available	0.00699	1.14	0.25	0.00572	1.33	0.19
Parking places available * Employees receiving customers	0.0235	1.96	0.05	0.0181	2.43	0.02

(Table 6.5 continued)

	FIML approach			Sequential approach[28]		
	Parameter	t	P	Parameter	t	P
Non-accessibility SC attributes						
Type of urban environment	-0.281	-2.65	0.01	-0.216	-5.15	0.00
Type of building	0.0520	0.98	0.33	0.0471	1.19	0.23
Price of real estate	-0.0285	-3.09	0.00	-0.0218	-12.40	0.00
Scale parameters						
Amsterdam	1.59	5.53	0.00	1.60	5.51	0.00
Rotterdam	1.34	6.32	0.00	1.32	6.42	0.00
The Hague	1.00	n.a.	0.00	1.00	n.a	0.00
Utrecht	1.31	5.84	0.00	1.31	5.83	0.00
Other	1.55	6.23	0.00	1.54	6.27	0.00
Scale parameter RC relative to SC	0.762	3.13	0.00	0.575	3.45	0.00
Observations	1633			297		
Maximum log-likelihood	-1747.22			-1054.03		
ρ^2 (pseudo-r^2)	0.205			0.226		

Table 6.5 shows the parameter estimation results for the combined SC/RC models. In general the results of the RC and SC sub-models are consistent with the separate RC and SC models and will not be repeated here. The main interest of this section is for the relative scale parameters for RC versus SC data and for possible other differences in the parameter estimations.

Both alternatives have satisfactory results in terms of model fit and parameter significance. The models show high parameter significance for both main effects and office heterogeneity parameters. For the FIML approach the validity of the data enrichment can be tested by a likelihood ratio test that compares the cumulative log-likelihoods of the SC and RC models with the combined models that has four degrees of freedom less. This test shows that merging of the attributes in the full-information approach is superior to separate SC and RC parameters at more than 99% certainty. For the sequential approach such a test cannot be applied. However, also for this approach the combination of SC and RC is clearly not performing badly, as the RC sub-model has a goodness-of-fit (ρ^2) only slightly lower than the separate RC model even though it has less degrees of freedom. Since the models are based on different data set-ups the maximum-likelihoods and corresponding ρ^2 values cannot be directly used for comparing the two combined models.

The only major distinction between the two approaches is a difference in the scale parameter. The sequential approach results in a somewhat lower scale parameter than the FIML approach. This is conceivable, because the station level-of-service parameters in the FIML approach are estimated to fit on both the SC and RC data where in the sequential approach these are estimated on SC data only. The explanatory power of the station level-of-service attributes is therefore higher in the FIML approach than in the sequential approach, which results in a higher relative scale parameter. The difference in scale parameter has as a consequence that the station level-of-service attributes have a lower influence on location attractiveness in the sequential SC/RC model than in the FIML combined model. The implications of this are further tested in the next chapter.

6.5 Discussion and conclusions

The results presented in the previous sections show that several issues require further attention when evaluating office location choices. A first topic is the information on which choices are based and how this is perceived by the decision makers. This is an aspect often ignored in the evaluation of discrete choice models. Thereafter, although this study is not based on longitudinal data, some remarks should be made about temporal aspects of location choices in the context of high-speed rail.

6.5.1 Information, perceptions and location choices

Within discrete choice theory decision makers are assumed to base their choice on their perceptions or beliefs of the choice alternatives' attribute levels. As discussed in chapter 3 these perceptive values can be different from the 'real' values and also from the measured values that are used in an RC model. In the random utility approach (using RC data) the difference between perceptive and measured attribute values is one of the aspects that is corrected for by the stochastic component in the model. The differences between measured values and attribute perceptions cannot be identified separately from other variances that influence decision-making. Hypothetically it can be assumed that there are two types of differences: (1) structural differences occur if the whole population or a distinguishable segment perceives an attribute consistently higher or lower than the measured value; (2) non-structural differences are individual variations in perceptions between decision makers under the same circumstances. The first type will be reflected by a higher or lower taste parameter and is thus unnoticeably accounted for in every type of utility-maximizing model. The second type occurs as unexplained individual heterogeneity in a mixed logit model or as unobserved utility in other logit models. Making the distinction between structural and non-structural differences is relevant for the interpretation of the location choice models.

Perceptions are particularly relevant in the case of high-speed rail. The presence of high-speed train services at a nearby station can make this station appear to have a good accessibility. In this respect perceptions are closely related to other subjective aspects of high-speed rail: the image effect, the perception of accessibility, the option value and the value of choice for long-distance train travel. A good image can be seen as a consequence of a good perceived accessibility and is thus dependant on perceptions. The option value and/or value of choice of high-speed rail appear if high-speed rail connectivity is perceived to be more important than would be expected from the number of trips that are made by high-speed rail. Furthermore, the interview results showed that high-speed train stations are also often associated with a good intraregional accessibility. These aspects can all be relevant for office location choices.

However, perceptions are difficult to catch explicitly in discrete choice models, either for location choices or other decisions. A sole study (Adamowicz *et al.*, 1997) is known to the authors that uses perception data to enrich a discrete choice data set. Such an exercise can be useful to see whether or not differences exist between taste parameters (for the structural perception differences) and scale parameters (for the non-structural perception differences), especially if besides RC data also SC data is used. In the current application an RC model with perception data was not feasible.

As discussed in section 6.1.3 questionnaires on attribute values can be used to evaluate differences between perceptions and objective values. In the context of an interview or questionnaire it seems plausible that doubts by the respondents about a question's answer leads to non-response to this question. In this case, non-response can be seen as an indicator for the respondents' awareness of attribute values. The results in section 6.1.3 showed that attribute values for train connectivity are difficult to assess by respondents. Many respondents perceive their nearby station to have intercity services if this is not the case. These respondents overestimate station connectivity for this attribute. The total frequency of trains at a station seems difficult to judge as well; awareness of respondents for this attribute is thus low. This does not mean that frequency is not a relevant attribute for location choices. Also without knowing exact numbers location decision makers will be able to evaluate the level-of-service of a station and to base their location choice on it. But this low awareness can be responsible for individual variation that appears as taste heterogeneity in a discrete choice model. Indeed in the random parameter SC model a random parameter with considerable standard deviation is found significant for this attribute.

High-speed train connectivity is not recognized by many respondents. Respondents seem unfamiliar with the current Thalys and ICE international services that use conventional track. High-speed train is not used by many of the respondents' employees for international business travel (or the respondents are not aware of this use). This would (again) result in individual variation in the location choice model. Unfamiliarity with high-speed rail can be a (partial) cause of the significant random parameter for the international high-speed rail attribute in the SC model. Uncertainty of respondents about this new attribute is closely related to the timing of the SC experiment, which is discussed in the next subsection.

6.5.2 Temporal aspects of location choices: the case of high-speed rail implementation

For the implementation of a new transport service temporal issues are important. Firstly for the dynamic of location two time aspects are particularly relevant: anticipation and time lags. Anticipation requires location decision makers to be informed well in advance of the new services. Preparing and building a new high-speed railway line takes much time, so decision makers have had sufficient time to adapt their location choices before the high-speed train services on the new track are implemented and also before the data for the current research were collected. Although it must be noted that uncertainty continues to exist about the exact working out of the services, as is evaluated in chapter 7.

Time lags occur because of the inertia of the land-use system. After a site has become more attractive (either in anticipation or after implementation of new transport services) it takes typically several years before its influence becomes fully visible. As was confirmed by the results in section 6.1.3 accessibility is only rarely a stimulus for relocations. The response speed of the land-use system to a new high-speed railway link is thus dependant on external factors.

The analysis of RC data did not reveal high-speed rail to already have a significant impact.

Anticipation was thus not detected to have a significant influence. Assuming that high-speed rail does have an impact on location choices (as the SC results show) either factors such as uncertainty about the future services prevented anticipation or the time lag has cancelled out the anticipation. From the results in this chapter nothing can be concluded for the issue of time lags; an analysis of longitudinal data would be more appropriate for this.

The timing of the SC experiment is another topic related to the temporal aspects of high-speed railway implementation. SC experiments are frequently used as a way to assess choice options or attribute values that do not yet exist. However, caution should be applied when interpreting the results of such an experiment. The timing of the SC questionnaires is of great importance here. Researchers and policy makers would like to evaluate a new choice option as early as possible. But the earlier an experiment is held the less familiar respondents will be with the choice options that are given, and the less accurate a respondent might be able to judge the alternatives. For SC experiments thus a trade-off seems to exist between an early evaluation and certainty about the outcome.

In the current application the SC experiment has been held four years before the foreseen implementation of new high-speed railway infrastructure and at a time that high-speed train services on conventional track had already been active in the Netherlands. High-speed rail has received sufficient attention in communication media over a several-years time-span to be considered a well-known concept. Still the question remains to what extent respondents are able to thoughtfully evaluate the value of high-speed train services compared to more conventional location attributes. As discussed in the previous subsection the respondents' unfamiliarity with high-speed rail can be found as similar to taste heterogeneity in the random parameter model and seems relevant for this application.

To conclude, the analyses in this chapter have resulted in a model that can be used in a scenario study of the effect of high-speed rail on the location choices of office establishments. As SC model results are scaled to the RC data also the SC attributes for high-speed train connectivity can be used in a practical application. The next chapter uses these results to study different scenarios for high-speed railway implementation in the Netherlands.

7. The impact of railway developments on the location choices of offices: a scenario study for the Amsterdam South axis

The implementation of high-speed rail in the Netherlands is accompanied by large redevelopment projects for several station areas, the so-called 'new key projects'. The projects are initiated and partially financed by the Dutch national government, mainly to enhance the international competitiveness of the Netherlands and to support the development of urban networks (Min. VROM, 2006). One of the sites that are redeveloped is the Amsterdam South axis, a location near Schiphol airport that is aimed to become a high-status site, being able to compete with other European top locations to attract international head offices. This type of redevelopment plans linked to high-speed rail is not uncommon. Similar station area redevelopments have taken place in several other western European countries (see e.g. Bertolini, 1998; Van den Berg and Pol, 1998a). As discussed in chapter 2 many station area sites indeed have gained employment (e.g. Sands, 1993; Mannone, 1997).

Although high-speed rail is thus often used as an incentive for large-scale urban regeneration projects, it is uncertain to what extent and how high-speed rail contributes to the attractiveness of station areas as locations for offices. Also without the higher speeds a station area can become more attractive if the quality of the site improves. For example, from the cost-benefit analysis for new infrastructure on the Amsterdam-Arnhem(- Frankfurt) ICE link (the HSL East) it was concluded that the time decrease would have little impact on the attractiveness of the station areas (Dijkman *et al.*, 2000a; Dijkman *et al.*, 2000b). Most benefit would come from the station area redevelopments themselves, from improved local/regional accessibility and from an image effect. For the HSL South, however, the travel time gains are considerably larger than for the HSL East and the cities it connects are seen as internationally competing cities, for which high-speed rail accessibility can be especially relevant.

Furthermore uncertainty exists on several aspects of the high-speed rail network, especially for the HSL South. Operation on the HSL South is supposed to start by the end of 2007, but several alternatives still exist with regard to how the train services are worked out. Issues still susceptible to changes are predominantly the height of the fare supplement for high-speed train services and whether the HSL South services have their end stop at Amsterdam central station or at Amsterdam South/WTC station. In addition to this, high-speed train services on the Zuiderzeelijn or the Hanzelijn could be relevant. Although these lines do not connect multiple cities within the study area, the connection between Amsterdam and the north of the Netherlands can still influence intraregional location choices within the Randstad (for a discussion on how external links can influence a region see Vickerman, 1991).

The analyses presented in this chapter aim to clarify how the HSL South influences the attractiveness of station areas for offices and how this attractiveness depends on the choices that are made for train services on this new line. The focus thereby is on the Amsterdam South axis. Although the South axis is intended to attract international head offices, given experiences in France (Sands, 1993; Mannone, 1997) it is likely that most employment effects will be intraregional distributional, by attracting offices that were previously located at other sites within Amsterdam or elsewhere in the Randstad. The analyses in this chapter will be limited to these intraregional effects.

Because of the abovementioned alternatives that exist for high-speed train services the study described in this chapter has the form of a scenario study. Hereby each of the scenarios is composed of a different combination of the alternatives. This scenario study should be regarded as an explorative analysis to reveal changes in the general image of the attractiveness of locations for offices and does not aim to give exact forecasts of transport and land-use effects for a specific year. For each of the scenarios distinction is made between three aspects of location attractiveness and location choices:

1. The potential accessibility of locations, to give an impression of the size of the labour and product markets and thus of the potential for spatial interaction;
2. The choice between cities or urban regions, to evaluate the role of high-speed rail in the competition between cities; and
3. The choice between different locations within the Amsterdam urban region, to analyse the relative attractiveness of different office sites in the same city.

Furthermore attention is given to how location attractiveness and the impact of high-speed rail differ among types of offices. These aspects together allow drawing conclusions for the expected role of high-speed rail in the attractiveness of locations for offices.

The scenario study described in this chapter is part of a case study on the Amsterdam South axis that is carried out in cooperation with researchers from Free University Amsterdam and Delft University of Technology (see Debrezion *et al.*, 2005). The purpose of this joint project is to study a single case by evaluating a range of aspects related to spatial economics and urban development. Thereby besides the topic of the current chapter also attention is given to the supply of railway services, the price of real estate and the physical development of the station area. The consequence of this joint case study is that the research described in the current thesis is exogenously demarcated; topics that are covered by related research are not dealt with in the current chapter. Furthermore, within this context specific attention is given to Amsterdam and the South axis area, which is used as a case study for presentation and interpretation of results. For the Amsterdam South axis extensive development plans have been developed, as are described in more detail below.

The next section gives more detail on the scenarios that are evaluated. Thereafter the results of these scenarios are discussed for potential accessibility, the choice of an urban region for an office establishment and the attractiveness of locations within the Amsterdam urban region. The final section of this chapter integrates and discusses the findings reported here.

7.1 Description of scenarios

The scenarios that are evaluated in this chapter consist of different combinations of changes in the railway network. For these scenarios the assumed travel time gains and fare supplements for two high-speed railway projects are used. These are the future HSL South high-speed railway and two of the proposed Zuiderzeelijn/Hanzelijn alternatives. To keep the results transparent all other aspects are held constant in the scenarios, including railway developments that are not explicitly mentioned in this section[29]. For the presentation and interpretation of the scenario study results a special focus is on the Amsterdam South axis area. At the Amsterdam South axis extensive building activities take place and more ambitious plans for development of this site have been proposed.

The first two subsections below describe the HSL South and Zuiderzeelijn/Hanzelijn projects in more detail. Subsequently in the third subsection some issues with regard to the methodology for this study are elaborated on. Finally, this section ends with a concise description of the South axis area.

7.1.1 The future HSL South high-speed railway

The HSL South is a new high-speed railway line that was under construction by the time of writing this thesis; services on this line are supposed to start in 2007 or 2008 (Het Financieele Dagblad, 2005; Min. V&W, 2005b). Two types of high-speed train services are planned to make use of this line: (1) international 'Thalys' services from Amsterdam to Belgium and France with stops at Amsterdam central station, Schiphol airport and Rotterdam central station (the current stop in The Hague will be abandoned when the HSL South is put into service) and (2) high-speed train services for shorter distances on two trajectories: Amsterdam-Rotterdam-Breda and The Hague-Rotterdam-Breda-Belgium (Min. V&W, 2005b). In this scenario study for the international services solely the connectivity aspect is taken into account, because these services are only relevant for a very small number of trips and would therefore have a negligible impact on the potential accessibility indicators that are used in this study. The second type of services is supposed to be a viable option for more trips and therefore its effect on potential accessibility can be larger. Domestic high-speed train services are accounted for via both a connectivity effect and a potential accessibility effect; for the potential accessibility analysis the travel characteristics of these services are described in more detail here.

For domestic services on the HSL South trains with a maximum operational speed of 250 kilometres per hour will be used. This speed is not as high as for some high-speed rail services elsewhere in Europe (for example in Spain the line Madrid-Barcelona-France that is under construction is supposed to allow speeds up to 350 kilometres per hour, Martín *et al.*, 2003), but a higher maximum speed will offer little travel time gain because of the short distances. Still these trains can be classified as high-speed trains.

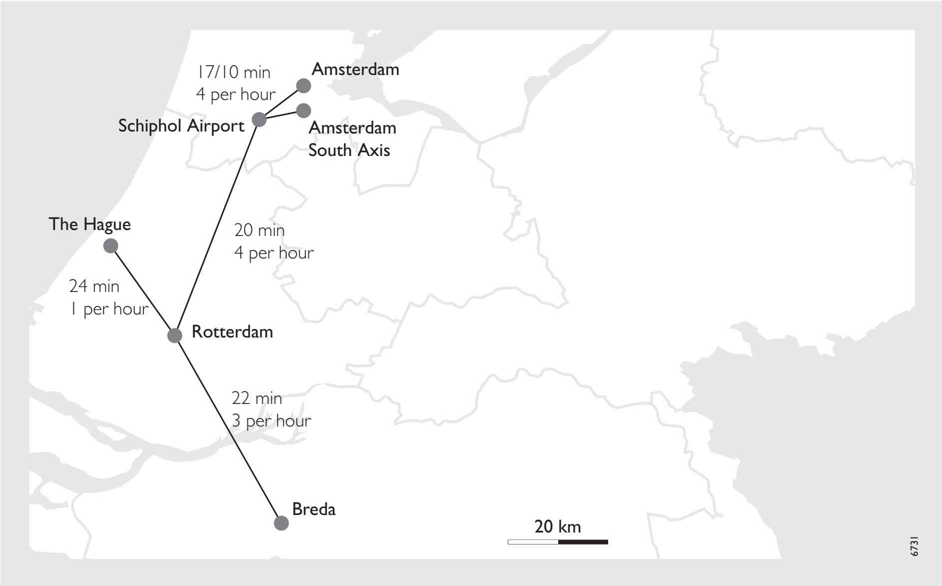

Figure 7.1 In-train travel times and frequencies (trains per direction per hour) between stations as assumed for the future domestic services on the HSL South (based on Rijkswaterstaat, 2006).

Frequencies are relatively high for the Amsterdam-Rotterdam connection where four trains per direction per hour are planned (Rijkswaterstaat, 2006). At Rotterdam half of these service will go through to Breda. The Hague-Breda services are far less frequent, with one train per direction per hour. These trains will go further to Brussels in Belgium, but this is left outside of the analysis. Figure 7.1 gives an overview of the assumed in-vehicle travel times and service frequencies.

By the introduction of train services on the new infrastructure the high-speed trains will serve the central station of Amsterdam. An alternative for the more remote future will be to have services from the station at the Amsterdam South axis. From this station travel time along the HSL South is seven minutes shorter than from Amsterdam central station, as is indicated in Figure 7.1. For the Amsterdam South axis such a connection would provide a higher gain in potential accessibility. However, since Amsterdam South axis is less well connected to other destinations compared to Amsterdam central station its accessibility effect on the wider region is not straightforward to identify. In this case study the two possible locations of the Amsterdam high-speed train station are studied as different scenarios.

Another issue that is relevant for the HSL South scenarios is the fare supplement that is charged to the travellers that make use of the high-speed train services. This supplement can have a large impact on the accessibility effect. Several supplement schemes are possible. In this case study two fare structures are studied: a percentage addition to a non-high-speed fare on the same connection and a fixed supplement the non-high-speed fare. The fixed supplement is currently used on the Amsterdam-Arnhem-Germany service, where the supplement is two euros; the same supplement is assumed for the HSL South services[30]. A variable fare is for example used by in the cost-benefit analysis (CBA) for the Zuiderzeelijn (see NEI, 2000b). Two supplement percentages are evaluated in this case study: a low supplement of ten percent and a higher supplement of 25 percent.

7.1.2 The proposed Zuiderzeelijn and Hanzelijn connections

The Zuiderzeelijn is a previously proposed connection between Amsterdam and Groningen, which has been abandoned by the government (Min. V&W *et al.*, 2006). Several options have been studied, including a conventional intercity line, a high-speed railway line and a connection using high-speed magnetic levitation. The rail alternatives would partly use existing infrastructure, but additionally extensive new infrastructure would be build. Within the Zuiderzeelijn project also alternatives have been evaluated that make use of the Hanzelijn, of which construction will start in the coming years, complemented by existing lines. One option of the Hanzelijn-alternatives is to upgrade existing track to increase the maximum speed, which would accommodate the use of high-speed trains on these lines. In this case study two alternatives are evaluated that make use of high-speed trains: the Zuiderzeelijn variant with high-speed trains and the high-speed train connection using the Hanzelijn and upgraded existing track. Figure 7.2 shows routing and service characteristics of these two alternatives.

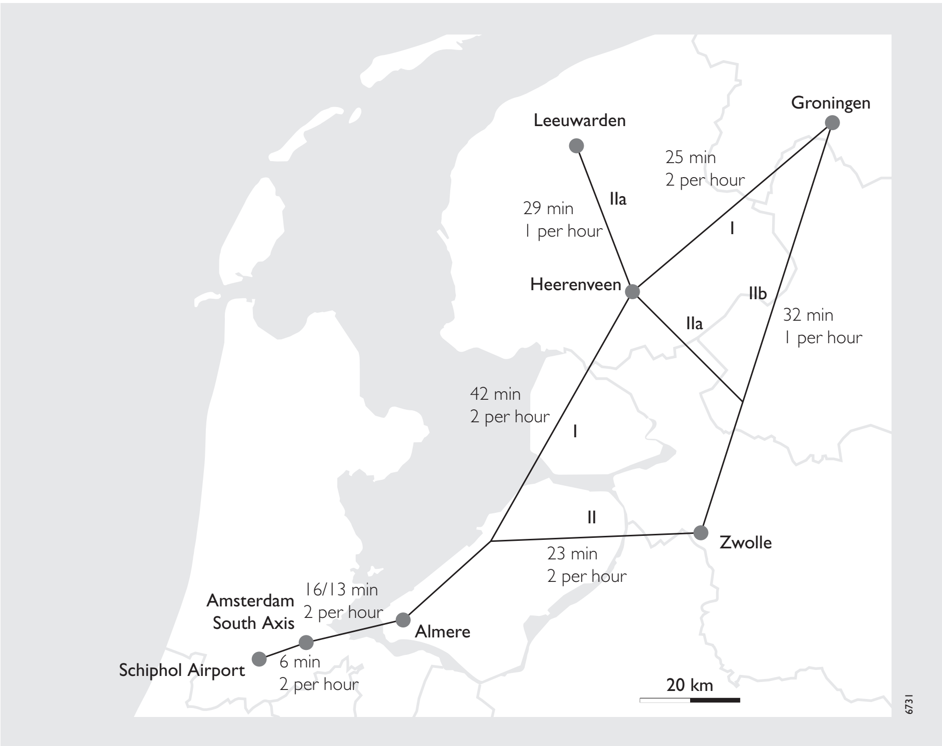

Figure 7.2 In-train travel times and frequencies (trains per direction per hour) between stations as assumed for proposed high-speed train services on the Zuiderzeelijn (I) and Hanzelijn (II) alternatives (based on NEI, 2000b).

Both alternatives drastically shorten travel times between the Randstad and the northern Dutch provinces: Between Schiphol and Groningen travel time is decreased from 144 minutes now to 73 minutes with the Zuiderzeelijn alternative and 74 minutes with the Hanzelijn alternative (NEI, 2000b). On shorter distances from Schiphol airport the Hanzelijn alternative has a somewhat larger travel time gain than the Zuiderzeelijn because of the upgraded track in that alternative.

The trains for both alternatives have five stops. Both alternatives have stops at Schiphol airport, Amsterdam South axis station and in Almere. Thereafter the Zuiderzeelijn alternative has stops in Heerenveen and Groningen. Trains in the Hanzelijn alternative go to Zwolle, after which half of the trains go to Leeuwarden and half of the trains to Groningen. The train to Leeuwarden passes the Heerenveen station but does not stop there.

The frequencies of high-speed train services are lower than for the HSL South. The Zuiderzeelijn alternative has two trains per direction per hour, whereas the Hanzelijn alternative has one train per direction per hour to each Leeuwarden and Groningen. This will limit the accessibility effect of this project. Furthermore, distances between major cities along the line are long compared to the HSL South and the cities are smaller. From these aspects it is expected that the Zuiderzeelijn and Hanzelijn have a lower accessibility effect than the HSL South.

7.1.3 Scenario methodology

The alternatives discussed above result in eight scenarios that have been evaluated. Three aspects are thereby evaluated: the influence of the reduced travel time by the different train services (HSL South, Zuiderzeelijn, and Hanzelijn); the influence of the choice between Amsterdam central station and Amsterdam South/WTC station for HSL South services; and the impact of different train fare supplements for the model results. Figure 7.3 below gives an overview of the scenarios. To reduce the number of scenarios the HSL South station choice and fare supplement alternatives are only modelled for one scenario each.

These scenarios are analyzed by using the models developed in the previous chapters. In an accessibility study the gravity-based and contour-based accessibility indicators are used to evaluate the effect of high-speed rail on the opportunities for spatial interaction. These potential accessibility indicators are then input to the location choice model, together with indicators for train connectivity. This model is firstly used to study the attractiveness of cities in the Randstad, and subsequently to compare different office sites in the Amsterdam urban region: Amsterdam city centre, Amsterdam South axis and Schiphol airport. The choice of a region for office establishments is modelled by using the same choice sets and sample of offices as are used for parameter estimation. As the modelled probability of choosing individual grid cells is accompanied by a relatively large uncertainty the intraregional differences in location attractiveness are presented aggregated to larger areas (see Figure 7.4). The focus here is on the Amsterdam urban region, which is used as a case study to evaluate the consequences of railway developments for the Amsterdam South axis area.

7.1.4 The Amsterdam South axis area

For location choices the focus is predominantly on Amsterdam and in particular the Amsterdam South axis area. At this location a high-status office park is created that is supposed to attract

Railway network	Station for HSL South services	Fare supplement	Number
Current situation (reference)	Not applicable	Not applicable	0
HSL South	Amsterdam central station	No	1
		10%	2
		25%	3
		? 2	4
	Amsterdam South/WTC station	10%	5
HSL South & Zuiderzeelijn	Amsterdam central station	10%	6
HSL South & Hanzelijn	Amsterdam central station	10%	7

Figure 7.3 Scenarios evaluated as a combination of different railway developments.

Figure 7.4 Amsterdam with railway lines and stations and selected office locations.

international head offices (see Rienstra and Rietveld, 1999). However, the location has to compete with several other office locations in the Randstad for which also development projects are under way. These locations include the central station areas of Rotterdam and Utrecht. But the South axis also faces competition from other locations within the Amsterdam urban region, most notably Schiphol airport and the Amsterdam central station area (see Figure 7.4).

Urban development at the Amsterdam South axis is supported by the Amsterdam South axis project. Several alternatives are proposed for this project, with varying quantities of real estate to be built for offices, residences and other activities. The most ambitious alternative includes having the central rail- and motorways running through tunnels and using the above space for building more real estate. However, an explorative CBA (Besseling *et al.*, 2003) showed none of the alternatives to have a net positive effect over the current situation with some minor adaptations to the motorway and railway station. Future developments are therefore still uncertain. Nevertheless, at the moment this area continues to be developed by building more offices. In the coming years therefore more office space becomes available in the South axis.

In the location model used no interaction effect is present for between land-use or urban environment on the one hand and accessibility on the other hand. Nevertheless the development of the South axis can influence the high-speed railway scenarios as it can be seen to partially represent the supply of office space. For location choices within the Amsterdam region the effect of such a land-use change on office location choices is therefore evaluated, in combination with a high-speed rail scenario.

7.2 Results of high-speed rail scenarios for potential accessibility

The explorative accessibility analysis in chapter 5 showed the effect on potential accessibility of the reference year and a basic scenario for the HSL South. The current chapter focuses on three aspects of high-speed railway developments in the Netherlands: the influence of the fare supplement, the effect of which station in Amsterdam receives HSL South services, and the impact of a second high-speed rail link, from Schiphol to Groningen. The results for potential accessibility of the different scenarios studied are discussed subsequently for these three topics below.

7.2.1 Influence of the fare supplement

The travel time effect of a new high-speed train service seems normally quite robust, but for the train fare much more variability is possible. Still, train supplements can reduce the attractiveness of using a high-speed rail link and it seems therefore relevant to consider the impact of this supplement on the potential accessibility effect. Figure 7.5 shows the effect of different fare supplements on potential accessibility for locations along the HSL South, both for commuting and business travel.[31]

Commuters on average have a relatively low value of time, which makes that for many connections the fare supplement is not fully compensated by a decrease in train travel time. The fare supplement therefore has a high impact on the accessibility effect of the high-speed train services. For the gravity indicator for business travellers, who have a higher value of time, the fare is of much lesser influence.

Remarkably it can be seen from Figure 7.5 that the impact of the supplement is not equal in size for different locations. For example, the increase of commuting accessibility without a fare supplement is for Amsterdam city centre about as high as for Schiphol airport, but if a supplement is introduced then the accessibility effect for Amsterdam is lower than for Schiphol.

The reason for this is that for a trip from Amsterdam central station to Rotterdam the fare has a higher share in the generalized cost than for a trip from Amsterdam South/WTC station to Rotterdam. The (for an average traveller) most efficient trip from Amsterdam South/WTC station has a transfer at Schiphol airport station[32], while for trips from Amsterdam central station such a transfer is avoided but a fare supplement is accounted for the trip section to Schiphol.

Another aspect that can be seen from Figure 7.5 is that the type of supplement, either as a percentage addition or as a fixed supplement, does not lead to noticeable different accessibility effects. For all locations the accessibility score for the €2 fixed fare is just above the score for a 25% addition. Thus, for trips on which the HSL South offers an advantage over conventional trains the €2 distance-independent supplement is on average below 25% of the basic fare.

In the remaining of this study a fare addition of ten percent of the basic fare is assumed. This is not a high fare that precludes noteworthy accessibility effects, but is still high enough to consider its network effects. For the analyses in the next sections it should be borne in mind that the results can be sensitive to both the structure and the height of the fare.

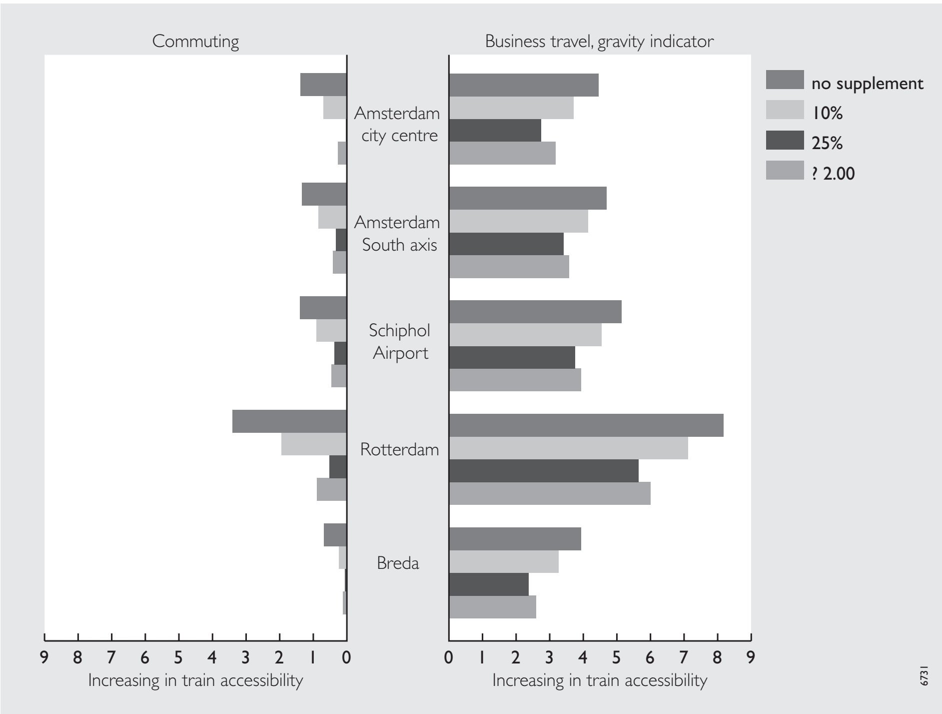

Figure 7.5 Effect of fare supplements for high-speed train services on the increase of potential accessibility for train (gravity-type indicator).

7.2.2 Influence of HSL South services from the Amsterdam South axis instead of Amsterdam central station

For start and end point of high-speed train services on the future HSL South two stations in Amsterdam are plausible options. At the upcoming implementation of the HSL South infrastructure train services will use Amsterdam central station. However, for a later stage train services from the Amsterdam South axis station becomes an alternative. Relative to the distances that are concerned with interregional travel these two stations are close to each other. However, their position in the regional and national railway network is different and the potential accessibility effect of these alternatives is therefore not the same.

In the number of train departures Amsterdam central station is the train station with the second-highest passenger numbers in the Netherlands, with on average 37.5 trains departing per hour in the regular day-schedule in 2000. The station is also the current starting point of the Amsterdam-Paris Thalys and the Amsterdam-Frankfurt ICE. The central station thus has an important node function for the regional network as well as for long-distance services.

Like Amsterdam central station the Amsterdam South axis station is an intercity station. However, the number of trains that stop at the Amsterdam South axis station is considerably smaller: 12 trains per hour in 2000. An advantage of the station is its proximity to Schiphol airport and compared to the central station a somewhat smaller distance to the other main urban centres in the Randstad area: Rotterdam, The Hague and Utrecht. To some extent this compensates for the lower train frequencies, but over all the Zuidas station is less well situated in the railway network. Furthermore, within the South axis project an extension of the railway capacity at this station is proposed (Besseling *et al.*, 2003), which would allow more and better connections from this station.

In the situation with a stop at Amsterdam central station the South axis does already have a higher accessibility increase than the city centre of Amsterdam for all accessibility indicators that are used. This is because of the high frequency of train services between the Amsterdam South/WTC station and Schiphol airport, which serves as an access point to the HSL South from the South and West of Amsterdam. Between Schiphol and Amsterdam central station no travel time advantage is assumed for the high-speed train service over conventional train services. For a journey from Amsterdam to Rotterdam and onwards the train travel impedance is therefore lower if the origin is Amsterdam South than if Amsterdam central station is the departure station.

For the same reason the possible shift of high-speed train services to the Amsterdam South/WTC station offers little extra advantage for the South axis. The high frequency of trains between Amsterdam South/WTC station and Schiphol makes a transfer less of a problem, while the fare supplement for high-speed train services and the absence of a travel time gain until Schiphol airport decrease the advantage of a direct connection from the South axis[33]. Direct high-speed train services from the South axis therefore result in only a small increase in the gravity-type accessibility indicators for the South and Southeast of Amsterdam. For the contour indicator the decrease in travel impedance is not enough to result in any effect for the South axis area.

Besides this weak positive effect for the South axis area accessibility decreases for most other places in the Amsterdam region. The city centre of Amsterdam is directly influenced by the loss of the direct connection. As train fares in the Netherlands are degressively depending on the distance travelled the fare supplement is lower relative to the travel time on the Schiphol-Amsterdam central station connection than on the Schiphol-Amsterdam South/WTC station line. But also for most other places in the Amsterdam region a stop at Amsterdam central station is most advantageous, because this station is better connected in the regional train network than Amsterdam South/WTC station.

For Rotterdam and its surroundings all indicators also give a higher accessibility for the stop at Amsterdam central station. The direct connection to Amsterdam South offers almost no advantage for a trip from Rotterdam to Amsterdam South axis (and/or beyond) and the increased travel impedance to Amsterdam city centre results in a lower accessibility score for Rotterdam. For Breda on the other hand the gravity-type indicators calculates a small increase in accessibility, because for the long distances the disadvantage of the fare supplement is smaller than the disadvantage of an extra transfer and the South axis offers a larger accessibility benefit for Breda because it is closer by than Amsterdam city centre. However, again this effect is very small and no effect is observed for Breda from the contour indicator.

From the above it can be concluded that several network effects play a role for how the choice between Amsterdam central station and Amsterdam South/WTC station influences the attractiveness of locations within and outside the Amsterdam region. The most important role is for the trade-off between an extra transfer at Schiphol and the fare supplement of high-speed train services (here assumed to be a percentage of the basic train fare), which has different outcomes per origin-destination pair. For the Amsterdam South axis a stop at the Amsterdam South/WTC station yields almost no accessibility benefit but results in a lower accessibility increase for other locations in the Randstad. Overall this has a negative influence, but for the competitiveness of the South axis it is an advantage. On an interregional scale the urban region of Amsterdam as a whole benefits less from the HSL South, and so does the Rotterdam region. But on an intraregional scale the South axis area is more competitive towards other locations in Amsterdam. For the remaining of this chapter high-speed train services on the HSL South are supposed to serve Amsterdam central station, unless it is stated explicitly otherwise.

7.2.3 Addition of the Zuiderzeelijn or Hanzelijn high-speed train services

The proposed Zuiderzeelijn or Hanzelijn high-speed train services are predominantly seen as a way to stimulate the regional economy of the northern Dutch provinces (NEI, 2000a). In this accessibility study, however, it is evaluated whether these links can have an effect on accessibility in the Randstad region. Hypothetically, the Zuiderzeelijn and/or Hanzelijn high-speed train services can make the Amsterdam region more attractive for offices relative to other parts of the Randstad.

The Zuiderzeelijn alternative is the most ambitious alternative, with large-scale new infrastructure. Travel between Amsterdam and Groningen decreases significantly and there is also a new direct link between Groningen and Heerenveen in the north of the Netherlands. However, the low potential of travellers does not allow for a frequency of services as high as the HSL South. This imposes a major limitation on the potential accessibility effect, since the train service headway weighs high in the train generalised travel cost. Because of the low frequency and because of the low attraction factor of cities in the north of the Netherlands the accessibility effect for the Zuiderzeelijn is much lower than for the HSL South in case of the gravity indicators and absent in case of the contour indicator. (A figure for the accessibility effects as in Figure 5.4 and Figure 5.5 is therefore not provided here.) For the north of the Netherlands the accessibility increase is low as well, with only Heerenveen having a considerable increase in train accessibility, although relative to the current accessibility scores in that part of the Netherlands the accessibility is not as insignificant as for the Randstad area.

The Hanzelijn alternative is called after the rail link that has already been decided to be built and that forms a short cut between Amsterdam and Zwolle. For the accessibility score of the Randstad area the Hanzelijn has two advantages over the Zuiderzeelijn. Firstly the Hanzelijn alternative includes upgrading of conventional railway track, which lowers also travel times on the connection between Schiphol and Almere. And secondly the Hanzelijn service connects to Zwolle, which is closer by and has a larger attraction factor than Heerenveen. The forecasted travel time between Amsterdam and Groningen is only marginally longer than for the Zuiderzeelijn, despite that no additional infrastructure has to be built. Nevertheless, the Hanzelijn suffers from the same limiting aspects as the Zuiderzeelijn. Although accessibility scores for this alternative are somewhat better for the Randstad, a significant increase in accessibility can only be found for the city of Zwolle. This is the case for both types of accessibility indicators.

For location choices the potential accessibility aspects of Zuiderzeelijn and Hanzelijn are of no significant influence. Their connectivity effect on the other hand can still play a role. The next two sections study the location choice effect of the different scenarios, on the interregional and intraregional level respectively.

7.3 Influence of high-speed rail on the probability of region choice

The potential accessibility indicators give a first indication of how high-speed rail influences location attractiveness, but a more complete image with both centrality and connectivity aspects can be achieved by applying a location choice model. In this chapter the results of the location choice model is dealt with in two parts. This sections focuses on the choice of an urban region. The region choice is relevant for the evaluation of the competitiveness of a city as a whole, compared to other cities within the study area. The next section deals with the choice of a location conditional on the region choice. Here the focus is particularly on the Amsterdam region.

Before going into detail on the outcome of different scenarios this section first evaluates the differences between different versions of the location choice model, which are described in more detail in chapter 3 and chapter 6. Thereafter the resulting average region choice probabilities are discussed for different scenarios. This is the main part of the scenario study at the regional level and particularly evaluates the interregional distributive effect of different high-speed train network alternatives. Finally, the region choice of some relevant sub-populations of offices is

Table 7.1 Differences between model versions: forecasted average probabilities for region choices and the change due to the HSL South scenario.

Urban region	RC model (%)			RC/SC model FIML approach (%)			RC/SC model Sequential approach (%)		
	Reference	With HSL South		Reference	With HSL South		Reference	With HSL South	
Amsterdam	16.1	16.2	(+0.7)	16.2	16.7	(+2.7)	16.0	16.8	(+4.7)
Rotterdam	13.6	13.7	(+1.1)	13.6	13.7	(+1.3)	13.6	13.8	(+1.6)
The Hague	12.6	12.6	(-0.6)	12.6	12.5	(0.0)	12.5	12.6	(+0.4)
Utrecht	24.4	24.2	(-0.9)	24.3	23.9	(-1.7)	24.6	24.0	(-2.4)
Other	33.3	33.3	(+0.1)	33.3	33.1	(-0.6)	33.3	32.9	(-1.3)

Percentages between brackets are the changes in choice probability relative to the HSL South scenario.

studied on the basis of segmentation criteria in the model. This aims to clarify the variation that exists in the location choices between different types of offices.

7.3.1 Differences between models

In the previous chapter it was indicated that the combined revealed choice/stated choice (RC/SC) model using the full-information maximum likelihood (FIML) approach is the preferred model. The question thereby arises to what extent the choice of the model has an influence on the results of the analysis. This section compares basic results for the three available models, before going into deeper analyses on scenarios in the next subsections.

Table 7.1 shows the region choice probabilities for the reference situation and with the HSL South (with 10% fare supplement and services from Amsterdam central station). From the table it can be seen that the differences in the calculated probabilities for the reference case are small between all three models. The addition of the HSL South services yields more evident differences, because connectivity is more prominent of influence in the combined RC/SC models. Especially for the sequential approach connectivity is dominant. This results in a much larger probability increase for Amsterdam, which has two high-speed train stations in this scenario.

Although the model versions do not give drastically different results for the reference case it can be concluded from Table 7.1 that the models do give different outcomes for scenarios. The results of the FIML model do seem most plausible, which is also inherent to the method because of the larger role of RC data in the parameter estimation. The FIML model is therefore used further in this chapter.

7.3.2 Average region choice probabilities

The results of the location choice model for the choice of an urban region is shown in Figure 7.6. The figure shows comparable results as the number of respondents in Figure 6.7; a possible bias that follows the size of the regions (see section 3.5.3) is difficult to detect. According to the location choice model the four main cities in the Randstad area are the most frequently chosen, which is as might be expected. In absolute figures Utrecht is most often chosen; this is partly because in the COROP demarcation the Utrecht region has the largest size of all urban

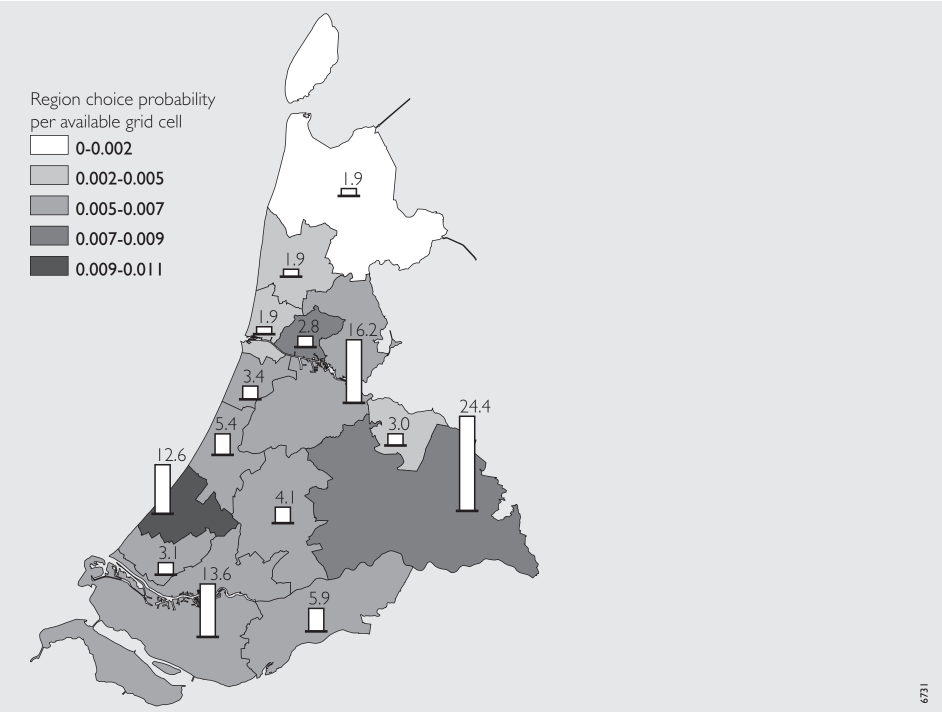

Figure 7.6 Probability of region choice for the reference case, in percents (bars) and in percents per available grid cell (shading).

regions in the study area. A better indicator might be the choice probability proportional to the total number of choice options in the region. According to this a location in The Hague is on average most often chosen, with Utrecht at a second stake. Amsterdam and Rotterdam have a much lower relative probability, because both regions in the COROP demarcation also include peripheral, less attractive areas. Outside of the four main cities the regions in the peripheral north of the study area show a very low probability to be chosen by offices.

Figure 7.7 shows how the region choice probabilities change when the HSL South is implemented. The Amsterdam region has the highest gain in accessibility, while Rotterdam and the southeast of the province of Zuid-Holland also benefit in attractiveness. All other regions loose in the probability to be chosen. Particularly for Utrecht this loss is extensive.

The Zuiderzeelijn and Hanzelijn can add an extra distributive effect of location choices to the effect observed for the HSL South. In Table 7.2 below the simulated region choice probabilities for these two lines are shown. The extra connection is seen to have a considerable impact on the probability that Amsterdam is chosen. Connectivity is the most important factor for this, since the effect of Zuiderzeelijn and Hanzelijn on potential accessibility in the Randstad is small. Furthermore, Amsterdam is the only region in the study area that benefits from these two lines, which enlarges the probability that Amsterdam is chosen.

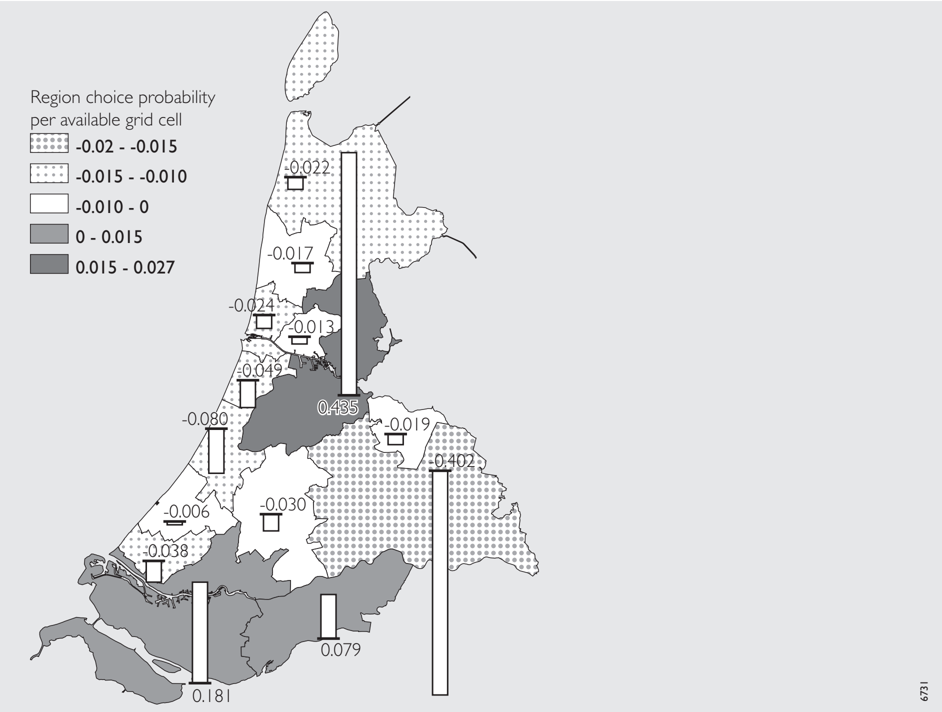

Figure 7.7 Change in probability of region choice in by the HSL South, in percent points (bars) and relative to the reference case (shading).

Table 7.2 shows changes in the region choice of up to 4.2 percent of the reference scenario. This is not a high figure, especially given that the research population of firms and institutions has been preselected to be potentially sensitive to train accessibility in general and high-speed train accessibility in particular. Within this population, however, further differences exist between types of offices. The next subsection examines the region choices of some relevant sub-groups of offices.

Table 7.2 Forecasted changes in average probabilities for region choices due to different high-speed rail scenarios.

Urban region	Reference (%)	With HSL South (%)		With Zuiderzeelijn (%)		With Hanzelijn (%)	
Amsterdam	16.2	16.7	(+2.7)	16.9	(+4.1)	16.9	(+4.2)
Rotterdam	13.6	13.7	(+1.3)	13.7	(+1.1)	13.7	(+1.0)
The Hague	12.6	12.5	(0.0)	12.5	(-0.3)	12.5	(-0.3)
Utrecht	24.3	23.9	(-1.7)	23.9	(-1.9)	23.8	(-2.0)
Other	33.3	33.1	(-0.6)	33.0	(-0.9)	33.0	(-0.9)

Percentages between brackets are the changes in choice probability relative to the reference case.

7.3.3 Heterogeneity in region choice probabilities

The location choice model takes account of several segmentation criteria that are a cause of heterogeneity among the location preferences of offices. This taste heterogeneity causes different types of offices to be unevenly distributed over the urban regions, and also has as a consequence that the outcome of the high-speed rail scenarios is different per office. The segmentation is meant to study this consequence of heterogeneity.

The results of the reference case and HSL South scenario for different segments of offices are shown in Table 7.3. These figures can be compared with the average region choice probabilities in Table 7.2. A first segmentation criterion is the office's branch of industry. This aspect is mainly of influence for sensitivity to the type of urban environment, but also the importance of the total train frequency at a station depends on it. Offices in the business and financial services are more susceptible to a station's train frequency than other offices. However, total train frequency is only marginally increased at stations that are to receive new high-speed train services. And the effect of additional train services on location attractiveness is even more limited for stations that already have a high frequency[34] (as is the case with all high-speed train stations in the study area). This explains why the percentage changes in region choice for offices in the financial and business services are broadly comparable to the average values in Table 7.2.

A second segmentation criterion is whether or not an office has employees who regularly make international business trips. The international orientation is very relevant for whether or not an office is attracted by a station with international high-speed train services. The HSL South services are therefore of a larger influence for this segment than for all offices on average. Especially the Amsterdam region benefits from the high-speed train, because it receives two stations with international high-speed train services.

Finally, the third heterogeneity aspect that is considered in Table 7.3 is the spatial orientation to customers. Offices that have their customers or clients located all over the country or also abroad, are assumed to be sensitive to long-distance accessibility. The Utrecht region is dominant for this type of offices because of its central location, both geographically as within the Dutch

Table 7.3 Differences between office segments: forecasted probabilities for region choices per segment and the change due to the HSL South scenario.

Urban region	Branch of industry is financial or business services (%)			Has employees who make international business trips regularly (%)			Spatial orientation to customers is national or international (%)		
	Reference	With HSL South		Reference	With HSL South		Reference	With HSL South	
Amsterdam	17.5	18.0	(+2.9)	16.8	17.6	(+4.7)	16.3	16.9	(+3.8)
Rotterdam	13.1	13.4	(+1.8)	13.9	14.2	(+2.2)	12.7	13.1	(+2.6)
The Haque	13.3	13.3	(+0.1)	11.9	11.8	(-0.8)	12.0	11.9	(-0.8)
Utrecht	24.5	24.0	(-1.9)	24.9	24.3	(-2.4)	28.4	27.6	(-2.5)
Other	31.6	31.3	(-0.9)	32.5	32.1	(-1.3)	30.7	30.5	(-0.5)

Percentages between brackets are the changes in choice probability relative to the reference case.

railway network. With the arrival of the HSL South it are predominantly Rotterdam and the region around Dordrecht (southeast of Rotterdam) that benefit most.

To conclude, if a distinction is made between different segments then the effect of high-speed train services can be seen to be larger for some sub-populations of offices than for others. Spatial orientation and travel behaviour are relevant from this respect. Still the changes in region choice probabilities that are reported in Table 7.3 and Table 7.2 are modest. It can be expected that changes in choice probabilities on the intraregional level are larger[35]. This is the subject of the next section.

7.4 High-speed rail's impact on the attractiveness of locations within the Amsterdam urban region

As discussed in chapter 2 high-speed rail can have its main influence on an intraregional scale. This subsection focuses on the effect of the high-speed train scenarios for competing locations within the Amsterdam region. Intraregional location choices are analysed by simulating location choices between all GIS grid cells that are available in the Amsterdam region. Since the choice probability for individual cells would not make much sense given the uncertainty that is associated with location choices, grid cell probabilities and changes in these probabilities are aggregated to larger areas as are shown in Figure 7.4 above. Location choice probabilities are thus averaged out over a larger area and are therefore presented here with less extreme values. Furthermore, for the interpretation of the results in this subsection it should be kept in mind that the percentages are very susceptible to the exact demarcation of the areas.

This section first examines the modelled average choice probabilities of some relevant locations in the Amsterdam region for different high-speed rail scenarios. Thereafter the variation in taste heterogeneity for intraregional location choices is focussed on. Finally, the last two subsections each explore an aspect that influences the location choices at this spatial scale: the choice which station in Amsterdam is used for HSL South services and the impact of a land-use change at the Amsterdam South axis.

7.4.1 Average probabilities for intraregional location choices

Within the Amsterdam urban region the South axis area competes with many other locations. Among the main competitors are the city centre of Amsterdam and locations at the Schiphol airport site. Each of these locations benefits from the HSL South. Figure 7.8 shows how the average utility at these three sites increases with the implementation of the HSL South. Utility is here a measure of attractiveness. Since utility is a relative quantity and also its absolute increase does not have a readily interpretable meaning, the utility in the figure is normalized to the change for the Amsterdam South axis.

Amsterdam city centre gains most in attractiveness. It benefits from both a large connectivity effect and a centrality effect. The South axis only has a centrality effect. Schiphol has an approximately equal connectivity increase as Amsterdam city centre but a lower gain in potential accessibility. In the direct vicinity of the Schiphol station the connectivity effect is larger than for

Table 7.4 Forecasted changes in average probabilities for location choices within Amsterdam due to different high-speed rail scenarios.

Location	Reference (%)	With HSL South (%)		With Zuiderzeelijn (%)		With Hanzelijn (%)	
South axis	7.3	7.3	(-0.9)	8.1	(+10.2)	8.4	(+14.1)
City centre	8.8	10.1	(+15.2)	9.9	(+12.6)	9.8	(+11.8)
Schiphol	1.8	2.0	(+14.6)	2.0	(+14.6)	2.0	(+13.8)
Other	82.1	80.6	(-1.9)	80.0	(-2.6)	79.8	(-2.8)

Percentages between brackets are the changes in choice probability relative to the reference case.

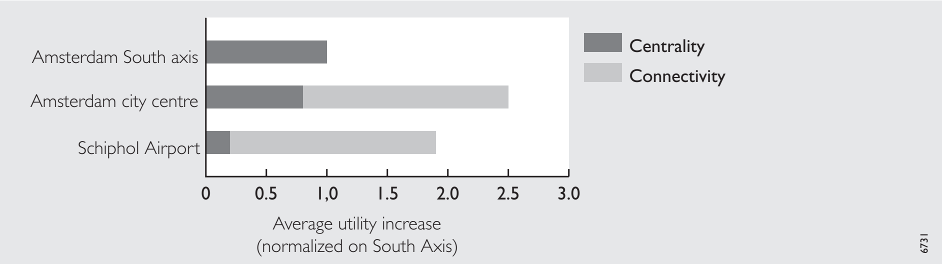

Figure 7.8 Increase in average location utility due to HSL South services.

Amsterdam city centre. Since high-speed trains stop at Schiphol in two directions the increase in train frequency is twice as large as for Amsterdam central station, which is the end point of the service. In addition to this for Amsterdam central station the initial frequency is higher than for Schiphol, and higher initial frequencies lower the effect of additional train services[36]. However, at Schiphol airport itself little space is available for offices; therefore in this section a somewhat larger area is used that does not fully fall within Schiphol station's catchment area.

The utility per grid cell results in a choice probability; Table 7.4 shows the calculated probabilities for location choices conditional on the region choice. In the reference case the city centre of Amsterdam is the most often chosen location. The high level-of-service of Amsterdam central station is an important factor for this as well as the high potential accessibility, which compensate for poor motorway connectivity. The Schiphol zone has a low probability, because in this area relatively little space is available for offices and because the self-potential for commuting accessibility is low. Finally, as the Amsterdam region is a large region in the COROP classification, there is also a large probability for choosing another site than one of the three examined here.

For the scenario with the HSL South, which has a stop at Amsterdam central station, the city centre of Amsterdam and Schiphol benefit most. Other locations, including the South axis, are less often chosen conditional on the region choice, even though these also have an increase in potential accessibility. The decrease in intraregional choice probability is lower than the increase in region choice probability (which was 2.7 percent, see Table 7.2) so in total the choice probabilities for these locations increase on average.

Table 7.5 Differences between office segments: forecasted probabilities for location choices within Amsterdam per segment and the change due to the HSL South scenario.

Urban region	Branch of industry is financial or business services (%)			Has employees who make international business trips regularly (%)			Spatial orientation to customers is national or international (%)		
	Reference	With HSL South		Reference	With HSL South		Reference	With HSL South	
South axis	8.6	8.4	(-2.3)	7.2	6.8	(-5.3)	7.5	7.4	(-1.4)
City centre	12.2	14.1	(+15.1)	8.6	11.0	(+28.1)	9.4	10.8	(+15.9)
Schiphol	1.5	1.8	(+19.0)	1.8	2.3	(+27.0)	1.8	2.1	(+16.8)
Other	77.6	75.7	(-2.5)	82.4	79.9	(-3.0)	81.4	79.7	(-2.1)

The Zuiderzeelijn and Hanzelijn scenarios mainly result in a higher train connectivity for the South axis. This is only connectivity for domestic high-speed train services and not for international high-speed train services. Still the relative increase in choice probability for the South axis is large. With the Zuiderzeelijn the increase for the South axis is almost as large as for the city centre, while with the Hanzelijn the South axis is the largest gainer in location choice probability. Schiphol also gains in attractiveness relative to the city centre, as it now becomes a transfer node between two the high-speed train links.

From these results it can be concluded that the intraregional distributive effect of high-speed rail is likely to be considerable for the Amsterdam region. The next subsection addresses the question to what extent these location choices differ between the segments in the model.

7.4.2 Heterogeneity in intraregional location choice probabilities

Similar to the choice of a region for an intraregional location choice taste heterogeneity can be of influence. Table 7.5 shows the intraregional choice probabilities subdivided to the same segments as in Table 7.3. For offices in the financial and business services the South axis and city centre are considerably more attractive than for other offices. This is mainly caused by the sensitivity of the different types of offices to the type of urban environment. For accessibility attributes less diversity exists between these branches of industry, although Schiphol gains relatively more for the business and financial services than for other branches of industry.

International business trips make an office much more responsive to connectivity to international high-speed rail services. For this type of offices the HSL South results in a large increase in the probability of the city centre and Schiphol airport to be chosen. This goes mainly at the expense of the South axis, which in combination with the region choice probability suffers a net loss in location choice probability for this type of offices.

The results for offices with a national or international spatial orientation are quite comparable with the average probabilities. The spatial orientation interacts with the availability of intercity services and the contour indicator for business travel potential accessibility. Intercity services do not change in this scenario, while the potential accessibility indicator has most of its impact at an interregional level instead of for the intraregional location choices. For the HSL South scenario

Schiphol gains more offices with a national or international orientation to customers, but the difference is not large.

To conclude, the only office characteristic in this model that really leads to a substantially larger impact of the HSL South at the intraregional level is regularly making international business trips. The South axis becomes considerably less attractive for this type of offices relative to the city centre. However, this outcome is conditional on choice of Amsterdam central station as the end stop for HSL South services. The next subsection explores how these results change if Amsterdam South/WTC station is chosen.

7.4.3 Choice between Amsterdam central station and Amsterdam South/WTC station for HSL South services

In subsection 7.2.2 it was concluded that with the alignment of the railway network as in the year 2000 a stop of the HSL South services at the Amsterdam South/WTC station leads to a marginally higher potential accessibility for the South axis but also to a substantially lower potential accessibility for the city centre and some other locations in the Amsterdam region. Although this has a negative influence on the Amsterdam region as a whole, it makes the South axis more competitive towards other locations in Amsterdam. This is even more the case if also connectivity is taken into account.

How the intraregional location choice probabilities change according to which station is chosen is shown in Table 7.6. If HSL South services stop at the Amsterdam South/WTC station then this station's environment becomes about equally often chosen as the city centre. Also Schiphol becomes more often chosen than in the case with a stop at Amsterdam central station, because it now has less severe competition from other locations in the Amsterdam region. Overall it can be concluded from these results that a stop at the South axis would be very beneficial for its development impact.

Besides the choice of the end station for HSL South services another factor of uncertainty are the development plans that are proposed or already carried out. The next subsection explores the possible consequences of these plans for the outcome of the scenario results.

7.4.4 Role of South axis development

The SC model results presented in section 6.2 suggest a relationship exists between the image of a site and the availability of international high-speed train services. In the model used in this chapter it is unfortunately not possible to include such an interaction effect between high-speed train services and the development plans to make the Amsterdam South axis a high-status office

Table 7.6 Impact for location choices within Amsterdam of the chosen station for HSL South services.

Location	Reference (%)	Stop at central station (%)		Stop at South station (%)	
South axis	7.3	7.3	(-0.9)	8.8	(+20.7)
City centre	8.8	10.1	(+15.2)	8.6	(-2.0)
Schiphol	1.8	2.0	(+14.6)	2.1	(+16.4)
Other	82.1	80.6	(-1.9)	80.5	(-2.0)

Table 7.7 Influence of South axis developments: contribution of a land-use change and accessibility from the HSL South with a atop at the South axis to a total change in intraregional location choices.

Location	Reference	Urban environment	Accessibility	Synergy	Total
South axis	7.3	+0.9	+1.5	+0.2	9.9
City centre	8.8	-0.1	-0.2	0.0	8.5
Schiphol	1.8	0.0	+0.3	0.0	2.0
Other	82.1	-0.8	-1.6	-0.2	79.5

site. Still, to some extent it is possible to study a synergy between the accessibility effect and the real estate developments in the form of a change in the land-use type.

A land-use change enhances the effect of an accessibility increase on location choice probability. Table 7.7 shows the effect on intraregional location choices for a scenario with an HSL South stop at the Amsterdam South/WTC station in combination with a change of the type of urban environment at the South axis towards the category of business sites in or near a city. This type of urban environment is more attractive to offices. In the table a distinction is made between the change in probability that can be ascribed to the land-use change, to the accessibility change and to a combination of these (the synergy effect). A synergy effect between attributes is supposed to be relevant for location choices in general. Although location choices are often assumed to be of a compensatory nature, to become a top location a site needs to have good levels for all attributes that are relevant to a certain type of decision maker[37]. Due to this synergy characteristic a change in urban environment enhances the effect of an accessibility increase on location choice probability. Thereby the land use typology also includes the aspect of supply: if more space is available for offices then the effect of accessibility can be larger.

It can be seen from Table 7.7 that the change in the type of urban environment yields a considerable increase in the location choice probability. A synergy effect is observable from the model results, but is small compared to the separate effects of the urban environment and accessibility. For the results of this scenario study, the synergy effect is not large enough to be of great influence on these relative changes.

7.5 Synthesis and conclusions

The current chapter has presented the accessibility and location choice effects of different scenarios for high-speed railway implementation in the Netherlands. This section aims to synthesize these results and to draw some conclusions that relate to the existing literature in this field. The first subsection gives an integral overview of the results and of the differences between scenarios. Thereafter the second subsection discusses the role of high-speed rail in the competition between cities. Finally, the third subsection discusses the influence of high-speed rail on the attractiveness of different sites within the same city.

7.5.1 Synthesis of scenario results

As noted in chapter 3 the purpose of the models used in this scenario study is to study the structure of changes in the attractiveness of locations within the Randstad area rather than to give exact forecast for a future situation. The quantitative results that have been presented in the previous sections are therefore here summarized and discussed in a qualitative way. Table 7.8 gives an overview of the high-speed rail scenario results, for the HSL South alone and in combination with the Zuiderzeelijn and Hanzelijn. The figures from the tables in the previous sections are herein converted to plus and minus signs on the basis of the evaluations that have been described in the text of this chapter.

The impact of high-speed rail on potential accessibility is moderate, since long-distance trips account for only a small proportion of all trips. A specific indicator for long-distance accessibility shows a larger increase, but this indicator is only assumed valid for a particular segment of offices that has a national or international orientation. The accessibility benefit is limited to Amsterdam, Rotterdam and nearby cities that have good train connections to Amsterdam or Rotterdam; hereby Zuiderzeelijn and Hanzelijn have a negligible impact additional to the HSL South.

Location choices are based not only on potential accessibility but also on aspects of connectivity. The connectivity effects further enhance the attractiveness of the Amsterdam and Rotterdam regions, as can be seen in Table 7.8. The Zuiderzeelijn and Hanzelijn have a further positive impact on Amsterdam, because this region now has three high-speed train locations. At the same time for all high-speed rail scenarios a decrease in the choice probability for other locations within the Randstad can be seen. This is especially the case for Utrecht, because many of the offices in Utrecht are of a type that is sensitive to long-distance accessibility.

Table 7.8 further shows the effect of high-speed rail on locations within the Amsterdam urban region. Compared to the choice of a region the intraregional location choice reacts stronger on a change in the accessibility attributes; this is a consequence of the spatial hierarchy in location choices that has been found to be relevant. Locations within Amsterdam that do not have an

Table 7.8 Overview of the effects of HSL South services for different scenarios.

Spatial level	Region/location	HSL South only		HSL South and Zuiderzeelijn or Hanzelijn	
		Potential accessibility	Location choice	Potential accessibility	Location choice
Interregional	Amsterdam	+	+	+	++
	Rotterdam	+	+	+	+
	The Hague	0	0	0	0
	Utrecht	0	--	0	--
Intraregional	Other	0	-	0	-
	Amsterdam South axis	+	-	+	++
	Amsterdam city centre	+	++	+	++
	Schiphol	+	++	+	++
	Other Amsterdam	+	-	+	-

Table 7.9 Influence of office characteristics on location choices and on the impact of high-speed rail.

Characteristic	Reference region choice	Region choice responsiveness	Reference location choice	Location choice responsiveness
Branch of industry is financial or business services	++	+	++	+
Has employees who make international business trips regularly	0	++	0	++
Spatial orientation to customers is national or international	+	++	0	+

accessibility increase in the high-speed railway scenarios suffer a larger loss in choice probability than similar locations in other regions. For the South axis connectivity to the Zuiderzeelijn/Hanzelijn leads to a substantial increase in choice probability, even in this case where it are only domestic high-speed train services.

The scenario outcomes are susceptible to the types of offices that are considered. In chapter 6 three office characteristics are found able to explain taste heterogeneity within the data set. These segmentation criteria have an influence on different aspects of the location choices. Table 7.9 gives an overview of this. The branch of industry is an often-used segmentation criterion in location choice studies and models (e.g. Abraham and Hunt, 1999; Waddell and Ulfarsson, 2003). In the current application it has indeed a large influence on the distribution of economic activities, both on an interregional and an intraregional level. However, it appears to be a less distinctive factor for reactions in location preferences due to a change in accessibility. On the other hand, the two accessibility-related segmentation criteria are of larger influence on the responsiveness of location choices to accessibility, but these have less impact on the spatial distribution of activities in the reference case. The spatial orientation of an office is thereby of larger influence on the interregional scale than on the intraregional scale.

The scenario study in this chapter also showed the sensitivity of the model results for several aspects that relate to the high-speed rail implementation. Firstly, if Amsterdam South/WTC station is used for HSL South services then the effect on location choices is more positive for the South axis but less positive for other locations in Amsterdam and also less positive for Rotterdam. However, results for this option can improve if Amsterdam South/WTC station receives more and better connections to other stations within the region. A second aspect that influences the model outcomes is the height of the fare supplement for travelling by high-speed train. This fare is found to have a considerable restrictive effect on the potential accessibility increase of sites for which the new high-speed rail services are an option. Finally, attention has been given to the development of the South axis to a more attractive urban environment. The analyses showed the influence of this land-use change to be of significant influence on location choices, but the synergy with high-speed rail is not very large.

To conclude high-speed rail is found to have an impact on office location choices at different spatial scales. At the regional scale different issues are relevant than at the urban scale. The next two sections elaborate further on the results of the scenario study for these two scales respectively, and relate them to concepts in literature.

7.5.2 High-speed rail and competition between cities

From a city's point of view high-speed rail connections are often seen as a means to compete with other cities. This becomes apparent when in the planning process of a new high-speed railway line there is a combat between cities for attaining on of the few possible high-speed train stops (see Plassard, 1991). An important motive to build the HSL South is the presumed importance for the Randstad to be connected to the Western-European high-speed railway network in order to gain and/or preserve offices from the international business services (Min. V&W, 1994). Thereby Amsterdam, Rotterdam and The Hague are seen as internationally competing cities. The possible connection of The Hague to the high-speed railway network was therefore an important point of debate for policy makers when the HSL South was decided on (see Min. V&W, 1994). However, also within the Netherlands a competition between cities takes place. In coordination with the HSL South several station areas are being upgraded; besides the South axis this includes office sites near the Rotterdam, The Hague and Utrecht central stations. This makes the effect of the HSL South on office location choices within the Randstad very relevant.

Previous accessibility studies on the Trans-European Networks programme (e.g. Gutiérrez *et al.*, 1996; Spiekermann and Wegener, 1996) have already shown that on a European scale it are the main metropolises that gain most from the new high-speed railway links. High-speed rail links typically interconnect the urban centres that already had the highest accessibility. The scenario study in the current chapter shows similar results. In the Randstad region Amsterdam and Rotterdam, the two largest cities in the study area, benefit from their increased mutual potential. More high-speed train stops in the Netherlands would lead to a less concentrated impact of high-speed rail, but at the same time causes a crowding-out effect of this influence because the number of offices affected by high-speed rail is limited.

For The Hague the absence of international high-speed train (Thalys) services results in a small loss in attractiveness for internationally oriented offices. Compared to Amsterdam and Rotterdam the city looses considerably for attracting this type of offices. However, other cities such as Utrecht suffer much more from being bypassed. More than The Hague Utrecht relies on nationally oriented offices, because of its central position in the country and (related to its location) its high long-distance accessibility. Nevertheless, the position of The Hague as an internationally competitive city is weakened by the absence of direct Thalys services, particularly for its competition with Amsterdam and Rotterdam.

The Zuiderzeelijn and Hanzelijn have an additional positive effect on the Amsterdam region. This is mostly due to the connectivity effect for domestic high-speed train services at the Amsterdam South/WTC station. Potential accessibility increases only marginally, mainly because the frequency of the services (2 trains per direction per hour) results in a considerable waiting time and/or planning penalty. The South axis benefits much from the Zuiderzeelijn/Hanzelijn, especially compared to a situation where the Amsterdam South/WTC station is bypassed by HSL South services. The effect of the Hanzelijn is thereby somewhat higher than for the Zuiderzeelijn, because the better connection to Zwolle by the Hanzelijn raises potential accessibility more than the better connection to Heerenveen by the Zuiderzeelijn.

To conclude, high-speed rail in the Netherlands leads to an increased competitiveness of the main urban centres (Amsterdam and Rotterdam) compared to other cities in the Randstad, similar to the studies at a European level. This study particularly shows that the degree to which a city without a high-speed rail connection suffers from this effect depends on the type of offices for which the city is especially attractive. As is shown in Table 7.9 in the previous high-speed rail is most relevance for nationally and internationally oriented offices; for other types of offices high-speed rail has less influence. Therefore bypassed cities that are most dependant on these types of offices will suffer the largest relative loss in office employment.

7.5.3 Development of high-speed train station sites

In literature it is suggested that the employment location effect of high-speed rail is largely intraregional distributive (Sands, 1993; Mannone, 1997). For France, Bonnafous (1987) and Mannone (1997) also conclude from entrepreneurial surveys that the TGV itself has played only an inferior role in the development of the high-speed train station areas in Lyon and Grenoble. Especially in the case of Grenoble, which has only a small increase in travel time with low frequencies (five trains per direction per day), the site development plans that accompanied the new TGV service might have more impact than the increased accessibility. Furthermore the government played a large role in the shift of employment to the station location, because redevelopment of the sites was initiated the arrival of offices from public and semi-public services, such as regional head offices of utilities (Mannone, 1997). For other countries with HST services (e.g. Japan and Germany) little information is found in literature on developments at an intraregional level (for qualitative descriptions of station area developments see e.g. Sands, 1993) and the exact role of high-speed rail in the attractiveness of sites remains undetermined.

The situation in the Netherlands is different in various respects from the above-mentioned French examples and also from other countries with HST services. Firstly, distances and travel times for which the high-speed rail connection is likely to be used is much smaller for the HSL South than for the TGV lines in France. On the one hand this is an advantage for high-speed rail as it is a viable transport option for more trips, but on the other hand high-speed rail suffers a more severe competition from the car. Secondly, the Netherlands does not have the structure with a strong national centre with regional branch offices such as France. Therefore the need for long-distance business travel is smaller in the Netherlands. This is a restrictive factor for the importance of high-speed rail in office location choices.

The case of the Amsterdam South axis is extraordinary in this context. The development plans for this site are linked to the high-speed train services, but the site will in the short run not be connected to the high-speed network and possible future connections seem still unsure. Despite of this for the development plans it has been anticipated that high-speed train services will stop at Amsterdam South/WTC station. In this case high-speed rail could thus have stimulated the development of a station site on which it does not have an actual stop.

The existence of seven HST stations in the Netherlands is also an aspect in which it differs from foreign cases. With this many stations in a relatively small area the effect of high-speed rail can be seen to flow out over these station areas. Locations are more competing to proximite locations than to more distant but otherwise similar locations. Competition between the several station areas in the Netherlands can therefore be expected to be more severe than between most foreign stations. For example, because of the larger distance one might expect less competition between Paris and Lyon than between Amsterdam and Rotterdam.

For answering the question *to what extent* high-speed rail contributes to the attractiveness of a location the results of the scenario study can be evaluated in a site-oriented way. As is shown by the results in section 7.4 a site with a high-speed train connection can be chosen (conditional on region choice) around 20 percent more than the reference situation. Compared to the case where a competing location has a high-speed train connection the impact of the high-speed train connection is of course larger. It can thus be seen that the influence of high-speed rail on location choices is much more apparent on the intraregional level than on the interregional level.

The question *how* high-speed rail influences location attractiveness seems more appropriately answered with an orientation at the office decision makers. From the results it can be seen that the number of offices for which high-speed rail is of decisive importance is not very large. The majority of offices that choose a high-speed train station site would also have chosen this location in a situation without high-speed rail, although part of these offices would choose a competing site if this has a high-speed train connection. Variation in the relevance of high-speed rail for offices is also visible. With high-speed train services at Amsterdam central station the city centre is most attractive for offices whose employees regularly make international business trips, because of the international high-speed train connectivity. Nationally oriented offices on the other hand are more influenced by the potential accessibility effect, which is higher for the South axis.

Overall it can be concluded that high-speed rail has a considerable effect on the attractiveness of locations, especially at the intraregional level. The connectivity effect is hereby dominant; this is mostly a combination of the characteristics of high-speed rail for image, the perception of accessibility, the option value and/or the value of choice. Travel time advantages are expressed as increases of potential accessibility, which is most of influence at an intraregional level (e.g. the competition between cities), but less for the development of specific sites. However, this potential accessibility effect can be very much restricted if a high fare supplement is charged. Finally, for the South axis being connected to the high-speed train network seems not necessary to attract sufficient employment in general, but specifically for being attractive to internationally oriented offices a high-speed train connection is of considerable significance.

8. Conclusions and discussion

8.1 Introduction

High-speed rail has become associated in literature and among policy makers with economic development and competition between cities. Initial apparent successes of high-speed rail, most notably in France and Spain, resulted in positivism among policy makers about the spatial economic effects of new high-speed railway infrastructure. Indirect effects have become a key issue in the evaluation of high-speed rail investment projects. Accumulation of empirical evidence in the past few decades has led to the view that for most cases the growth of employment around high-speed train stations is largely due to an intraregional distributive effect. Still, little research has focussed on the topic how high-speed rail affects the relative attractiveness of different sites within a region or city.

The current thesis has focussed on this topic of intraregional distributive effects. More precisely, the research goal that has been addressed to in this thesis is *"To determine to what extent high-speed rail has an impact on the location of office activities within the Dutch Randstad region, and which types of offices are most sensitive to high-speed rail."* The case of the Randstad can thereby be seen as an *ex ante* evaluation of high-speed rail in the Netherlands, because no real high-speed railway infrastructure is operational up till the time of writing this thesis.

The next section focuses on the answering of the research questions that have been put forward in this thesis. Subsequently, several subjects relevant to the indirect effects of (high-speed) railway infrastructure are discussed. Recommendations are made for policy makers who deal with issues related to high-speed railway projects. Finally, recommendations are made about possible directions of future research.

8.2 Conclusions

To achieve the above-stated research goal three research questions were formulated in the introduction of this thesis. The first two questions are of an analytical nature and focus on the impact of high-speed rail on accessibility and of accessibility on office location choices respectively. Answering these questions involves an evaluation of causal relationships as well as methodological issues. The third research question is about how different alternatives for high-speed rail connections have an effect on the attractiveness of locations for offices. For answering this question the results of the analyses for the previous two questions have been used. The developed models enable to evaluate how the spatial distribution of offices can change with a new high-speed railway line. These questions are subsequently discussed in the next three subsections below.

8.2.1 Effects of high-speed railway developments on accessibility

The first research question put forward in this thesis is: *"What are the effects of high-speed railway developments on accessibility for commuting and business travel in the Netherlands?"* Accessibility is the factor that is most directly affected by high-speed rail. Within this thesis a distinction has been made between two different aspects of accessibility: (1) centrality, which relates to the position of a location within the transport network relative to (possible) trip origins and destinations, and (2) connectivity, which is how easily from a location a traveller has access to the transport network. For this research question it is mostly centrality that is of relevance; the connectivity effect of high-speed rail is rather trivial and more relevant in the context of location choices. An accessibility study using potential accessibility indicators was performed to answer this question.

On centrality high-speed rail can have an influence by reducing the impedance to travel between locations. In this thesis train travel impedance has been seen as a combination of station-to-station travel time, train fare and the access and egress distances. By empirically studying the attributes and shape of the impedance function it has been shown that high-speed rail can considerably reduce travel impedance between cities in the Netherlands. With the impedance functions that have been found optimal, long-distance journeys have a larger influence on accessibility for train than for other transport modes. However, two issues are found to be especially relevant for the eventual accessibility effect.

Firstly, different types of accessibility indicators exist, which give different outcomes for accessibility analyses. For commuting a gravity-type indicator is found to be most suitable as an attribute of office location choices; here most emphasis lays on short-distance trip opportunities, so that high-speed rail has little effect on accessibility. For business travel long-distance trip opportunities are more relevant than for commuting; a contour indicator is used for this.

The second relevant topic for accessibility is transport modes being complementary and competitive to each other. Competition reduces the importance of a transport mode's travel opportunities in overall accessibility; complementarity increases the number of travel opportunities. Especially competition is an aspect that is often ignored in accessibility studies. Train accessibility typically accounts for only a small portion of a location's overall accessibility. Car accessibility is normally much larger. As a result, even if high-speed rail results in a large increase in train accessibility then its effect on overall accessibility can still be small. In the current research results this is more the case for commuting than for business travel.

Overall it can be concluded that in the case of the Netherlands the accessibility effect of high-speed rail for commuting is negligible. Accessibility by train plays a smaller role than accessibility by car and bus/tram/underground.

For business travel on the other hand it is concluded that high-speed rail does have a considerable effect on potential accessibility: Accessibility scores (scaled on 0 to 100 percent of the maximum in the Netherlands) increases up to 6.7 points for a reference scenario with the HSL South. This result is specifically found for an accessibility indicator that emphasizes long-distance travel.

8.2.2 Influence of accessibility by train on the attractiveness of sites

The second research question in this thesis was: *"What is the influence of accessibility by train on the attractiveness of sites within the Randstad area for the location choices of office employment?"* To answer this question telephone interviews have been carried out, accompanied by stated choice questionnaires. Location choice models were estimated based on stated choices, revealed choices and a combination of these. When making a location choice the decision maker(s) of an office establishment can base their choice on aspects of centrality, connectivity and non-accessibility factors. The first two categories are addressed to in this research question.

Potential accessibility is the total number of opportunities that can be reached from a location, given the travel impedance to these opportunities. From the viewpoint of an office's decision maker this can be interpreted as the size of a market: the labour market in case of commuting accessibility and the size of the product market in case of business travel accessibility. Theoretically decision makers could rate potential accessibility either positively or irrelevant (an exception to this can be spatial competition Pellegrini and Fotheringham, 2002, but in the current thesis spatial competition is accounted for by the nesting of the logit model). Potential accessibility for commuting is found to be significant for the location choices of offices accumulatively. For business travel an indicator for all offices did not yield satisfactory results. However, significant results were achieved with a specific indicator for long-distance business travel; this indicator is assumed to be only relevant for nationally or internationally oriented offices.

Connectivity refers to the access to a nearby network node (e.g. the distance or travel time to a station or motorway) in combination with the quality (level-of-service) that is provided at this node. For high-speed rail the concept of connectivity embeds aspects such as an image effect (i.e. high-speed rail can raise the status of a site), the perception of accessibility (proximity to a large station can give the impression of a good train accessibility), and its option value and value of choice (these are the extra values that the option to use high-speed rail can have over the benefits of its actual use). The analyses presented in this thesis have shown that connectivity for high-speed rail has a considerable influence on location attractiveness on top of connectivity for conventional train services: connectivity has a larger influence on utility than potential accessibility for stations in the Amsterdam region that are to be connected to the HSL South. Connectivity for international high-speed train services has thus a large effect on location attractiveness, but only for office establishments of which employees regularly make international business trips. Domestic high-speed train services are found relevant for a broader group of offices, but its influence on location choices for each of these offices is much smaller.

Overall it can be concluded that high-speed rail can be of significant influence, but only for a very specific group of office establishments. Centrality by domestic services is relevant for nationally and internationally oriented offices, while connectivity for international services is significant for office establishments from/to which often international business trips are made. Additionally, analysis results support the hypothesis that an image effect plays a role.

8.2.3 Scenarios for high-speed rail implementation and the impact on office location choices

The final research question that has been addressed is: *"What effects can be expected for the implementation of high-speed rail in the Dutch Randstad area on location attractiveness and the location choices of office establishments for different scenarios of high-speed railway developments?"* This question is of a different nature than the previous two questions that involved data analyses. Answering this question requires first the integration of the models that are used to answer the former two questions and then the use of these models to simulate accessibility and location choices for different scenarios. For location choices thereby an explicit distinction is made between the choice of a region and the choice of a location conditional on the chosen region.

Within the scenario study the reference scenario is the situation as in the year 2000. The base high-speed rail scenario consists of the reference scenario with the implementation of the HSL South. Other scenarios consist of this base high-speed rail scenario with for each one out of three variations: the height of the fare supplement for high-speed train services, the choice between Amsterdam central station and Amsterdam South station for high-speed train services, and the addition of a new Schiphol-Groningen high-speed train connection via the Zuiderzeelijn or the Hanzelijn.

For the base high-speed rail scenario it is concluded that high-speed rail makes cities more competitive for nationally and internationally oriented offices, but for all offices together the effect is not very large: with the HSL South Amsterdam has a 2.7 percent higher probability to be chosen than the reference scenario and for Rotterdam probability is 1.3 percent higher. At an intraregional scale high-speed train connectivity is more distinctive and can contribute considerably to the attractiveness of a station area. If HSL-South services stop at Amsterdam central station then the city centre of Amsterdam is expected to have a 15 percent higher probability to be chosen, conditional on the choice of the Amsterdam region. Still even for most offices in the vicinity of a high-speed railway station, high-speed rail is not likely to be the decisive factor in their location choice. Furthermore, the importance of connectivity on top of centrality in location attractiveness is not only seen as a way to increase the spatial resolution of the model, but also as a further indication that an image effect, the perception of accessibility and concepts such as option value and/or value of choice are relevant.

The height of the high-speed train fare supplement is found to significantly influence the accessibility effect of high-speed rail. A 25 percent supplement cancels out most of the travel time advantage. The structure of the fare supplement (fixed or distance-dependant) has less influence on the accessibility effect.

The choice between Amsterdam central station and Amsterdam South station for high-speed train services on the HSL South has a considerable influence on the attractiveness of these particular station sites. For the South axis a high-speed train connection can be a stimulus for the demand of office space. According to the location choice model the average probability of a location at the South axis being chosen, conditional on region choice, is increased by 21 percent if HSL-South services stop at the Amsterdam South/WTC station, compared to a 1 percent decrease if the South axis is bypassed by high-speed rail. But also without a direct connection the

South axis benefits from an increased potential accessibility, and the overall effect (conditional location choice and region choice) is positive.

The addition of high-speed train services on the Zuiderzeelijn or the Hanzelijn offer little potential accessibility benefits for the Randstad. Connectivity can attract extra office employment to Amsterdam, in particular to the South axis.

On the whole for high-speed railway implementation in the Randstad it is concluded that high-speed rail has an effect on the location choices for a limited group of offices with a nation-wide or international focus. At an interregional level high-speed rail leads to an increased polarisation of these offices: the large urban cores Amsterdam and Rotterdam will be preferred by more office decision makers, at the expense of other places in the Randstad. But the effect of high-spead rail on station developments in the Netherlands can be rather spread out among the high-speed railway station areas, because compared to foreign cases quite many high-speed railway stations exist in a small area in the Netherlands. Among the other locations in the Randstad particularly Utrecht suffers from a reduced interest, because this city is currently relatively attractive for the type of office establishments that is susceptible to highs-speed railway accessibility.

Within the Amsterdam urban region high-speed rail has a considerable impact on the relative attractiveness of different office sites. Having high-speed train services at a nearby station seems not a precondition but still a significant beneficial factor for the development of office locations. Especially for attracting internationally or nationally oriented offices high-speed rail is a relevant factor.

8.3 Railway infrastructure and land-use/transport interaction

This thesis has used the concept of land-use/transport interaction (LUTI) as a basis for the conceptual model. The research also focuses on a major issue in LUTI theory. In the context of LUTI the question to what extent there is a feedback from transport networks on the location of firms and households is critical. High-speed rail in the Netherlands seems an interesting case in this respect, because it leads to a drastic decrease in travel time within the Randstad as well as a better connection to some of the main Western-European cities. This section discusses the indirect effects of high-speed rail in the context of LUTI. The focus of this discussion is grouped into three main topics:

1. The spatial-economic effects of high-speed rail in the Netherlands,
2. The influence of railway infrastructure on the location choices of offices,
3. How interregional infrastructures have an influence on location choices at different spatial scales.

The following subsections each deal with one of these topics.

8.3.1 Indirect effects of high-speed rail: the case of the Netherlands

Several decades have elapsed since the first high-speed railway connections were put into service:

the Japanese Shinkansen connections since 1964 and the French TGV lines since 1981. It could therefore be expected that more clarity would have arisen on what the indirect effect of such a high-speed rail link would be. Nevertheless, the literature review in chapter 2 has shown that the spatial-economic effect of high-speed rail links is difficult to determine and dependant on the specific circumstances, with respect to among others the spatial distribution of economic activities and households. The new HSL-South high-speed railway in the Netherlands is again a case on its own. This subsection aims to relate the conclusions drawn for this case in the previous section in a broader context of high-speed railways.

Differences between the transport effects of high-speed railway cases exist especially for the travel distances for which passengers use the line. Although the HSL South is to a great part intended to serve (international) long-distance travel, the travel studies for the HSL-South reported in chapter 2 already forecast larger passenger volumes for shorter connections within the Netherlands. The planned train scheme on the HSL South also suggests a dominance of domestic travel on this line. Of all 96 high-speed trains that are to depart daily from Amsterdam only 32 are extended to Belgium, 16 of which go on to France. The HSL South is therefore expected to have other transport effects (e.g. with regard to trip generation and trip distribution) than existing lines in e.g. France, Spain, Germany and Italy, which connect cities over much longer distances. More than for the other lines in the chapter 2 literature review the HSL South competes with the car and hardly with air transport.

This has consequences for the potential accessibility effect of high-speed rail. Border effects may limit the potential spatial interaction on the longer distances, for which in other cases the main portion of high-speed rail's potential accessibility score would come. On smaller distances the competition of the car reduces high-speed rail's effect on potential accessibility.

Within the context of accessibility the Zuiderzeelijn/Hanzelijn case is an example of the choice between different technological options: either to build new, dedicated high-speed railway infrastructure or to upgrade existing track possibly combined with the use of tilting-trains. The first option is most ambitious, the second option is in literature regarded as an intermediate form between conventional rail and very-high-speed rail (e.g. Vickerman, 1997). However, the new infrastructure alternative is not necessarily better for accessibility than upgrading existing track. As was shown in chapter 7 for potential accessibility the Zuiderzeelijn high-speed rail alternative was advantageous over the Hanzelijn high-speed rail alternative only for the north of the Netherlands, for which the Zuiderzeelijn was intended to have a regional development impact. The Randstad and the surroundings of Zwolle benefited more from the Hanzelijn. But travel opportunities in the north of the Netherlands are not numerous enough for the Zuiderzeelijn/Hanzelijn to have a noticeable impact on potential accessibility in the Randstad.

High-speed rail is often associated with the international competitiveness of cities. In the Netherlands, Amsterdam and Rotterdam would thereby compete with cities such as Brussels and Cologne. But the mutual competition between Amsterdam and Rotterdam and the competition with other Dutch cities is at least as relevant for the attraction of economic activities to these cities. In chapter 7 it has been shown that the HSL South leads to an increased polarisation of the location choices of offices: Amsterdam and Rotterdam become further attractive relative to other locations in the Randstad. The results also show that some cities suffer more from being bypassed by high-speed rail than other. Especially Utrecht, which is an attractive city for nationally oriented offices, is expected to (relatively) loose offices employment.

At the urban level the main interest lays at the 'key projects' for the development of station areas in the Netherlands. For individual sites care should be taken when estimating what the possibilities for further development are with or without a direct high-speed rail connection. Although demand is a relevant factor, exogenous political developments have a major influence as was for example also visible in France (see Plassard, 1991). Still, it can be concluded that being connected to high-speed rail is an enhancement in the attractiveness of a site for offices. With these favourable market conditions high-speed train station locations are more likely to develop than other sites.

8.3.2 The influence of railway infrastructure on the location choices of offices

With the trend of LUTI models from aggregated models of spatial interaction towards disaggregated activity-based models a better view at the micro level is necessary of how actors (the decision makers of households, firms or institutions) treat accessibility in their location choices. Residential location choices have attracted most attention in past research on the land-use impacts of transport. The topic of firm location seems to be underrepresented in literature; the current thesis can add to this topic. The purpose of this subsection and the next subsection is to evaluate this thesis' conclusions within a broader framework of land-use transport interaction. The current subsection thereby focuses on the influence of accessibility on location choices at a micro level. The next subsection addresses the spatial scale and spatial demarcation of studies on interregional infrastructure from a LUTI point of view.

LUTI models, and the studies that underlie these models, typically use branches of industries for segmentation among types of economic activities. Branches of industries are generally convenient because of data availability, but this segmentation criterion might not be optimal for the purpose of evaluating the impact of accessibility on location choices. In the current research, other segmentation criteria are shown to be better suitable for identifying taste heterogeneity of accessibility attributes. This thesis' specific focus on office establishments as a type of economic activity is consistent with this.

For office establishments 'soft' location factors are seen to play a large role, as offices are less bounded to non-movable resources than many other economic activities. Furthermore, the role of accessibility is normally limited to personal travel: commuting and business travel; freight transport is of little or no relevance for most offices. In the surroundings of railway stations often concentrations of offices can be found. Stations seem a prominent location factor for offices, but it is still unclear what aspects of a station make a station location attractive to office decision makers. The analysis results presented in this thesis have shown that a mixture of potential accessibility aspects and level-of-service characteristics can be held responsible for this effect.

With respect to railway accessibility it can also be seen that railway infrastructure has a rather varying influence on office location choices. The quest for an explanation for this variance has an important place in this thesis. The results indicate that specific travel-related characteristics of office establishments are relevant for how decision makers rate railway accessibility. The plausibility of making use of the characteristics through customized questionnaires is shown, as well as the practical possibility to apply such a model. For location models these results put concerns to the common use of the branch of industry as a segmentation factor. This economic factor appears well suitable in explaining the current location of firms, but performs poorly in assessing the impact of accessibility on location choices.

Another topic for the impact of railway infrastructure on land use is the importance of subjective factors. Proximity to an infrastructure can lead to the perception of a good accessibility for an office site. In correspondence to this, the better image of such a site can make it more attractive to offices. For high-speed rail this research has provided indications that such an effect is relevant. In the telephone questionnaire 20 percent of the respondents see HST station sites as viable alternatives for location choices because of the image of such a location. This finding supports the Dutch national government's policy for the redevelopment of the Dutch HST station areas (the 'new key projects'), as these redevelopments have additional value in combination with high-speed train connectivity.

Related to this, the option value and/or value of choice appear to be of importance. Most business travel and commuting trips use either the car or slow modes. Train use seems not high enough to account for the number of offices located near railway stations via potential accessibility. Instead the limited flexibility of using public transport makes being located near a station to be seen as a precondition for train travel. From these aspects it can be seen that the impact of transport on land-use exists not only via travel times, as is traditionally the core of LUTI models, but also via connectivity.

To summarize, the importance of employment location as a generator of business travel and commuting seems not reflected in research on this topic. For LUTI models it seems relevant that better account is taken of typologies and taste variation among firms and institutions. Furthermore, the relevance of perceptions, image effects, option value and value of choice opt for the inclusion of railway connectivity indicators as location factors for offices.

8.3.3 Spatial scales and interregional transport infrastructure

LUTI models typically focus on the spatial developments of cities or agglomerations, thereby treating the total level of economic activities as exogenous. With the emergency of better and faster transport and communication technologies the question arises whether this spatial demarcation is still appropriate. If urban economics are becoming increasingly open then the transport system can also have an impact on the total employment in a city, especially as interregional access points such as high-speed train stations and airports become more important.

The research described in this thesis makes an explicit distinction between the *inter*regional and *intra*regional level, in order to study how high-speed rail has an influence on the location of offices at different spatial levels. At the interregional level transport infrastructures can affect competition between cities; at the intraregional level it is an incentive for the development of specific sites.

The conclusion that at an intraregional level effects are larger than at the interregional scale is partly due to the averaging-out of local effects around stations if larger geographical zones are used, and partly due to the spatially hierarchical structure of location choices. The latter is most interesting here. It implies that office employment is to some extent bounded to their region. A similar effect is as well possible at higher spatial scales than considered in this thesis (e.g. at the national level), especially if barrier effects decrease relocation possibilities between countries. This would limit the ability of the HSL-South to attract international (head) offices to Dutch cities. For the current research it is assumed that relocations to/from the Randstad due to high-speed rail are negligible.

Another issue related to spatial scale is the demarcation of regions, so what is *the* regional level? National borders, language borders and cultural border are fixed (despite efforts of the European Union to erase obstacles between European countries), but regions are susceptible to change. Many regional demarcations are possible on different levels, and there is likely a gray area between the interregional and intraregional level. In the research described in this thesis a fixed regional demarcation is used, based on the COROP classification.

Within the context of high-speed rail it has been argued (e.g. Blum *et al.*, 1997) that new connections can have an influence on the outline of what are called 'functional regions', i.e. regions that function as an entity e.g. by sharing a common labour market. If a site's potential accessibility increases due to a better transport connection then its functional region can be seen to expand. Some (although little) empirical evidence can be found in literature that might support this theory. For example, Sands (1993) mentions the possibility that regional branch offices can be abolished if high-speed rail allows a region to be served from a head office or another branch office. For the HSL South in the Netherlands, however, the results of the current research suggested that such an effect would occur only in rare cases.

To summarize, this research has found evidence on a geographically hierarchical structure of the location choices of offices. It has been shown that a distinction can be made between the interregional and intraregional levels of location choices. Theory on border effects suggests that a further hierarchy is also likely to be relevant at higher spatial scales. The distributional effects between the Randstad and more peripheral regions or between the Netherlands and foreign regions are therefore expected to be small.

8.4 Implications for policy on high-speed railway projects

In the Netherlands in the last decade several infrastructure projects have been proposed for which high-speed rail was an option. Only one of these (the HSL South) has been approved by the time of writing this thesis. The reasons for the rejection of most projects concern the high cost of the infrastructure that are not justified by the monetarized expected benefits (which are also regarded to be highly uncertain) in cost-benefit analyses. However, the integral evaluation of infrastructure projects is a topic that exceeds the scope of the current thesis. Still the results of this thesis can give information on some issues that are relevant to decision makers.

Firstly, a comment can be made on the use of different evaluation tools, which have been described in section 2.1.2. In the light of the current thesis the use of advanced spatial models for the evaluation of the most recent high-speed railway proposals (the Zuiderzeelijn, Eding *et al.*, 2000; and the Rondje Randstad, Haubrich, 2001) is seen as a favourable development. With these models a more comprehensive and theoretically sounder assessment of the likely benefits per geographical area is possible than with for example comparisons of individual cities with foreign cases (such as DEGW and BCI, 1998). Although in the next section further recommendations are made for the methodological improvement of location choice models, it is advised that this type of evaluation methods is continued to be used. This also urges for a method to include intranational spatial developments in cost-benefit analyses.

Furthermore, recommendations can be made with regard to urban developments. In the Netherlands large investments are made for the urban development projects to revitalize or further develop the surroundings of Dutch HST stations, the so-called 'new key projects'. For each city with a high-speed train service this implies that more office space is being built. The Amsterdam South axis is the most prominent example of this, as is discussed in chapter 7. The results presented in this thesis emphasize the importance of image for the attractiveness of HST station sites. Because of the image effect of high-speed rail the presence of a HST station at a location and a good quality of the surroundings can presumably reinforce each other. Further research is recommended to collect more direct evidence of the size of this possible relationship. If this relationship is confirmed then city planners can indeed attract extra office employment to a HST station site by urban developments such as the new key projects, including offices that are little sensitive to HST accessibility per se. As was already mentioned in the previous section, the policy of the Dutch national government to support the 'new key projects' (Min. VROM, 2006) can be seen to be a good thing given the importance of image. However, care should be taken that this policy does not lead to an oversupply of offices at this type of location, because it has also been shown that the number of offices that are sensitive to high-speed rail (via either accessibility or image) is limited. Five HST station areas with a large office supply could easily be too much for an office market that already has many vacant offices.

As a result of the new key projects the number of choice options at locations near intercity stations in the Randstad will increase greatly. This has consequences for competing locations without a high-speed train connection. Policy making in the context of high-speed rail seems focussed on development of the HST locations and not on coping with a possible decline of other locations. Still, because of the oversupply of office space that exists in the Netherlands at the time of writing this thesis (see e.g. Dynamis, 2006) it seems plausible that the new key projects lead to vacancies of office buildings elsewhere. In policy making the emphasis seems to lay on the development of HST areas and proximate sites and not on the possibility for negative effects for other sites in a city or region (this also seems to apply to literature that focuses on concepts and theories for the urban effects of high-speed rail, e.g. Pol, 2003). It is therefore recommended that more attention be given to guiding changes for other locations within the Randstad.

A similar issue is possibly relevant for other regions in the Netherlands. High-speed train stations in Breda along the HSL South and in Arnhem along the Amsterdam-Frankfurt line could lead to attracting mostly offices that originate from other locations in their respective regions. This seems especially likely to occur in combination with the current station area redevelopment projects. Furthermore, this mechanism can also be relevant for the Zuiderzeelijn and Hanzelijn, which are under discussion by the time of writing this thesis. North-Dutch policy makers expect that these connections will attract new employment to the north of the Netherlands. However, these lines may have a much larger effect on the distribution of office employment within the north of the Netherlands instead.

Finally, similar to what is argued by Vickerman (1997), this thesis makes clear that policy makers should generally have no high expectations for high-speed rail as an instrument to boost a national or regional economy. The indirect economic effects of a HST-project are likely to be distributive (i.e. leading to a different intraregional distribution of economic activities) rather than generative (i.e. stimulating the total regional or national level of economic activities).

8.5 Recommendations for further research directions

The issues discussed in the previous section raise several aspects that can progress further research on related topics. This section gives an overview of recommendations for further research that are based on this research and for research that can extend the research described in this thesis.

8.5.1 Recommendations for further research on high-speed rail

Within the literature on high-speed rail little researches can be found on the intraregional distributive effects for employment location. This thesis has focussed on this topic and confirmed the relevance of this effect. From these results the following recommendations for further research are made.

The accessibility indicators used in this thesis are based on the national travel survey. This is a general survey, which lacks some aspects particularly relevant to high-speed rail. Although high-speed trains have much in common with conventional trains, there are also differences that might lead to a different valuation of travel. Main issues for this are the comfort and image of high-speed rail, which can be seen to be better than for conventional trains. These and other aspects could have an impact on high-speed train's alternative-specific valuation and the valuation of travel time. Further research on the transport or accessibility impact of new high-speed train connections is advised to make use of techniques that can take account of high-speed rail specifically, such as stated choice surveys or meta-analyses of existing high-speed railway lines.

In the current research accessibility indicators are calculated for domestic trips only. International accessibility was not seen to be relevant for location choices within the Randstad. Still, for the case of high-speed rail it would be an interesting option to extend the accessibility model to the international scale. It is recommended that such a model be estimated on empirical data in a similar setup as the domestic spatial interaction model used in this thesis. An empirical model would provide information on existing high-speed train connections and provide an empirical base for the border effects that are here assumed to be relevant. Such a model would add to the existing literature on high-speed train accessibility, which generally ignores competition between transport modes and is not based on empirical travel data.

For the land-use and economic development effects of high-speed rail this thesis has used a model that includes multiple levels in a spatial hierarchy. It has been demonstrated in this thesis that a micro-economic framework can effectively be used to study the indirect effects of high-speed rail at an urban and regional level. An advantage of this model is that it does not only regard the benefits of station sites, cities or regions that receive a high-speed train connection, but also the loss of places that lack such a connection. Further research is recommended to use a similar micro-economic setup, possibly expanding this to a higher spatial level.

With regard to studies that focus on the indirect effects of high-speed rail it is advised that account be taken of the possibility that intraregional distributive effects occur. Concentrations of offices (or other economic activities) that appear in case studies as being attracted by a high-speed train station might very well originate from other places within the same city or region. These relocations can mostly not be accounted as economic benefits. Furthermore an increased concentration of employment around offices can also have effects on the transport system. The use of the train is facilitated, but on nearby roads increased congestion can occur.

To summarize, this thesis has developed a model to study train accessibility, thereby taking account of competition between transport modes and of the shape of the impedance function. Interesting possibilities for further research are to extend this model by introducing high-speed rail as a separate (but related) transport model from conventional rail or to apply a similar model to a larger spatial scale. Furthermore, in this thesis the effect of interregional high-speed railway links on the intraregional scale is studied. On the basis of the results, research on the indirect effects of high-speed rail is advised to include the intraregional distributive effects in the analyses and to use a spatially hierarchical structure for distinguishing between the intra- and interregional spatial levels.

8.5.2 Recommendations for further research on railway accessibility

The research described in this thesis has paid attention to the specification of accessibility indicators for the railway network. On the basis of this experience the following recommendations are made for further research.

For the current research some simplifying assumptions have been made regarding the impedance of train travel. Most notably these are the assumption that the nearest station to the origin (or destination) being the access station (or egress station) for a trip and the assumption that all passengers use the train connection with the lowest generalized cost. These assumptions have been made because a further detail was expected to have little effect on the outcome of the location choice model and because the data from the OVG (Dutch National Travel Survey) that were used do not include information on the route choice of train travel. However, if the accessibility effect of railway infrastructure is the specific aim of a research then a more detailed treatment of train travel utility is recommended. A further level-of-detail is possible because recently data from the OVG's successor MobiliteitsOnderzoek Nederland (MON) has become available, which includes information on the route travelled for train journeys. Therefore aspects of train travel such as the choice of the access and egress stations could be better accommodated for and characteristics of these stations could be used in the model, for example the availability of parking space at a station.

In the current thesis attention is given to accessibility for commuting and business travel. Where for commuting accessibility many applications can be found in literature, information on accessibility for business travel is scarcer. For travel by high-speed rail (or on other long-distance railway links) on the other hand, business travel seems a much more important travel motive (see subsection 2.4.1). Business travel is also referred to frequently in studies on the spatial-economic impacts of high-speed rail (e.g. Bonnafous, 1987; Sands, 1993) However, business travel is not dealt with in much detail by general travel surveys such as the OVG that is used in this study, nor by its successor MON, probably because business travel accounts for only a small part of total travel. The travel surveys on the TGV in France (e.g. Bonnafous, 1987) have shown that making a distinction between different types of business travel and between different types of occupation can be a useful addition to travel surveys. Research of this type could not only provide more information on the travel behaviour of business travellers, but also on linkages within and between firms. Future research could focus on this topic for the Netherlands, particularly via customized interviews.

More information on the characteristics of business traveller's or commuter's employer could also be used for a further segmentation of accessibility indicators. If it is known for observations in the travel data set to which segment in the location choice model the traveller's office belongs, then for each office segment specific potential accessibility indicators can be calculated. This could benefit the office location choice model. Like every individual traveller, in theory each office can be seen to have a different impedance function for travelling. If travellers in a travel survey could be linked to office segmentation characteristics, then this might improve the accessibility indicators for use in a location choice model.

Finally, another issue relevant for business travel is the occurrence of trip chains. The possibility for chaining business trips increases the potential accessibility of a site. And the flexibility in travel choices that is required for chaining trips can be a limiting factor for the use of public transport (Hensher and Reyes, 2000). Further research could focus on how to take account of trip chaining in potential accessibility indicators.

8.5.3 Recommendations for further research on land-use/transport interaction

The topic of this thesis is the influence of transport on location choices; thereby this research has focussed on a major issue in land-use/transport interaction. Several issues are relevant that can further extend the scope of the research on this key link.

As was discussed in chapter 2 for the impact of new transport infrastructure on the location of activities many aspects are relevant. This thesis has focussed on one of these topics: the influence of the infrastructure on the attractiveness of locations from the point of view of offices. This is regarded as a very important link in the context of high-speed rail. However, for an overall assessment of the land-use effects of transport infrastructure several related topics can be relevant as well. Firstly, despite that revealed choices are susceptible to aspects of the supply of office space, in a strict sense a location choice model considers the demand side of the real estate market only. But transport infrastructure investments can influence the supply side as well. New infrastructure influences the location of new office constructions, both directly (e.g. via the governments' land-use plans) and via the market mechanism. A relevant issue for further research would therefore be the effect of high-speed rail on real estate prices. But also limitations in the available space around railway stations, e.g. due to legislations, is an issue that requires further attention.

Furthermore, for a full evaluation of the indirect effects of high-speed rail the reaction of household locations and the location of other economic activities is relevant. A location choice model as is developed in this thesis can be embedded into a larger LUTI model that would provide a more complete evaluation framework. This would have the advantage that also a feedback is provided from the location of activities to accessibility. And also the use of a more sophisticated road transport model in such a framework would allow studying the interaction of station developments with local congestion and the implications of more (exogenous) congestion on the motorway network for the potential of high-speed rail and high-speed rail's role in accessibility. For an integral analysis of the indirect effect of new (high-speed) railway links it is suggested that a location choice model, such as the one developed in this thesis, be embedded in the larger framework of a LUTI model.

Several topics of further research are possible for the office location choice model itself. These are particularly issues of a methodological nature. In this thesis the emphasis has lain on the distinction between the interregional and intraregional levels in a nested logit model. But also alternative nesting lay-outs in a nested logit model are possible, both instead of and in combination with the regional nesting; the latter via a cross-nested logit model. A useful alternative nesting can be for example a distinction between location types: station locations versus motorway locations and other types. Such a model would require additional research on location types, but can yield additional results on competition between locations of the same type.

Another possibility is to use mixed logit techniques to represent taste heterogeneity, for which a method has also been described in chapter 3. This has methodological advantages for the multiple observations in the stated choice data. In addition to this, the mixed logit model fits well within the increased use of microsimulation for urban modelling. In the mixed logit model explicit attention is given to uncertainty and taste variation, and it allows replicating a nesting structure. From a theoretical point of view, such a model would be superior to the nested logit model. However, such a model is much more complex to estimate and apply.

To conclude, this thesis has shown that it is relevant to study high-speed rail in the context of LUTI. High-speed rail can be expected to have a considerable influence on location choices, which works through in the wider land-use and transport systems. Further research on the indirect effects of high-speed rail is advised to take explicit account of the feedback between land use and transport, especially if also relative short-distance links are present.

Samenvatting

1 Inleiding

Met hogesnelheidstreinen kan een reductie in reistijd bereikt worden voor reizen op middellange afstanden. De eerste hogesnelheidslijnen in Frankrijk waren een zodanig succes voor zowel het aantal reizigers als voor de regionale economie, dat dit heeft geleid tot de verdere ontwikkeling van netwerken van hogesnelheidstreinen in Europa. Zo is onder andere het PBKAL-project ontstaan, dat de belangrijkste West-Europese agglomeraties met elkaar verbindt. Voor Nederland houdt dit project in dat de HSL-Zuid is gebouwd, een hogesnelheidslijn van Amsterdam naar Antwerpen. Deze HSL-Zuid biedt niet alleen voordelen voor internationale reizen maar ook voor binnenlandse reizen, bijvoorbeeld doordat de reistijd tussen Amsterdam en Rotterdam wordt verkort van ruim een uur tot ca. 35 minuten. Andere voorgestelde hogesnelheidslijnen, zoals de HSL-Oost tussen Amsterdam en Arnhem en de Zuiderzeelijn- of Hanzelijnverbinding tussen Amsterdam en Groningen, hebben totnogtoe geen doorgang gevonden.

Voor de evaluatie van nieuwe infrastructuur zijn in eerste instantie de opbrengsten en kosten van de constructie, de exploitatie en het gebruikt van de infrastructuur van belang; deze worden ook wel de directe effecten genoemd. Bij de evaluatie van nieuwe hogesnelheidslijnen wordt daarnaast ook relatief veel aandacht besteed aan de zogenaamde indirecte effecten van de lijnen, zoals de gevolgen voor de regionale of stedelijke economie. Toch is de precieze aard en omvang van deze indirecte effecten nog niet duidelijk en worden ze vaak te gunstig ingeschat (zie bijvoorbeeld Vickerman, 1997). Rond buitenlandse stations met hogesnelheidstreindiensten (HST-diensten) zijn weliswaar aanwezig zijn toenames van de werkgelegenheid waargenomen, maar dit blijkt vaak het gevolg te zijn van verplaatsingen van bedrijfsactiviteiten vanuit andere locaties in dezelfde stad of regio. Dit kan niet als een economische baat voor de stad of regio worden beschouwd. Ook prognosestudies hebben vaak zwakke punten. In case studies naar stedelijke ontwikkeling wordt vaak geen rekening gehouden met netwerkeffecten en concurrentie tussen locaties. Modelstudies houden meestal geen rekening met zogenaamde 'zachte' locatiefactoren, zoals het image van een locatie en de perceptie van bereikbaarheid.

Dit proefschrift richt zich op de directe en vooral ook de indirecte effecten van hogesnelheidstreinen in de Randstad. Dit wordt gedaan door middel van een *ex ante* evaluatie van de invloed van hogesnelheidslijnen op locatiekeuzes door de beslissingsmakers van kantoren. Hiervoor worden drie onderzoeksvragen geformuleerd. De eerste vraag heeft betrekking op bereikbaarheid, een concept dat centraal staat in de relatie tussen het transportsysteem en de locatie van economische activiteiten:

"Wat zijn de gevolgen van de ontwikkeling van hogesnelheidslijnen op bereikbaarheid voor forenzenverkeer en zakenreizen in Nederland?"

De tweede vraag legt vervolgens de relatie tussen bereikbaarheid en de locatie van kantoren:

"Wat is de invloed van bereikbaarheid op de aantrekkelijkheid van locaties binnen de Randstad voor de locatiekeuzes van kantoorvestigingen?"

De derde vraag, ten slotte, richt zich meer specifiek op verschillende ontwikkelingen voor het netwerk van HST-diensten:

"Welke effecten zijn te verwachten ten gevolge van de implementatie van hogesnelheidslijnen in de Randstad voor de aantrekkelijkheid van locaties en de locatiekeuzes van kantoorvestigingen, voor verschillende scenario's van HST-diensten?"

Hierbij is in het bijzonder aandacht gegeven aan de gevolgen van hogesnelheidslijnen voor Amsterdam en de Amsterdamse Zuidas. Voor de Zuidas zijn voornemens om het gebied te ontwikkelen tot een locatie met een hoge status, die aantrekkelijk zal zijn voor nationale en internationale hoofdkantoren.

2 Theorie en conceptueel raamwerk

Voor het beantwoorden van bovenstaande onderzoeksvragen is eerst geëvalueerd welke gevolgen transportinfrastructuur in theorie heeft op de locatie van activiteiten. Vervolgens is gekeken naar literatuur op de directe en indirecte effecten van hogesnelheidslijnen. Dit vormt de basis van het conceptueel model van dit proefschrift.

In Nederland wordt voor de beoordeling van investeringen in transportinfrastructuur de Leidraad OEI (Overzicht Effecten Infrastructuur) gevolgd. Deze leidraad geeft richtlijnen voor het uitvoeren van een kosten-batenanalyse (KBA). Hierbij zijn ook expliciet gegeven aanwijzingen voor de evaluatie van indirecte effecten. Een variëteit van verschillende evaluatiemethoden komt in aanmerking. Voor de KBA zijn dit voornamelijk kwantitatieve modellen, vanwege het streven om de gevonden effecten te monetariseren. In de literatuur komen daarnaast ook (vaak meer exploratieve) kwalitatieve methoden voor. In dit proefschrift is gekozen voor een benadering vanuit locatiekeuzemodellen binnen een raamwerk van *land-use/transport interaction* (LUTI). Locatiekeuzemodellen bieden de mogelijkheid om zowel complexe netwerkeffecten als subjectieve locatiefactoren met behulp van empirische data te analyseren, maar zijn toch intuïtief te doorgronden en relatief eenvoudig toe te passen. Het theoretische kader van LUTI is daarbij bruikbaar om deze locatiekeuzemodellen in een groter geheel te beschouwen van het transportsysteem en de locaties van activiteiten.

Volgens de LUTI theorie is er een wederzijdse afhankelijkheid tussen het transportsysteem en de locatie van activiteiten. Een verandering in het transportsysteem heeft invloed op de bereikbaarheid van locaties, wat leidt tot andere locatiekeuzes van de ontwikkelaars en gebruikers van onroerend goed. De locatie van activiteiten is weer een drijvende kracht voor transportstromen, bijvoorbeeld doordat forenzenverkeer de connectie vormt tussen de locaties van huishoudens en de locaties van bedrijven. Binnen de LUTI theorie is de invloed van bereikbaarheid op locatiekeuzes een cruciale link, omdat dit verband complex is en empirisch moeilijk te analyseren. In LUTI-modellen wordt deze relatie steeds vaker via locatiekeuzemodellen met bereikbaarheidsindicatoren gemodelleerd, in plaats van met ruimtelijke-interactiemodellen. Dit proefschrift richt zich in het bijzonder op deze relatie, waarbij gebruik is gemaakt van concepten uit de LUTI-modellen.

Voor hogesnelheidslijnen kunnen verschillende typen studies onderscheiden worden die zich richten op de directe of indirecte effecten. Uit ex ante en ex post studies naar de vervoervolumes op hogesnelheidslijnen blijkt dat naast een modal-split effect (veranderingen van vervoerwijzen) ook een distributief en/of generatief effect van belang is, dat wil zeggen een verandering in reisbestemming en/of in het aantal reizen. Dit geldt ook voor de Nederlandse HSL-Zuid. Een verschil tussen de HSL-Zuid en buitenlandse lijnen is dat de HSL-Zuid vooral concurreert met de auto in plaats van het vliegtuig. Bovendien zijn voor de HSL-Zuid verbindingen over een korte afstand (tussen Amsterdam, Rotterdam, Den Haag en Breda) van relatief groot belang. Voor indirecte effecten laten verschillende typen studies een ander beeld zien. Japanse studies op een interregionaal niveau hebben positieve correlaties gevonden tussen de aanwezigheid van HST-diensten en de groei van bevolking en werkgelegenheid, maar de causaliteit van dit verband staat niet vast. Bereikbaarheidsstudies in Europa hebben aangetoond dat vooral voor de grote, goed bereikbare agglomeraties in West Europa de bereikbaarheid verder toeneemt en hogesnelheidslijnen dus een polariserend effect hebben. Studies in met name Frankrijk naar bedrijven in de omgeving van HST-stations laten zien dat veel van deze bedrijven voorheen op andere locaties in dezelfde stad of regio gevestigd waren en dat HST-bereikbaarheid in de meeste gevallen geen belangrijke rol speelt in locatiekeuzes.

Op basis van deze bevindingen is een conceptueel model opgesteld voor dit proefschrift. Hierin wordt gesteld dat verschillende aspecten van hogesnelheidslijnen relevant zijn in de context van LUTI. Hogesnelheidslijnen kunnen locatiekeuzes beïnvloeden via enerzijds potentiële bereikbaarheid door de reductie in reistijden, en anderzijds connectiviteit vanwege hun imago-effect, de invloed op de perceptie van bereikbaarheid, de optiewaarde en de keuzewaarde (d.i. de waarde van de mogelijkheid om van hogesnelheidslijnen gebruik te maken, los van het daadwerkelijke gebruik). Bovendien moet er expliciet in het locatiekeuzemodel een onderscheid worden gemaakt tussen het *inter*regionale en het *intra*regionale niveau van locatiekeuzes. In dit onderzoek zijn verplaatsingen van kantoren tussen de Randstad en de rest van Nederland of het buitenland buiten beschouwing gelaten. Het aantal van dergelijke bedrijfsverplaatsingen is naar verwachting echter niet groot, onder andere omdat nationale, culturele of taalgrenzen als een barrière kunnen werken voor zowel reisgedrag als bedrijfsverplaatsingen.

3 Methodologie voor kantoorlocatiekeuzes

Om de invloed van bereikbaarheid op de locatie van kantoren te analyseren worden verschillende locatiekeuzemodellen ontwikkeld. De modellen zijn gebaseerd op de discrete-keuzetheorie en veronderstellen dat de beslissingsmakers van kantoren een keuze maken tussen een aantal alternatieve locaties. Er is hiervoor gebruik gemaakt van twee typen data: waarnemingen van de huidige locaties van kantoorvestigingen (*revealed choices*, of RC data) en voorgenomen locatiekeuzes op basis van hypothetische keuzeopties (*stated choice*, of SC data). Beide data sets hebben eigen specifieke voordelen en een eigen functie binnen dit proefschrift. SC data is vooral geschikt voor het beoordelen van invloed van individuele locatiefactoren op de locatiekeuzes. En het kan gebruikt worden om het belang van nieuwe factoren zoals de aanwezigheid HST-diensten op een station te kwantificeren. RC data levert een betere weergave op van de marktaandelen en onzekerheden die in een werkelijke markt ervaren worden.

Data worden verzameld door middel van telefonische enquêtes, gevolgd door een korte vragenlijst per e-mail of post voor het verkrijgen van SC data. Op basis van een steekproef uit het LISA (Landelijk Informatie Systeem Arbeidsvoorziening) worden kantoorvestigingen met ten minste 20 werknemers geselecteerd. Van iedere vestiging is een potentiële respondent gezicht: een beslissingsmaker of medewerker die vanuit zijn/haar functie nauw betrokken is bij een eventuele locatiebeslissing. Vragen in de telefonische enquêtes hebben voornamelijk betrekking op eventuele locatiekeuzes in het recente verleden, mobiliteitsgerelateerde kenmerken van de kantoorvestiging en de percepties van de respondenten ten opzichte van hun huidige kantoorlocatie. De SC vragenlijst bestaat uit acht hypothetische keuzesituaties, elk bestaande uit twee keuzeopties. Indien de respondenten hierin toestemden werd hen één van acht versies van deze vragenlijst toegezonden.

De discrete-keuzedata zijn geanalyseerd met verschillende typen logit-modellen, gebaseerd op micro-economische nutsmaximalisatie. Naast het welbekende multinomiaal logit-model is hierbij ook gebruik gemaakt van meer geavanceerde modellen. *Nested* logit-modellen zijn gebruikt om een ruimtelijke hiërarchie van locatiekeuzes te bestuderen door een onderscheid te maken tussen het intraregionale en interregionale niveau van locatiekeuzes in de RC data. *Mixed* logit-modellen worden gebruikt om heterogeniteit in locatievoorkeuren te bestuderen en om correct om te gaan met meerdere observaties per respondent in de SC data.

Een belangrijk methodologisch aspect is het combineren van de SC en RC data sets met het doel om een model te verkrijgen dat de voordelen van beide typen data verenigt. Verschillende methoden hiervoor zijn geëvalueerd en uiteindelijk is een methode gekozen die gebruik maakt van nested logit-schattingen.

4 Methodologie voor ruimtelijke interactie en potentiële bereikbaarheid

Potentiële bereikbaarheid is het aantal potentiële bestemmingen dat voor een bepaald vervoersmotief vanaf een locatie bereikt kan worden. Per potentiële bestemming bestaat het uit een attractiecomponent voor het belang van de bestemming, dat vermenigvuldigd wordt met een weerstandscomponent voor de reisweerstand tussen de locatie en de betreffende bestemming. In dit proefschrift is de weerstandsfunctie met empirische data vastgesteld door middel van een ruimtelijke-interactiemodel. Twee ruimtelijke-interactiemodellen worden geschat: een model voor woon-werkverkeer en een model voor zakenreizen. De bereikbaarheidsindicator voor woon-werkverkeer kan geïnterpreteerd worden als de omvang van de arbeidsmarkt, die voor zakenreizen als de afzetmarkt.

Om een bestemming te bereiken kan van verschillende vervoerwijzen gebruik gemaakt worden. Voor bereikbaarheidsindicatoren is daarom ook de concurrentie tussen vervoerwijzen van belang: een nieuwe spoorverbinding tussen twee plaatsen heeft meer invloed op bereikbaarheid als meer reizigers er gebruik van maken, in plaats van dat zij bijvoorbeeld de auto gebruiken. Daarom is een multimodale weerstandsfunctie geschat in de ruimtelijke-interactiemodellen. Hiertoe is gebruik gemaakt van een logit-model dat vervoerwijzekeuze met bestemmingskeuze combineert. Vier typen vervoerwijzen zijn onderscheiden: auto, trein, bus/tram/metro en overige vervoerwijzen (vooral lopen en fietsen). Voor de trein bestaat de nutsfunctie in deze toepassing uit de voortransportafstand, de natransportafstand en de gegeneraliseerde kosten van beginstation naar eindstation. De gegeneraliseerde kosten bestaan uit gemonetariseerde reistijd en de kosten van een treinkaartje.

Een ander aspect van de weerstandsfunctie is de vorm van de functie. Deze bepaalt hoe het bereikbaarheidseffect van een reistijdreductie afhankelijk is van de afstand waarover deze reistijdwinst effect heeft. In de literatuur wordt vaak een exponentiële functie gebruikt in toepassingen op korte afstanden en een machtsfunctie in toepassingen op lange afstanden; bij deze laatste hebben reistijdwinsten op korte afstanden een veel groter effect dan op lange afstanden. In dit proefschrift worden verschillende typen weerstandsfuncties gebruikt en is de optimale weerstandsfunctie op empirische basis bepaald. Hierbij is ook gebruik gemaakt van de gegeneraliseerde Tanner en Box-Cox functies, die meer flexibiliteit hebben voor de vorm van de functie dan de conventionele typen weerstandsfunctie.

In dit proefschrift worden twee typen bereikbaarheidsindicatoren gebruikt: een zwaartekrachts-indicator en een contourindicator. Bij de zwaartekrachtindicator wordt de weerstandsfunctie uit het ruimtelijke-interactiemodel vermenigvuldigd met de attractiefactor. Deze indicator legt de meeste nadruk op korteafstandsrelaties. De contourindicator wordt specifiek gebruikt voor bereikbaarheid over lange afstanden. Deze indicator is de som van de attractiefactoren van alle zones die binnen een bepaald maximum weerstand liggen. Met het RC locatiekeuzemodel is de relevantie van de verschillende indicatoren bestudeerd en is een optimale maximum weerstand voor de contourindicator gezocht.

5 Resultaten voor ruimtelijke interactie en potentiële bereikbaarheid

De resultaten van de ruimtelijke-interactiemodellen laten zien dat de Box-Cox functie een significant beter model oplevert dan de andere vormen weerstandsfunctie, zowel voor forenzenverkeer als voor zakenreizen. De gebruikelijke exponentiele en machtsfuncties zijn dus niet optimaal om reisweerstand te representeren. In tegenstelling tot reistijdwinsten van andere vervoerwijzen kan voor de trein een daling van de station-tot-station gegeneraliseerde kosten ook een beduidende invloed hebben op de reisweerstand voor relatief lange binnenlandse reizen. Naast de keuze voor het attribuut waarin reisweerstand wordt uitgedrukt komt dit ook doordat de trein vooral een vervoermiddel voor de lange afstand is. Dit geldt voor zakenreizen meer dan voor forenzen.

Uit de ruimtelijke-interactiemodellen blijkt ook dat de trein slechts een kleine bijdrage levert aan de ruimtelijke interactie, omdat het aandeel van korte reizen veel groter is dan dat van lange reizen. Dit heeft ook consequenties voor de bereikbaarheidsindicatoren. Het aandeel van treinbereikbaarheid in de totale bereikbaarheid is beperkt voor de zwaartekrachtindicatoren. Een relatief grote toename voor treinbereikbaarheid kan dus verwaarloosbaar zijn voor de totale indicator. Voor de contourindicator heeft de trein een groter aandeel en ook een groter effect.

Voor de zwaartekrachtindicatoren is in het basisjaar de grootste bereikbaarheid te vinden in de Randstad, en dan met name in Amsterdam, Rotterdam en Den Haag. Dit komt doordat in deze indicator korte afstanden dominant zijn. De contourindicator kent de hoogste waarden toe aan Utrecht en omgeving. Deze regio ligt centraal in het land en voor de contourindicator zijn met de gevonden optimale grenswaarde vooral lange afstanden van belang.

6 Resultaten voor de invloed van bereikbaarheid op kantoorlocatiekeuzes

Het SC model richt zich voornamelijk op het kwantificeren van treinconnectiviteit. Ten eerste gaat het hierbij om de toegang tot het station. Beslissingsmakers waarderen een kantoorlocatie meer als het op loopafstand van een station ligt. Er lijkt een omslag te liggen bij circa 10 en 15 minuten lopen, waar de aantrekkelijkheid van een locatie sterker daalt door een toename van de looptijd dan het geval is met looptijden van minder dan 10 minuten of van meer dan 15 minuten lopen. Voor lage voortransporttijden wordt de bus als voortransportmiddel lager gewaardeerd dan lopen met dezelfde voortransporttijd.

Daarnaast is door het SC model een vergelijking gemaakt tussen het belang voor locatiekeuzes van verschillende aspecten van de level-of-service van stations: de totale frequentie van treinen en de aanwezigheid van intercitydiensten. Beide aspecten blijken van belang te zijn, maar het belang van intercitydiensten neemt af als een groot deel van de werknemers van een kantoor zakenreizen maakt. In dat geval wordt vaak door de werkgever een auto ter beschikking gesteld aan werknemers.

Voor HST is een onderscheid gemaakt tussen binnenlandse en internationale diensten. De internationale diensten hebben een groot effect op de aantrekkelijkheid van locaties voor een beperkt aantal kantoren. Dit zijn kantoren waarvan de werknemers regelmatig internationale reizen maken naar landen die een directe HST-verbinding met Nederland hebben; dit zijn 38 procent van de kantoren in de dataset. Er is ook een interactie-effect gevonden tussen internationale HST-diensten en de architectuur van het gebouw: een architectonisch hoogstaand pand heeft een meerwaarde als het nabij een station met internationale HST-diensten ligt, en vice versa. Dit interactie-effect kan worden opgevat als een indicator voor het imago-effect van HST, aangezien het HST-bereikbaarheid relateert aan de uitstraling van een locatie. Daarnaast is er in het SC-model nog een vrij grote onverklaarde variatie onder respondenten voor de waardering van internationale HST-diensten. Deze heterogeniteit kan onder andere het gevolg zijn van onbekendheid met HST. De invloed van binnenlandse diensten op de locatiekeuzes is kleiner dan die van internationale diensten, wat een mogelijke oorzaak is voor het niet vinden van een statistisch significante heterogeniteit onder beslissingsmaker voor de aanwezigheid van binnenlandse HST-diensten op een station.

Een belangrijk doel van het RC-model is het testen van de indicatoren voor potentiële bereikbaarheid als verklarende variabelen voor locatiekeuzes. Voor bereikbaarheid naar forenzen bleek alleen de zwaartekrachtindicator van belang. De contourindicator gaf hier geen bevredigende resultaten, ondanks dat een serie verschillende grenswaarden is getest. Voor zakenreizen bleek echter juist de contourindicator van belang te zijn. De zwaartekrachtindicator leverde een theoretisch onverwacht negatief resultaat op en is daarom weggelaten uit het model. Omdat de contourindicator zich vooral richt op langeafstandsbereikbaarheid is deze indicator alleen relevant verondersteld voor kantoren met een nationale of internationale oriëntatie. Dat wil zeggen dat de klanten of cliënten van deze kantoren verspreid zijn over heel Nederland en eventueel ook in het buitenland; dit is een groep van 48 procent van de steekproef.

Een ander belangrijk aspect voor het RC-model is de ruimtelijke hiërarchie van locatiekeuzes. Volgens deze hiërarchie hebben locaties in dezelfde regio meer overeenkomsten en beconcurreren zij elkaar daardoor meer dan locaties in verschillende regio's. Dit onderscheid tussen het intraregionale en interregionale niveau blijkt inderdaad relevant te zijn voor de meeste COROP-regio's. Hierdoor heeft een nieuwe HST-dienst over het algemeen een groter effect op een niet-HST locatie in een regio met een HST-station voor deze nieuwe lijn dan op een verder gelijkwaardige locatie in een regio zonder directe HST-aansluiting.

Het gecombineerde SC/RC-model corrigeert de op hypothetische keuzes gebaseerde SC data voor de onzekerheden die gelden bij werkelijke locatiekeuzes. Hierdoor kunnen de level-of-service variabelen uit het SC-model gebruikt worden in een praktische toepassing. In het SC-experiment zijn minder verstorende exogene invloeden, zodat de verklarende variabelen een grotere invloed hebben op de gemaakte hypothetische keuzes dan bij een werkelijke keuze het geval is. Van de twee geteste methoden bleek een methode die gebruik maakt van een nested logit schatting het meeste voordeel op te leveren.

7 Resultaten van de scenariostudie voor de invloed van hogesnelheidstreinen op de locatiekeuzes van kantoren in de Randstad

De scenariostudie heeft tot doel om van verschillende mogelijkheden voor het HST-netwerk de gevolgen voor bereikbaarheid en locatiekeuzes van kantoorvestigingen te evalueren. Naast een referentiescenario zonder HST zijn acht scenario's bestudeerd, die een combinatie zijn van verschillende factoren: het effect van de HSL-Zuid alleen en in combinatie met de Zuiderzeelijn of de Hanzelijn, de gevolgen van de keuze tussen Amsterdam centraal station en Amsterdam Zuid/WTC als station voor HST-diensten over de HSL-Zuid, en de invloed van de hoogte van de HST-toeslag die voor deze treindiensten bovenop de prijs van een standaard treinkaartje wordt gerekend. Alle andere factoren zijn constant gehouden in de scenario's.

Voor potentiële bereikbaarheid zijn er duidelijk verschillen te zien tussen de typen indicatoren. In de zwaartekrachtindicatoren hebben de verschillende scenario's een verwaarloosbare invloed op bereikbaarheid, omdat voor deze indicator de mogelijkheden voor korte reizen domineren. Met de contourindicator, waarvoor langeafstandsreizen een groter effect hebben, is een grotere bereikbaarheidstoename voor de HSL-Zuid berekend: tot aan bijna zeven procent van de maximale bereikbaarheid in de referentiescenario. Opvallend is dat de toename van potentiële bereikbaarheid voor de Amsterdamse Zuidas groter is dan voor de Amsterdamse binnenstad, ook voor een scenario waarin station Amsterdam Zuid/WTC geen directe HST-verbinding heeft. Dit komt doordat de Zuidas ook zonder de HSL-Zuid al een frequente verbinding met Schiphol heeft. De keuze voor station Amsterdam Zuid/WTC in plaats van Amsterdam centraal station voor HST-diensten over de HSL-Zuid heeft een verder positief effect voor de bereikbaarheid in de omgeving van de Amsterdamse Zuidas, maar een negatief effect voor de bereikbaarheid van de meeste andere locaties. De hoogte van de HST-toeslag heeft een aanzienlijke invloed op de omvang van het bereikbaarheidseffect. Toevoeging van HST-diensten over de Zuiderzeelijn of de Hanzelijn heeft nauwelijks een effect op potentiële bereikbaarheid, voornamelijk vanwege de lage frequentie van de diensten.

HST-verbindingen beïnvloeden de concurrentie tussen steden en stedelijke regio's. De steden met een directe aansluiting op de HSL-Zuid worden aantrekkelijker voor kantoorvestigingen in verhouding tot concurrerende steden. De kans om gekozen te worden door een kantoorvestiging (gemiddeld over alle vestigingen) stijgt voor Amsterdam met 2,7 procent en voor Rotterdam met 1,3 procent. Met name Utrecht wordt minder vaak gekozen door kantoorvestigingen (een daling van 1,7 procent). Dit komt doordat de Utrechtse stedelijke regio in de referentiescenario vooral aantrekkelijk is voor kantoren met een nationale en internationale oriëntatie, die juist gevoelig zijn voor langeafstandsbereikbaarheid. Een HST-verbinding over Zuiderzeelijn of Hanzelijn versterkt de aantrekkelijkheid van Amsterdam verder.

Voor de intraregionale verdeling van kantoren richt de scenariostudie zich op de regio Amsterdam. Binnen deze regio zijn twee toekomstige HST-stations: Schiphol en ofwel Amsterdam centraal station of Amsterdam Zuid/WTC. Op dit lagere schaalniveau zijn zoals verwacht veel duidelijkere veranderingen te zien in de locatiekeuzes. Met Amsterdam centraal station als HST-station neemt de kans voor de binnenstad om gekozen te worden, gegeven de keuze voor de regio Amsterdam, toe met 15,2 procent en voor Schiphol met 14,6 procent (al speelt de precieze afbakening van deze locaties een rol in de percentages). De kans voor de Zuidas neemt in dat geval af met 0,9 procent. Met een stop van HST-diensten op Amsterdam Zuid/WTC neemt de kans van de Zuidas om gekozen te worden juist toe met 20,7 procent. De HSL-Zuid kan dus een grote stimulans zijn voor de ontwikkeling van de Zuidas.

Bij de evaluatie van deze scenario's voor locatiekeuzes is expliciet onderscheid gemaakt tussen verschillende typen kantoorvestigingen, op basis van hun bedrijfstak, ruimtelijke oriëntatie en het internationale reisgedrag van hun werknemers. Er blijken grote verschillen te zijn tussen de locatiekeuzes van deze typen kantoren. Voor de locatiekeuzes in het referentiescenario is de bedrijfstak de meest onderscheidende factor, zowel op een interregionaal als intraregionaal niveau. Echter, voor de reactie van locatiekeuzes op een verandering in HST-bereikbaarheid zijn de aan bereikbaarheid gerelateerde factoren belangrijker. Ten eerste heeft de ruimtelijke oriëntatie van een kantoorvestiging vooral een invloed op een intraregionaal niveau en minder op een interregionaal niveau. Daarnaast is de gevoeligheid voor HST-bereikbaarheid duidelijk groter, op zowel een intraregionaal als een interregionaal niveau, als een kantoorvestiging werknemers heeft die regelmatig internationale zakenreizen maken.

8 Conclusies en discussie

8.1 Conclusies

Op basis van de resultaten van deze studie kunnen antwoorden gegeven worden op de onderzoeksvragen die aan het begin van dit proefschrift gesteld zijn.

De eerste vraag had betrekking op de gevolgen van HST-diensten voor potentiële bereikbaarheid. Voor bereikbaarheid is in dit proefschrift een tweedeling gemaakt tussen centraliteit (de locatie in het transportnetwerk ten opzichte van potentiële herkomsten/bestemmingen) en connectiviteit (de toegang tot een transportnetwerk); potentiële bereikbaarheid richt zich op het eerstgenoemde aspect.

Voor potentiële bereikbaarheid van forenzen is geconcludeerd dat het effect van HST gering is. Dit komt doordat hiervoor korte afstanden dominant zijn. Bereikbaarheid per auto en bus/tram/metro is belangrijker voor forenzenverkeer. Voor zakenreizen zijn HST-diensten meer van belang, maar specifiek voor langeafstandsreizen.

De tweede onderzoeksvraag betreft de invloed van treinbereikbaarheid op de locatiekeuzes van kantoren. Hiervoor is geconcludeerd dat zowel centraliteit als connectiviteit van belang zijn. Potentiële bereikbaarheid voor forenzenverkeer kan gezien worden als de omvang van de arbeidsmarkt, voor zakenreizen als de omvang van de afzetmarkt. Voor locatiekeuzes zijn de zwaartekrachtindicator voor forenzenverkeer en de contourindicator voor zakenreizen significant; deze laatste alleen voor kantoorvestigingen met een nationale of internationale oriëntatie.

Naast centraliteit is ook connectiviteit van belang voor locatiekeuzes. Hieruit blijkt dat niet alleen reistijden en -kosten maar ook aspecten zoals imago, perceptie van bereikbaarheid, optiewaarde en/of keuzewaarde een rol kunnen spelen in the effect van bereikbaarheid op locatiekeuzes. De relevantie van het imago-effect blijkt verder uit de telefonische interviews en uit het SC-experiment.

De derde onderzoeksvraag is beantwoord aan de hand van de scenariostudie. Voor de HSL-Zuid is geconcludeerd dat een HST-verbinding steden in beperkte mate beter concurrerend maakt voor nationaal en internationaal georiënteerde kantoorvestigingen. Toch heeft HST-connectiviteit een groter onderscheidend vermogen op een intraregionaal niveau dan op een interregionaal niveau. HST-connectiviteit is echter niet vaak een doorslaggevende factor voor de locatiekeuzes van kantoren, zelfs niet voor kantoren die zich dicht bij een HST-station vestigen.

Voor de resultaten hebben de hoogte van de HST-toeslag en de keuze tussen Amsterdam centraal station en het station Amsterdam Zuid/WTC als station voor HST-diensten over de HSL-Zuid een beduidende invloed. Het additionele effect van een HST-verbinding over een Zuiderzeelijn of Hanzelijn is daarentegen klein.

8.2 Spoorweginfrastructuur en land-use/transport interaction

Na meerdere decennia met hogesnelheidslijnen zijn de indirecte effecten nog steeds niet geheel duidelijk. Deze effecten blijken erg afhankelijk van de specifieke omstandigheden van de lijnen, zoals ook het geval is voor de HSL-Zuid. Vergeleken met andere hogesnelheidslijnen zijn voor de HSL-Zuid relatief korte afstanden belangrijk. Volgens de vervoersprognoses voor de HSL-Zuid (zie Rietveld *et al.*, 2001) gaat het voor het grootste deel van de verwachte reizigers om binnenlands verkeer. De HSL-Zuid concurreert daardoor meer met de auto in plaats van met het vliegtuig. Dit heeft ook gevolgen voor het effect op potentiële bereikbaarheid: concurrentie van de auto beperkt het effect van de HSL-Zuid op de totale bereikbaarheid.

Hogesnelheidslijnen worden vaak geassocieerd met de internationale competitiviteit van steden. Het onderzoek dat beschreven is in dit proefschrift toont echter aan dat de onderlinge concurrentie tussen Amsterdam en Rotterdam en hun concurrentie met andere Nederlandse steden minstens zo relevant is. De HSL-Zuid leidt tot een grotere polarisatie van kantoorwerkgelegenheid in de Randstad. Daarnaast hebben HST-diensten een grote invloed op de aantrekkelijkheid van verschillende locaties binnen de steden met een HST-aansluiting, al zijn voor de uiteindelijke ontwikkeling van deze locaties vooral ook aanbodsfactoren van belang.

Dit proefschrift richt zich op een belangrijk onderwerp binnen de theorie van LUTI: de invloed van bereikbaarheid op locatiekeuzes. De aandacht is hierbij specifiek uitgegaan naar de rol van treinbereikbaarheid. Een belangrijk onderwerp hiervoor blijkt de segmentatie van economische activiteiten, aangezien er aanzienlijke verschillen bestaan in hoe de beslissingsmaker van kantoren het belang van treinbereikbaarheid beoordelen. De bedrijfstak is een veelgebruikt segmentatiecriterium, onder andere vanwege de databeschikbaarheid. Het huidige proefschrift laat zien dat de bedrijfstak echter slecht in staat is om de variatie in de waardering van treinbereikbaarheid te representeren. Aan bereikbaarheid gerelateerde factoren die afgeleid kunnen worden van specifieke vragenlijsten blijken hier beter toe in staat.

Een ander onderwerp is het belang van subjectieve factoren voor locatiekeuzes. De nabijheid van een spoorwegstation kan leiden tot de perceptie van een goede bereikbaarheid. Daarbovenop komt dat het imago of de status van een dergelijke locatie beter kan zijn. Dit proefschrift heeft verschillende indicaties aangedragen dat een imago-effect relevant is in de context van hogesnelheidslijnen. Vanwege de verwachte meerwaarde van een locatie met een hoge status in combinatie met een HST-station steunt dit resultaat het overheidsbeleid voor de herontwikkeling van de locaties rond de Nederlandse HST-stations (de ‘nieuwe sleutelprojecten’). Hieraan gerelateerd zijn de optiewaarde en keuzewaarde van treinconnectiviteit. Het daadwerkelijk gebruik van de trein voor reizen lijkt niet hoog genoeg om via potentiële bereikbaarheid het aantal kantoren op stationslocaties te verklaren. Uit deze aspecten blijkt dat de invloed van transport op *land-use* niet alleen via reistijden, -kosten en dergelijke gaat, maar ook via connectiviteit.

Een belangrijk aspect voor de ruimtelijke effecten van hogesnelheidslijnen is het onderscheid tussen ruimtelijke schalen. In dit proefschrift is een expliciet onderscheid gemaakt tussen de *inter*regionale en *intra*regionale schaalniveaus. De conclusie dat op het intraregionale niveau de effecten duidelijker waarneembaar zijn dan op het interregionale niveau, komt deels door het uitmiddelen van lokale effecten rondom station als grotere geografische eenheden gebruikt worden en deels door de ruimtelijk hiërarchische structuur van locatiekeuzes. Dit laatste effect is interessant aangezien het impliceert dat kantoorwerkgelegenheid in zekere mate gebonden is aan hun regio. Voor hogere schaalniveaus dan in dit proefschrift zijn geëvalueerd wordt eveneens een ruimtelijke hiërarchie verwacht, onder andere omdat daarvoor zogenaamde grenseffecten of barrière-effecten van belang zullen zijn.

Een laatste onderwerp dat hier behandeld is, is de afbakening van regio's. In dit proefschrift is uitgegaan van een indeling in COROP-regio's, omdat deze afbakening gebaseerd is op de functionele afhankelijkheid van locaties. De indeling is echter constant, terwijl in de HST-literatuur geopperd is dat hogesnelheidslijnen functionele regio's kan veranderen (Blum *et al.*, 1997). Deze verandering van regio's zou plaatsvinden doordat voorheen van elkaar geïsoleerde stedelijke regio's nu qua reistijd binnen elkaars bereik liggen. Gezien de beperkte relatieve toename die voor potentiële bereikbaarheid gevonden is, wordt voor het geval van de HSL-Zuid niet verwacht dat een dergelijk effect relevant is.

8.3 Implicaties voor beleid

Op basis van het onderzoek dat beschreven is in dit proefschrift kunnen op enkele onderwerpen aanbevelingen voor beleidsmakers gegeven worden. Ten eerste is dit het gebruik van methoden om voorstellen voor infrastructuur te evalueren. Het gebruik van geavanceerde ruimtelijke modellen voor de evaluatie van de meest recente voorstellen voor HST-verbindingen in Nederland wordt gezien als een positieve ontwikkeling. Er wordt aanbevolen om dergelijke modellen te blijven gebruiken voor HST-projecten.

In de context van stedelijke ontwikkeling benadrukken de resultaten in dit proefschrift het belang van imago voor de ontwikkeling van HST-stationslocaties. Als verder onderzoek de versterkende relatie tussen HST-bereikbaarheid en de kwaliteit van de omgeving kan bevestigen dan kunnen projecten zoals de nieuwe sleutelprojecten inderdaad extra kantoorwerkgelegenheid aantrekken, waaronder kantoren die anders weinig gevoelig zijn voor HST-bereikbaarheid. Het ondersteunen van de nieuwe sleutelprojecten lijkt daarom een goed beleid van de Nederlandse overheid. Maar het zou gezien de beperkte markt ook kunnen leiden tot een overmatig aanbod van kantoren op de vijf HST-locaties in de Randstad.

Daarnaast wordt aanbevolen om meer aandacht te geven aan de gevolgen van HST-stations voor alternatieve locaties in regio's met een HST-verbinding. In de Randstad zal in het kader van de nieuwe sleutelprojecten een toename plaatsvinden van hoogwaardige kantoorruimte rond stations. Dit kan leiden tot een verlies van kantoorwerkgelegenheid voor concurrerende locaties, waar het huidige beleid en beleidsgericht onderzoek rond HST-projecten weinig aandacht voor lijkt te hebben. In andere Nederlandse regio's (het oosten rond Arnhem en het zuiden rond Breda) is een zelfde ontwikkeling mogelijk. Dit zou ook van belang kunnen zijn in het kader van de discussie rond de Zuiderzeelijn en Hanzelijn, die op het moment van dit schrijven actueel is.

Tenslotte kan mede op basis van dit proefschrift gesteld worden dat beleidsmakers geen al te hooggespannen verwachtingen moeten hebben van de invloed van HST-verbindingen op economische ontwikkeling. De indirecte effecten van het HST-projecten zijn immers naar verwachting grotendeels distributief in plaats van generatief.

8.4 Aanbevelingen voor verder onderzoek

De aanbevelingen voor verder onderzoek richten zich op drie terreinen, namelijk (1) onderzoek naar hogesnelheidslijnen, (2) onderzoek naar treinbereikbaarheid, en (3) onderzoek naar LUTI. Voor hogesnelheidslijnen ligt een eerste onderwerp van verbetering op de uitbreiding van het ruimtelijke-interactiemodel. Ten eerste kan dit door een onderscheid te maken tussen hogesnelheidstreinen en conventionele treinen om verschillen in de waardering van het reizen met HST en conventionele treinen anders dan reistijd en -kosten tot uitdrukking te laten komen. Een tweede uitbreiding kan zijn om ook internationale reizen toe te voegen aan het ruimtelijke-interactiemodel. Voor beide uitbreidingen zijn additionele databronnen nodig.

Een tweede onderwerp voor hogesnelheidstreinen zijn de indirecte effecten. Dit proefschrift heeft aangetoond dat een micro-economisch raamwerk van locatiekeuzes goed werkt als daarbij onderscheid wordt gemaakt tussen de intraregionale en interregionale niveaus. Het advies wordt gegeven aan studies die de indirecte effecten van hogesnelheidstreinen bestuderen om expliciet rekening te houden met intraregionale distributieve effecten. Ten slotte kan verder onderzoek zich ook richten op de lokale transporteffecten van hogesnelheidsverbindingen, bijvoorbeeld door congestie op wegen rondom HST-stations.

Voor potentiële bereikbaarheidsindicatoren per trein kunnen verschillende verbeteringen worden doorgevoerd. Een eerste verbetering is het uitgebreider modelleren van de keuze van de begin- en eindstations van een treinreis en van routekeuze voor treinreizen in het onderliggende ruimtelijke-interactiemodel; recent beschikbaar gekomen data van het Mobiliteitsonderzoek Nederland biedt mogelijkheden hiervoor. Een tweede verbetering is mogelijk indien voor de reisgegevens van zakenreizen en woon-werkreizen de kenmerken van de werkgever bekend zijn. In de context van de locatiekeuzes van bedrijven en instellingen kunnen daarmee per segment van werkgelegenheid specifieke bereikbaarheidsindicatoren berekend worden.

Verschillende verbeteringen zijn daarnaast mogelijk voor specifiek zakelijke reizen. Zakenreizen nemen weliswaar een klein deel van alle reizen voor hun rekening, maar zij kunnen vanwege hun invloed op de locatiekeuzes van bedrijven wel belangrijk zijn voor de ruimtelijk-economische effecten van infrastructuur. Een verder onderscheid tussen motieven voor zakenreizen kan meer informatie verschaffen in de variatie van afstandsverval tussen reizigers. Ook het expliciet rekening houden met de mogelijkheid om zakenreizen in ketens uit te voeren kan voordelen opleveren.

In de context van LUTI zijn er voor HST twee terreinen waarop verder onderzoek wordt aanbevolen. Ten eerste zijn er enkele aanvullende aspecten van LUTI die onderzocht kunnen worden, zoals de invloed van HST-bereikbaarheid op de locatiekeuzes van huishoudens en niet-kantoor werkgelegenheid en op de prijs van onroerend goed. Om ook de gevolgen van HST voor indirect beïnvloede elementen uit LUTI te bestuderen wordt aanbevolen om een locatiekeuzemodel zoals ontwikkeld is in dit proefschrift te integreren in een breder LUTI-model.

Ten slotte is verdere studie ook mogelijk naar alternatieve specificaties van het kantoorlocatiekeuzemodel. Andere mogelijkheden zijn onder andere een nested logit model met nesten op basis van locatietype (bijvoorbeeld stationlocaties versus andere locaties) in plaats van of in combinatie met nesten van regio's. Ook een mixed logit vorm heeft theoretische voordelen, vooral als het toegepast wordt in een model met microsimulatie zoals steeds vaker gebruikt wordt in LUTI-modellen.

Notes

1 Office establishments are in this thesis also shorter referred to as 'offices'. Hereby thus the establishment is meant and not the office building, unless this is explicitly mentioned.
2 Although these decision are often dependent on longer-term habits or relationships.
3 Also known as ITLUP in combination with a transport model.
4 Includes exogenous growth in transport volume.
5 Note that Kwan *et al.* (2003) assign a somewhat different meaning to the term 'centrality': being centrally located in absolute space. The meaning of centrality used in this thesis is referred to by Kwan *et al.* (2003) as 'accessibility', which in our view ignores the connectivity aspect of accessibility.
6 In literature stated choice analysis is also referred to as choice-based conjoint analysis.
7 In this way it is attempted to avoid that response is biased due to the omission of important attributes, which is a drawback of bridging designs (Oppewal *et al.*, 1994).
8 NLogit version 3.0.3 (Econometric Software, 2003).
9 Note that in many cases highly correlated attributes cannot be included as explanatory variables in the same model. In this case, however, it is allowed to include the linear, quadratic and cubic terms of station access time in the same model, because these form together a single polynomial function (and do not have a meaning on their own) and because in the design of the SC experiment specific account is taken for inclusion of this polynomial function.
10 In a NL model these terms would have an extreme value distribution that is hereby approximated by a normal distribution.
11 Eight SC observations and one RC observation, the latter being replicated to a total of eight observations to match the number of SC observations.
12 Although theoretically spatial interaction could also apply to disaggregated behaviour, to the author's knowledge in literature the term 'spatial interaction models' usually refers to models that are applied to aggregated flows.
13 For zones at the border of the study area less neighbouring zones are present in the model, leading to an underestimation of their accessibility; see also Geurs and Ritsema van Eck (2003).
14 Since 2004 the OVG travel survey is replaced by the 'Mobiliteitsonderzoek Nederland' (MON) travel survey. The data used in this research are from the year 2000 survey, before the implementation of this replacement.
15 By convention, for commuting trips the home location is always seen as the orgin and the work location as the destination.
16 In literature sometimes referred to as a pre-distribution modal split model as opposed to the post-distribution modal split model of Equation 4.4. This terminology dates back to the

time that conditional logit models were used for this model instead of nested logit models with full-information maximum likelihood estimation.

17 In that case V=βx_{ij}-β, but the constant term has no effect in the multinomial logit model if applied to all choice options.

18 The current Amsterdam-Brussels-Paris and Amsterdam-Cologne-Frankfurt services that make use of conventional track within the Netherlands.

19 Percentage of relevant offices

20 Percentage of revealed choice respondents

21 No weighing is applied for the figures in this paragraph.

22 Some offices use other terms, such as 'clients', but for simplicity this type of contacts is just referred to as 'customers' in this thesis.

23 As a criterion the office should have either many employees who have face-to-face contacts with customers or employees who frequently have face-to-face contacts with customers.

24 Offices that had not made a location decision in more than 41 years are omitted, as well as offices that had relocated in 2003 because that year had not been completed by the time of the interviews.

25 In this case it seems reasonable to assume that timetable data are consistent with the 'real' value for station level-of-service indicators.

26 Recall from chapter 3 that the linear, quadratic and cubic terms together form a polynomial function and do not have a meaning on their own.

27 The log-likelihood of the MNL and RPL models can be directly compared, because the MNL model is a special case of the RPL model (i.e. the case where all random parameters have a standard deviation of zero).

28 For the sequential approach the reported t and P values are the values from the separate SC and RC sub-models. Parameters for SC attributes are corrected for the scale parameter.

29 For the near future a large rescheduling of train services in the Netherlands is foreseen. This includes the abolition of existing services and the implementation of new services. For the topic of the current chapter it is relevant that it is assumed that more train services will stop at Amsterdam South/WTC station and less on Amsterdam central station.. The effect of these changes is thus not studied in this scenario study.

30 The ticket price for domestic use of Thalys services (second class) is a fixed € 15 for all origin-destination combinations within the Netherlands. However domestic use of the Thalys seems not common practice, among others because, unlike ICE supplements, Thalys tickets are not available from standard train ticket dispensers. Furthermore on Thalys seat reservation is compulsory. Therefore the € 2 supplement seems more plausible for domestic services.

31 Please note that a high uncertainty is involved in the accessibility scores for individual zones. Attribute values are averaged over the zones, so that the potential accessibility of a location depends on the size of its zone: in large zones the accessibility scores show less extremes than if the same zones were subdivided into smaller zones. The figure can therefore only be used to examine general tendencies for the accessibility effect of fare supplements.

32 Note that transfers cost time (valued twice the in-vehicle time) but no money, see chapter 3.

33 The specification of the fare addition as a percentage of the basic train fare is of issue here; a fixed addition per trip can yield a different result per origin-destination pair.

34 This is because of the logarithmic conversion of train frequency in the location choice model.
35 In the model this is represented by a nested logit structure of intraregional versus interregional location choice.
36 A logarithmic conversion that is applied to train frequency embeds this effect in the model.
37 In the logit function the exponential form represents this effect.

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Curriculum Vitae

Jasper Williger s was born in Wijk bij Duurstede on January 14, 1979. In 1997 he received his 'Atheneum' diploma from the Revius Lyceum in Doorn. He studied 'Science and Policy' at Utrecht University where he received his propadeuse diploma (cum laude) in 1998 and his MSc degree in 2001. He got involved in the transport field with his master thesis, which was based on a nine-month internship at the Dutch National Institute for Public health and the Environment (RIVM) in Bilthoven. At the RIVM he subsequently served a temporary contract. In February 2002 he started as a PhD student at the Urban and Regional research centre Utrecht of Utrecht University, Faculty of Geosciences. Since February 2006 he works as an analyst at Rand Europe in Leiden.