Future Urbanization Patterns:
In the Netherlands, under the Influence of Information and Communication Technologies

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Future Urbanization Patterns: In the Netherlands, under the Influence of Information and Communication Technologies

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Saim Muhammad

1 Introduction

1.1 Subject and background

Human settlements were formed in response to the social and economical needs. In the early history humans started living together near water bodies, as those were the only areas, having better access to resources. This first wave of accessibility was focused on food gathering and production, like crop cultivation and cattle raising. Then, after a long journey of evolution, during the nineteenth century with the invention of the steam engine, the industrial revolution took place. With the introduction of ships and trains, the accessibility took the form of transportation of raw material to processing facilities and then to customers. This development revolutionized the human settlements, as people felt freedom to live far from natural resource areas, but still they were obliged to live within a commutable distance from their workplace. Later in the post-fordist era, this friction of distance has been further reduced with the introduction of trams, buses and cars (Gould 1997).

During nineteenth century, innovations in and broad development of Information and Communication Technologies (ICTs) started. Samuel F.B. Morse in 1835 developed a code to represent letters and numbers (the Morse code). Public use of Morse's telegraph system began in 1844. Then in 1876 Alexander Graham Bell developed the telephone to transmit speech sounds over electric wires, which was a revolutionary invention. By the late twentieth century the telegraph had been replaced in most applications in developed countries by digital data transmission systems based on networked computer technology (termed as Internet) (Cairncross 1998; Britannica 2006).

During last three decades, ICTs have evolved to a level and scale where they can facilitate people to access a wide range of opportunities and facilities. For example: jobs, shopping, education and recreation and many other public and private services. So a virtual space has emerged where the friction of distance and time has to a large extent disappeared. (Mokhtarian 1991; Gould 1997; Martens *et al.* 1999; Mitomo & Jitsuzumi 1999; Shen 2000). Accessing job opportunities in virtual space is termed as telecommuting or teleworking. A telecommuter, generally interpreted as someone with an arrangement to (largely) avoid commuting in physical space. By working at home, or closer to home and communicating to the usual place of work using electronic or other means, instead of physically travelling to a more distant work site (Mokhtarian 1991; Johnston & Nolan 2001). Thus in this age of ICTs, the friction of distance is further loosing its importance. In virtual space, the people can access opportunities, in a matter of seconds, which earlier needed travelling of hours in physical space.

In the same manner, teleshopping, telebanking, teleconferencing, telerecreation, e-learning, e-governance and e-medicine are also developed as webservices (Martens *et al.* 1999). So, an information revolution is on its way, which is affecting daily activities of the people, and will result in changed meanings of distance and an enhanced accessibility of the people. (Mokhtarian 1988; Castells 1992; Handy & Mokhtarian 1996; Mokhtarian 1998; Shen 1998a; Mitomo &

Jitsuzumi 1999; Scott 2000; Shen 2000; Golob & Amelia 2001; Graham 2004). This technological revolution of historic proportions is transforming the fundamental dimensions of human life: time and space (Gould 1997; Castells 2000). New scientific discoveries and industrial innovations are extending the productive capacity of working hours while superseding spatial distance in all realms of social activity (Ruchelman 2002).

Generally, demographic development, economic development (in particular agglomeration and urbanization economies) and advancements in transport and communication technologies are considered the main forces driving urban change (Castells 1989; Carter 1995). Hence, this technological revolution, like the agriculture and industrial revolution, will again change the urban landscape (Nilles 2001; Mitchell 2004). In some periods this change is gradual and according to trends. In other periods urban change accelerates and includes structural transformations, which might be the case in this age of ICTs. Thus, the unfolding promise of information technology opens up unlimited horizons of creativity and communication, inviting us to the exploration of new domains of experience, from our inner selves to the outer universe, challenging our societies to engage in a process of structural change (Castells 1989).

1.2 Theoretical framework and scientific relevance

With the emergence of the new virtual space, based on ICTs, along with the existing physical one, a hybrid space (comprising of a space of flows and a space of places (Castells 2000)) is established, where the meanings of distance will be modified. On this paradigmatic change, different schools of thought have produced thought provoking ideas. Well known examples are: 'death of distance' (Cairncross 1998), 'may be the death of distance but not end of geography' (Malecki & Gorman 2001), 'the rise of new places' (Wilson *et al.* 2001), 'feed off and fuel' (Graham & Marvin 2000), and 'old script replayed with new actors' (Mitchell 2000).

Post-industrial theorists (or futurists) predict that the 'death of distance' will lead to prevailing urbanization in the form of low-density urban fields dominated by electronic cottages (Toffler 1980; Shen 2000; Ellen & Hempsted 2002). According to Webber (2004), 'spatial proximity continues to be considered a necessary condition, but it is now becoming apparent that it is the accessibility rather than propinquity aspect of place that is the necessary condition'. As accessibility becomes further freed from propinquity, cohabitation of a territorial place, whether it be neighbourhood, a suburb, a metropolis, a region, or a nation, is becoming less important to the maintenance of social communities.

The impact of ICTs on urban development has emerged as an interesting and relevant new frontier in urban research (Castells 1989; Indovina 1999; Kotkin 2000; Mitchell 2000; Wheeler *et al.* 2000; Gepts 2002; Castells 2004). But predictions about complex spatial systems need more thorough thought and research. In a structuralist analysis, Castells (1989) postulates a change in society towards an informational mode of production, characterized by information processing as the dominant activity. The clustering of high-tech industries in technopoles with innovative production milieus (Castells & Hall 1994) and the spatial rearrangement of urban activities as a consequence of emerging information networks (flows, nodes and hierarchies, also named 'space of flows', 'cyberspace' or 'infobahn') are geographical outcomes of such an information society. This implies a new urban 'spatial logic' based on new dialectics between centralization/concentration and decentralization/dispersion processes.

Plaut (2004), Kotkin (2000) and Indovina (1999) postulate from an urban point of view, optimistic prospects by stressing the fact that many new technologies (transportation, communication, information) in fact reinforce the 'raison d'être' of cities as they increase rather than decrease the need for physical proximity. ICTs give great opportunities to revitalize cities and improve city life. While city regions may continue to grow, their internal structure will change (for example with respect to the role of the city centre) as will their relationships with other city regions (Graham & Marvin 1996).

A crucial issue in the theoretical discussion on the relationship between ICTs and urban development is the question whether and how physical transportation will be replaced by telecommunication. In a 'space of places' cities are transportation nodes and centres, but what will become the role of cities in a 'space of flows'? Graham and Marvin (2000) refer to a British study that shows that 'transport and telecommunications actually feed off and fuel, more than simply substitute for each other'. The relationships are complementary. They argue that urban economies, urban cultures and urban communities will remain active and vibrant alongside and in relation with information economies, cyber cultures and virtual communities. As a consequence, metropolitan dominance will remain or even increase.

Beyers (2000), elaborates the urban consequences of use of ICTs. His arguments are based on empirical research and his conclusion is that 'human space' will dominate 'cyberspace'. Producer and consumer services based on ICTs will become the most important sector of the 'new economy'. This means new bases for locational choice of economic activities. Location margins will widen and location decisions will be more dominantly based on place qualities and personal preferences. Beyers (2000) expects 'the selection for most enterprises of an urban setting while a growing undercurrent of businesses seek out sites in exurban locations'. This view is supported by Weterings (2006), Van Oort *et al.* (2003a), Mokhtarian and Bagley (2000) and Mugerauer (2000) by their finding that for ICTs' companies, their employees utilitarian factors (house prices, airport accessibility etc.), social factors (interpersonal relationships) and amenities (quality of life) are of about equal importance and very much interlinked in location decisions. In residential location preferences social factors and amenities can also be expected to gain importance. The conclusions of the Office of Technology Assessment (OTA 1995) of the Congress of the United States were in line with these observations. OTA expects mid-size (second tier) metropolitan regions, lower-cost regions and higher-amenity regions to benefit the most. But OTA also points at intra-metropolitan differences. Inner city regions (excluding the central business district, but including inner suburbs) are expected to weaken. Outer suburbs and exurbs will benefit from continuing urban dispersion.

The aforementioned developments require new theories and models of urban form, polarization and location (Handy 1996; Hall 1999; Beyers 2000; Mitchell 2000; Moss & Townsend 2000; Van Wee *et al.* 2001). A number of hypotheses from this review of early scientific research into the relationship between the 'information society and the new economy' and the 'new urban geography' can be drawn:

- ICTs are expected to complement and interact with physical transport and face-to-face contacts to give distance and accessibility new meanings.
- Quality aspects of places (social characteristics of and amenities in local and regional environments) will become more important in location decisions and subsequent urban change and growth patterns.

- There are no signs that cities (city regions) will loose their dominance, but current urban hierarchies will change in nature.
- However, most profound changes in the urban landscape will most likely occur within urbanized regions, especially with respect to specialized centers and districts and edge development.

This research will analyze these hypotheses for the Netherlands. In the Dutch society, ICTs appear to have a spatial character somewhere between existing structure and entirely footloose. These two poles are often erroneously presented as the only development paradigm (Van Oort *et al.* 2003a). Hence empirical evidence is required to improve understanding of the spatial impacts of ICTs on urbanization in the Netherlands.

1.3 Status of use of ICTs in the Netherlands

Use of ICTs is continuously growing in the Netherlands. Eighty percent of the Dutch population has access to Internet, of which sixty percent have broadband Internet connection. More than 90 percent of all businesses own one or more computers. The entire economy relies on the support of ICTs (Statistics Netherlands, CBS 2005a). For its part, the ICTs sector has developed to become an important economic activity over the past decades. Between 1995 and 2000, its share of the total economy (in production value) grew from 4.5 percent to almost 6 percent (Raspe & Van Oort 2004). Thus ICTs have had an undeniable influence on Dutch society.

In the Netherlands, it is the ICTs' services sector that has accounted for most of the economic growth in the ICTs industry as a whole. Between 1995 and 2002, there was a particularly marked increase in the employment volume within ICTs' services, with the number of people working within the sector rising by 77 percent, from 138,000 to more than 288,000 (Statistics Netherlands, (CBS 2005a)). This increase is considerably larger than the growth in employment volume for the ICTs production sector (stable at 68,000 since 1995).

The transition of the Dutch economy towards one based on services and information is reflected in an increase in the number of people whose daily work is conducted at a computer monitor. These are the potential telecommuters. In the mid 1990s, approximately half the active working population fell into this category. By 2001, the figure had increased to over sixty percent (Statistics Netherlands, (CBS 2001)). There has also been a clear intensification in the (existing) use of ICTs: the volume of Internet data traffic increased more than one hundredfold between 1997-2002 (Statistics Netherlands, (CBS 2003)). The Netherlands has a continuous growth of telecommuting (Hamer *et al.* 1991; Johnston & Nolan 1997; Johnston & Botterman 1998; Johnston & Nolan 2000; Bates & Huws 2001; Huws & O'Regan 2001; Johnston & Nolan 2001; Johnston & Nolan 2002; TWF 2004) with highest percentage of telecommuters, viz. 21% of the total working population as compared to the US: 17% and the EU average: 7% (Todd 2006).

Thus the Dutch society is standing on the threshold of a new wave of socio-economic developments brought about by ICTs (Hajer & Zonneveld 2000). Some believe that it has already been engulfed by that wave and others expect that ICTs could well bring about major changes to the spatial-economic structure of the Netherlands, and in the behaviour and functioning of Dutch households and businesses. Much has been postulated about the effects of use of ICTs for telecommunication as mobility-restricting, about effects of e-commerce and e-business as footloose companies and about effects of telecommuting as freedom to live in green environment away from the existing work locations. (Lemberg 1996; Havyer & Zonneveld 2000; Van Geenhuisen & Nijkamp 2001; MuConsult 2003; Van Oort *et al.* 2003a; Raspe & Van Oort 2004). But still the empirical insight about the effects of use of ICTs on future urbanization patterns is missing.

1.4 Objective of the study

In this age of information technologies, the spatial effects of ICTs on future urban and regional land use are a major concern for land-use planners and policy makers. Many scholars and politicians assume that the information and communication revolution (or rapid evolution) will have a profound and structural impact on urban development. Urban theories will have to be changed or adjusted and policies have to be revised. This study wants to contribute to this scientific and policy debate by analyzing the retrospective and prospective effects of ICTs on job accessibility, place quality and urbanization patterns by applying state-of-the-art geo-information data sources and research tools. Hence there is a need to explore, that what will be the new meaning of distance in hybrid space and how will it affect the accessibility of people for their jobs. Earlier accessibility for opportunities was measured as a function of travel time or distance (Hansen 1959; Sheppard 1984; Shen 1998a; Geurs & Ritsema van Eck 2001), now what will be new measure of accessibility in the hybrid space?

In the Netherlands, along with geographical inertia (existing urban patterns and structures, territorial space limitations) and spatial land-use policies, job accessibility has been considered an important driver for allocation of residential, commercial and industrial land-use (De Nijs *et al.* 2001; Engelen *et al.* 2002; Veldhuisen *et al.* 2003; Verburg *et al.* 2004). Among these drivers, job accessibility is being changed with the use of ICTs, which will influence the place quality for the allocation of different land use (Shen 2000). In this research, the extent to which the new developments (in particular telecommuting) caused by ICTs are indeed likely to bring about major changes in the job accessibility in the hybrid space will be analyzed. Will this change in the job accessibility have profound effects on residential relocation in the Netherlands, or will the information era merely serve to enhance the efficiency and effectiveness of existing residential location patterns?

Thus the objective of this research is 'to provide an insight into the possible effects on urbanization patterns of the changed meaning that distance (accessibility) and place quality (land use suitability) are assumed to get under the influence of use of ICTs for telecommuting'.

1.5 Research questions

In order to achieve the main objective, this research is designed to answer these questions:

a. What will be the new meaning of distance in this age of ICTs?
b. How can job accessibility surfaces be generated that reflect the new meaning of distance in the information society?
c. What can be the effects of use of ICTs for job accessibility (by telecommuting) on residential locational preferences?

d. How can suitability surfaces for future residential areas be generated that reflect the new meaning of place quality in the information society?
e. What possible changes can be expected in future urbanization patterns under the influence of ICTs in near future?
f. What will be the implication of these possible urbanization patterns on future spatial land-use policies?

1.6 Research design and methodology

The methodology adopted for studying the effects of ICTs on the future urbanization patterns in the Netherlands, is shown in Figure 1.1. The methodology includes the use of two scenarios, one for the Physical Space (Physical Space Scenario (PSS)), in which, drivers responsible for land use change in physical space will be considered. The second one is for Hybrid Space (Hybrid Space Scenario (HSS)), in which, the drivers effecting land use in both physical and virtual space will be taken into account. The drivers are present in both scenarios, but with a different influence.

ICTs are facilitating to the people to communicate with others and access opportunities in virtual space (telecommute, teleshop, e-recreation, e-learn etc.), along with the activities in the long existing physical space. Thus in HSS, not only the accessibility of the people to their opportunities will be affected but also their other socio-economic characteristics, which will finally affect their residential location choices. The interaction in the virtual space by using ICTs may make them to move in the physical space to have face to face interaction or other way around. For example, in case of telecommuting, the people will be free to have their residence located in the environment of their own choice away from their existing place of work and residence. The time saved by telecommuting might be used for social or recreational activities (Marcus 1995; Mokhtarian 1998; Mokhtarian & Krishna 1998; Martens *et al.* 1999; Mitomo & Jitsuzumi 1999). In order to find out the effect of ICTs on the meaning of distance, a literature review will be performed. Based on this review a model to measure job accessibility for PSS and HSS will be designed and applied.

By taking into consideration the direct and indirect effects of ICTs on the allocation of future land use, a conceptual model for future land use suitability will be designed. On the basis

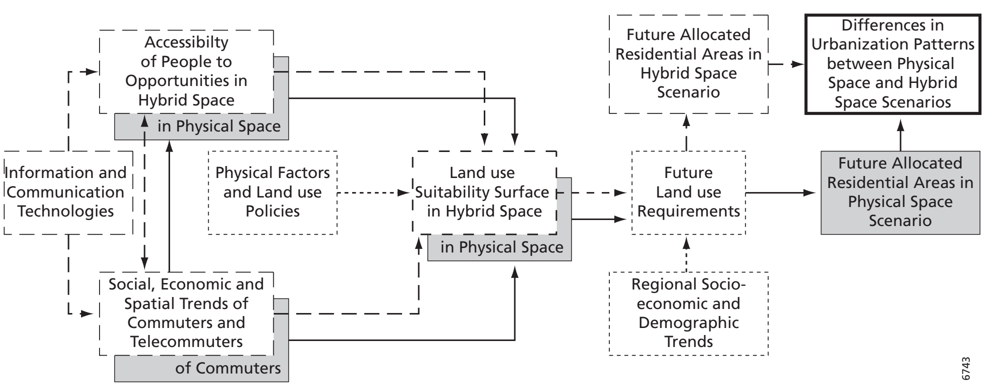

Figure 1.1 Research methodology

of this conceptual model, residential land-use projection model for the Netherlands will be developed. In this model, along with physical factors and future land use policies, the measured accessibility for job, social and recreational areas and land use transition potential computed by Cellular Automata (CA) model will be used to compute land use suitability surfaces. The future land requirements for residential use estimated in existing recent applications of land use models by using the regional socio-economic growth patterns in the Netherlands will be adopted to model future allocation. By applying these future residential land-use requirements on the computed residential land-use suitability surfaces, the future residential areas will be allocated for the Netherlands. A comparable process will be adopted for both PSS and HSS, but for PSS without taking into consideration the effects of ICTs. To find out the differences in urbanization patterns, the final outcome from both these scenarios will be analyzed by using spatial statistical tools.

This research will analyze the retrospective (for the years 1986, 1995 and 2000, the change in job accessibility) and prospective (for the years 2020) effects of ICTs on the job accessibility and future urbanization patterns (for the years 2030) in the Netherlands. The year 1986 was selected, as it was the early period of use of ICTs in the Netherlands, however the introduction and use of modern ICTs really took off in the 1995-2005 period. For the future the year 2020 was selected for the job accessibility, as the projection of the use of ICTs for telecommuting along with the travel time for the Netherlands were available for that year. The year 2030 for future urbanization projection was adopted to be able to compare the results of this study with the future urbanization projection performed by the Netherlands Environment Assessment Agency for that year.

1.7 Thesis structure

As shown in Figure 1.2, first of all the effects of ICTs on the meaning of distance are explored by taking into consideration the ideas and hypotheses of different schools of thought. Meanings of distance for the allocation of residential areas, concerns the most in the form of spatial separation between the location of jobs and job seekers, termed as job accessibility. Hence in *chapter two*, new meanings of distance for job accessibility in the age of ICTs are explored and a conceptual model is presented.

In *chapter three*, in order to analyze the change in job accessibility under the influence of ICTs in the Netherlands, among different job accessibility measures, two models are selected and implemented for the Netherlands for the years 1986, 1995, 2000 and 2020 for both PSS and HSS. For measuring job accessibility, the distance decay parameter's value matters a lot. In the HSS, its value is relaxed, as mean trip length is enlarged. How distance decay parameter's value, is affected by the mean trip length and the shape of the area concerned, are discussed in *chapter four*.

Along with job accessibility, other socio-economic drivers and spatial trends for the allocation of residential areas are also being affected. These socio-economic drivers and spatial trends for the allocation of future residences by commuters and telecommuters are studied based on data from the Dutch housing demand survey (Woning Behoefte Onderzoek (WBO) in Dutch), commissioned in 2002 by the Netherlands Ministry of Housing, Spatial Planning and Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (MVROM) in Dutch). The results are presented in *chapter five*.

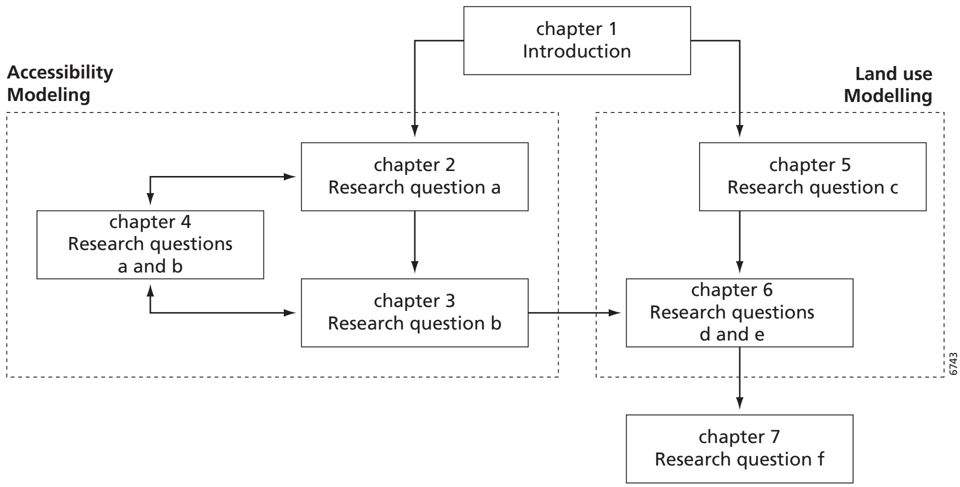

Figure 1.2 Schematic presentation of research

In *chapter six*, by taking into consideration the effects of ICTs on the future residential land-use suitability, a conceptual model is developed, that is implemented in the form of residential land-use projection model. With this model, the future residential areas are projected for PSS and HSS for the year 2030. The future projected residential land-use patterns by PSS and HSS are compared by visual analysis and using spatial statistical tools.

Finally in *chapter seven*, the conclusions about the possible effects of ICTs on future urbanization patterns in the Netherlands and their consequence on the spatial land-use policies are discussed. Further, the scope for future research is described.

2 New Meanings and Measures of Accessibility

Muhammad, S. (2006), New meanings and measures of accessibility in the age of information and communication technologies. Networks and Communication Studies (NETCOM) 20/1-2, pp. 69-90. Copyright © NETCOM Association.

Abstract

The use of Information and Communication Technologies (ICTs) is changing every aspect of human life. People have access to opportunities like jobs, shopping, public and private offices, etc., in virtual space (the space of flows), without facing the friction of distance in physical space (the space of places), which means that there is now a hybrid space. Changes in the way the activities are being conducted in this hybrid space have the biggest impact on the areas of transportation and communication, where the space of places may be substituted, modified, enhanced or result in higher traffic by the space of flows, where physical distance are reduced to nothing. In the past, physical distance was the measure of accessibility, but distance is now taking on a different meaning, resulting in a change in accessibility. In order to measure accessibility in the emerging hybrid space, we need to take the personal characteristics of people and the nature of the opportunities they are seeking into account more than ever before. By doing so, a model to measure accessibility in this hybrid space is developed that suggests that ICTs will enhance the accessibility of people to their opportunities.

2.1 Introduction

The first civilizations saw accessibility in terms of the gathering and production of food, which meant that they generally settled near fertile areas. The second wave of civilizations treated accessibility in terms of transporting raw materials to processing facilities, and from there on to the customer. During the last three decades, and especially the most recent one, society has been inundated with information technologies in a development that is called the information revolution (Castells 2000; Kellermann 2002). The emergence of Information and Communication Technologies (ICTs) has given the concept of accessibility a new meaning, which means it can no longer merely be described in terms of spatial separation, since virtual space has reduced distances (Gould 1997).

Although there was a slump in the global economy after the terrorist attacks in New York on September 11, 2001, the use of ICTs has continued to grow at a steady, albeit with slower pace. Major ICTs' firms will certainly work to reduce the vulnerability of their operations by decentralising their ICTs systems (Townsend 2004). People feel safe and comfortable working at home (telecommuting), shopping at home or somewhere else away from shopping centres (teleshopping) and communicating with each other (telecommunication) in a frictionless and timeless manner, using new forms of ICTs like the Internet, mobile telephones, etc. (Drucker *et al.* 2002).

ICTs are also being used to figure out the best time, route and destinations to travel, to avoid time waste. Students can learn at home (distance learning), taking interactive courses on the Internet. Also, people can consult their doctor online (telemedicine). In addition, in countries like the USA, Canada and the United Kingdom e-government is being established, which means that most of the communication between people and government will take place in virtual space using ICTs.

The world is becoming a global village in real terms, a place where people can access opportunities in virtual space all over the world, without facing the friction of distances or administrative boundaries. All this has changed and will continue to change the way people live and travel. New activity patterns are evolving that will result in new and different types of fragmentation and clustering (Van Oort *et al.* 2003a; Mitchell 2004), and lead to improvements in people's living environments (Vilhelmson & Thulin 2001; Van Oort *et al.* 2003b).

The areas most affected by the use of ICTs are transportation and communication. The question is what the effect will be if people are able to access opportunities using ICTs in virtual space without facing the spatial and temporal constraints, whereas traditionally they could only access those opportunities in physical space, and for instance had to travel. There are various schools of thought with regard to the effects that these developments will have on the physical space, the space of places. Graham and Marvin (2000) argue that communication in virtual space will in part substitute communication in physical space, but that it will also make people to move in physical space, as the virtual contacts will enhance the physical ones.

Cairncross (1998) is of the more extreme opinion that it will lead to what he calls the 'death of distance'. Malecki and Gorman (2001) argue that, even if it does lead to the end of distance, that does not mean that it leads to the end of Geography. According to Wilson *et al.* (2001) the death of distance is mistakenly seen as a vanishing of difference between places as people communicate in virtual space. In actuality, it is not so much the end of distance as it is the emergence of a new space where distance still plays a role, a hybrid space where virtual and physical space come together and become interwoven (Koch 2004).

Human activity in the post-industrial society is becoming increasingly person-based: so economic and other activities are no longer linked to geographic locations (Couclelis 1998). Hence, according to Mitchel (2000), what we see is an old script being played by new actors, with silicon as the new steel and the Internet as the new railroad. Mitchell may be right; as the new actors are playing the same role in different ways, and in a world where distances are becoming less and less important. And it was especially distance that in the past determined the meaning of the term accessibility. It is therefore worthwhile to look at what the effects will be of the developments outlined above in terms of accessibility, taking into account the thought-provoking viewpoints, that were just mentioned.

Much theoretical work regarding the new paradigm is being carried out. This article takes a glimpse at the state of the art in this area, looking in particular at the effects ICTs has on job accessibility. This way of accessing a job from home or a call centre, away from the regular workspace, is usually referred to as distance working (Gray *et al.* 1993) or homework (Hamblin 1995) or telework (Huws *et al.* 1990; Huws & O'Regan 2001) or telecommuting (Nilles 1988; Nilles 1994; Mokhtarian & Bagley 2000). To emphasize the topic of this article, the term telecommuting will be adopted. We start by describing the conventional meaning of accessibility in physical space (commuting), which is based mostly on physical and economic interpretations. Then the affects of ICTs on accessibility (through telecommuting) are discussed, and a model to measure job accessibility in hybrid space is presented.

2.2 What is accessibility

'Accessibility… is a slippery notion… one of those common terms that everyone uses until faced with the problem of defining and measuring it' (Gould 1969).

Accessibility is not a distinct physical entity that is easily counted or measured, it is a concept, a perception, something that we all experience, evaluate, or judge differently (Scott 2000). Accessibility is indeed a relative and contextual notion, and the correct definition largely depends on the scope and context of the investigation. In its broadest conceptual sense, accessibility depends on the performance of the transport network in physical space and on the locational systems (Appert 2004).

It also depends on various short term temporalities (the variability of transport network performance throughout course of the day). In terms of the locational aspects of urban areas, accessibility is the geographic definition of opportunities. Opportunities individuals have to participate in necessary or desired activities or to explore new ones is contingent upon their abilities to reach the right place at the appropriate time and with a reasonable investment of resources and efforts (Couclelis 2000).

Shen (1998b) defines urban space as a whole set of geographical relationships among urban residents and their socio-economic activities. Accessibility is a measure of the strength and extensiveness of these geographical relationships, for instance between home and workplace or shopping centre. Hence, accessibility has a number of different aspects, like physical, social and economical. Generally, accessibility is defined as:

A dictionary definition: "the ease with which one place may be reached by another" (Johnston *et al.* 1994),

A definition related to the geographical aspects: "the potential for interaction, both social and economic. It is determined by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality, and character of activities in each destination" (Handy 1994),

A definition related to the economic aspects: "the log sum of expected utility of all potential destination and mode choices" (Ben-Akiva & Lerman 1985).

These traditional definitions of accessibility focus on physical proximity, which is why three of the major approaches to measuring accessibility are the constraint-based, attraction-based and benefit-based approaches. Constraint-based measurements demarcate the activity locations that are available to an individual, typically from a space-time perspective. Attraction-accessibility measurements assess the trade-off between the attractiveness of destinations versus their interaction costs. Benefit measurements involve a similar trade-off, but they attempt to measure explicitly the benefits accruing to the individuals from a choice set. All three approaches explicitly assume that physical distance is a major structuring factor influencing spatial choices and consequently accessibility (Batty & Miller 2000).

Thus, in physical space accessibility is the potential interaction between places for performing different activities at different times; people use different modes of transport or communication in order to overcome distance. Hence, earlier the following four components were considered to measure accessibility (Geurs & Ritsema van Eck 2001):

Transport component: reflecting the travel time, costs and effort to travel between origin and destination.

Land-use component: reflecting the spatial distribution of opportunities (destinations).

Temporal component: reflecting the time restrictions of individuals and availability of activities at different times of the day.

Individual component: reflecting the needs, abilities and opportunities of individuals.

Now a fifth component has been added: that of ICTs, which allow people to access opportunities through virtual space. Their ability to provide freedom from the constraints of space and time makes ICTs ever more popular. Hence people are adopting the virtual alternative on a massive scale. In 1999, for instance, the number of telecommuters in the European Union had reached 9 million (Gareis & Kordey 2000), with predictions that the number could reach 27 million by 2010 (Johnston & Nolan 2002). This means that it is no longer possible to measure job accessibility in terms of travel time, distance or generalized cost, the way it was done traditionally for physical space only, as we need to take the virtual component into account as well.

The development and use of ICTs is growing at a fast pace. People all over the world are telecommuting, teleshopping and involved in distance learning with the use of modern technologies. The number of telecommuters in the Netherlands is growing continuously (Hamer *et al.* 1991; Johnston & Nolan 1997; Johnston & Botterman 1998; Johnston & Nolan 2000; Bates & Huws 2001; Huws & O'Regan 2001; Johnston & Nolan 2001; Johnston & Nolan 2002; TWF 2004; CBS 2005a). In 2000, 9% of the total employed population in the Netherlands telecommutes for more than one full day per week, while for the EU this is 2% and for USA 5%. Along with this, in 2000, 45% of total jobs in the Netherlands were suitable for telecommuting, as compared to this, overall for the EU this percentage was 31% and for the USA 37% (Empirica 2003). In 2006, 21% of the total employed population of the Netherlands telecommutes as compared to the 17% of the USA and an average of 7% overall in the EU (Todd 2006).

All this affects the overall accessibility of the people. According to Handy and Mokhtarian (1996), a desire for more free time may be a strong motivator for telecommuting. Because most back office activities, like administration and accounting, are suitable for telecommuting, this will also reduce the requirement of office space (Couclelis 2000). According to Shen (1998b), people who lack ICTs skills have less access to opportunities than people who do possess the necessary skills and use them to access opportunities in virtual space.

Thus, the geographical interaction between residents (socio-economic activities) takes place in hybrid space, which means that its strengths and breadth is taking on new forms, which will be discussed in next section.

2.3 Effects of ICTs on accessibility

In the past people could access opportunities by using four modes of physical transport, namely road, rail, water and airways. A fifth (virtual) mode has now been added in the form of ICTs, which allows them to access opportunities through virtual space. What it means is that they can telecommute, teleshop, engage in distance learning and even visit different places of their interest virtually. This has raised the question concerning the effects these new means of communication have on accessibility.

Hall (1999) and Indovina (1999), argue against the idea of the death of distance by pointing out that this idea ignores the significance of face-to-face contact, which is very likely part of human nature. Thus, a majority of opportunities is still available in physical space. Even opportunities that are available in virtual space are not restricted to that space, which means that either it is the nature of the opportunity to transcend virtual space or it is simply human nature to need face-to-face contact, that causes people to move in physical space, although less frequently than regular commuters. To compensate for the time they save while telecommuting, telecommuters may choose to live in the environment of their choice, which may result in longer commuting distance than the regular commuters. Thus, the effect of the ICTs on job accessibility is quite complicated, as it has changed the concepts of space and time (Gepts 2002).

Graham and Marvin (1996) have tried to capture the impact of ICTs on urban patterns. However they stated that their dichotomous model fails to grasp the complex and contradictory nature of linkages. Gepts (2002) has improved their model by incorporating Castells (2004)'s idea of the space of flows and the space of places, to determine the effect of ICTs on people's accessibility to their opportunities.

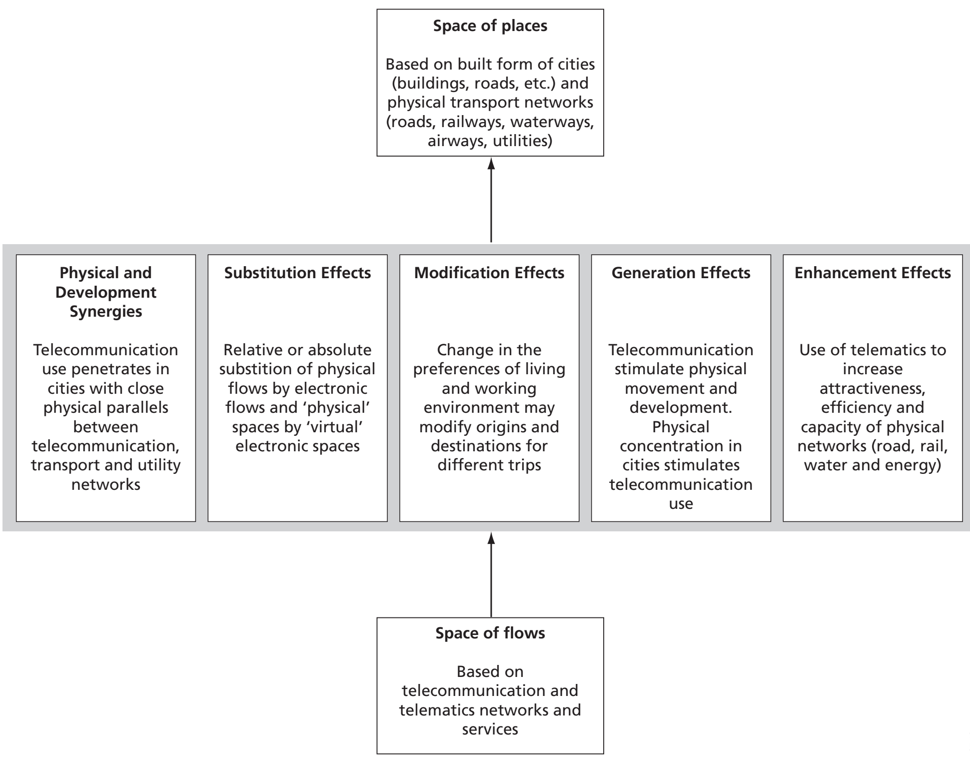

Figure 2.1 A typology of the relationships between the space of places and the space of flows
(Source: Adopted from (Graham & Marvin 1996) and (Gepts 2002) with some additions and modifications)

The model presented by Gepts (2002) lacks the effect of ICTs with regard to the modification of travelling patterns. The time saved through telecommuting will be used for other purposes, like visiting friends, relatives or recreational areas etc. This modification effect is incorporated in the model shown in Figure 2.1, resulting in a framework that now consists of five relationships between virtual space (the space of flows) and physical space (the space of places): synergy, substitution, modification, generation and enhancement. These effects will be discussed further.

2.3.1 Synergy

ICTs' infrastructure is concentrated in cities. The current ICTs' landscape is characterized by two important evolutions, the first of which is the shift away from national monopolies towards liberalization and globalisation. Secondly, the market is characterized by a strong growth of fibre-optic networks, which are considered the fastest transmission medium (Gepts 2002). Building these networks is a costly affair. The Internet has a hierarchical structure based on bandwidth, connecting the Internet exchange points that are situated in strategic places, where data is exchanged between different networks. Both tendencies inevitably lead to a concentration of ICTs providers in the most profitable areas and markets.

Thus, at the moment ICTs' infrastructure follows existing urban patterns. The network nodes are situated where there are concentrations of economic activities with high telecommunication expenditures. Most telecommunication traffic is concentrated in cities, and as a result it is the cities that attract ICTs' networks (Gareis & Kordey 2000; Kellermann 2002; Lorentzon & Paradiso 2004). Although new ICTs applications would allow providers to adopt a different geographical approach, they prefer being located in urban regions, for the reasons mentioned above. In other words, the space of flows clings to existing nodes in the space of places. An example of synergy between information-intensive activity and the Internet exchange is Zaventem (Belgium) (Gepts 2002). Zaventem houses the Belgian National Internet Exchange and also possesses a high concentration of ICTs industry. The same trend occurs in Amsterdam, where the American network products and services company Cisco Systems has located its new European headquarters.

Detailed networks in the north-west European Delta are shown in Figure 2.2, which makes it clear that the tendency of ICTs infrastructure to follow the existing hierarchy of settlements is not restricted to the national level, but to a large extent can be seen at the regional level as well. The main Internet exchanges are developed in major economic and administrative centres, like Amsterdam, which is the cultural capital and economic hub of The Netherlands, is located almost at the centre of the Delta, and has the global Internet exchange called Amsterdam Internet Exchange (AMS-IX). Brussels in Belgium and Köln and Frankfurt in Germany house the sites for Internet exchanges for north-west Europe.

These synergy effects can also be found at the local level. In the UK, Mercury, Britain's second largest telecommunications company, located its City of London network within an old network of hydraulic ducts that lies beneath the main financial district (Graham & Marvin 1996). So the ICTs' network follows the existing network of places. It is most likely that the space of flows will follow the space of places.

A recent study conducted in the Netherlands by Van der Laan *et al.* (2005) revealed that ICTs-related employment is generally not dispersed over non-central areas, but there has been an emergence of new concentration both on the urban fringe and in non-central locations within existing urban systems. In other words, ICTs' networks' nodes at the same time have a centralizing and a decentralizing effect. These nodes attract information-intensive businesses as a result of the structure of ICTs' networks. The closer one is located to the so-called ICTs' nodes, the faster the information or data that can be transmitted.

2.3.2 Substitution

Using ICTs in communication can substitute for physical travelling, as much as face-to-face communication is replaced by virtual communication (Mokhtarian 1998; Mokhtarian & Krishna 1998; Mokhtarian & Bagley 2000; Shen 2000). People can telecommute, teleshop etc., which means that there is less need for them to travel. An experiment with 30 employees of the Ministry of Transport in the Netherlands showed that that there was clearly a reduction in the number of daily trips they had to make (Hamer *et al.* 1991). According to Mitomo and Jitsuzumi (1999), in Tokyo, telecommuting will reduce the congestion from 10.9% to 6.9% by the year 2010, based on their estimates. At that time there will be 9 to 14 million telecommuters. A study by Choo *et al.* (2005) indicates that in 1998, in the USA telecommuting had led to an

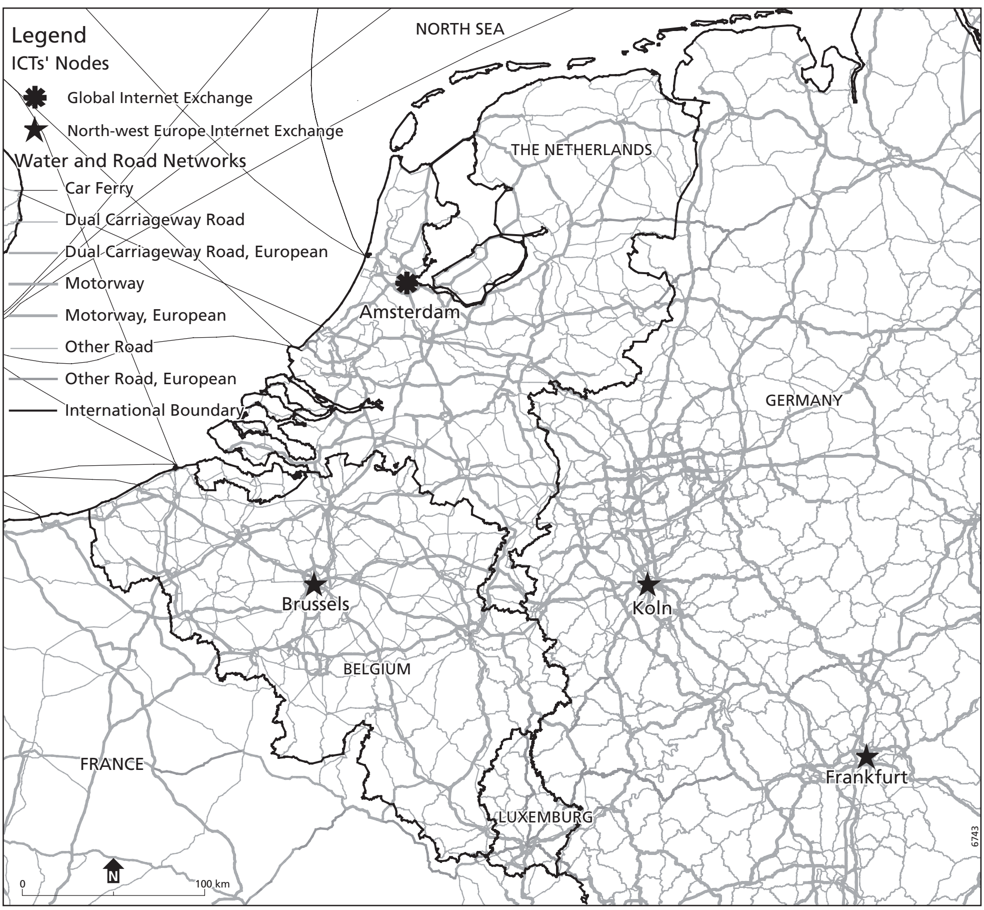

Figure 2.2 Location of Internet exchanges in the north-west European Delta

0.8% reduction in the total number of miles travelled. In a small country like the Netherlands, telecommuting resulted in a 19% reduction in peak-period trips, with no shift from peak to non-peak periods (Keskinen *et al.* 2001).

Lenz et al (2003), Ferrel (2005) and Papola and Polydoropoulou (2006) have found that teleshopping too, will have substitution affect for shopping trips in physical space. In short, virtual space has a great potential for substituting physical space.

2.3.3 Modification

ICTs are used to conduct (in the virtual space) or change (modify the travel time and route) the activities people plan (Hjorthol 2002). This may alter regular travel behaviour. Studies (Mokhtarian 1988; Nilles 1988; Mitomo & Jitsuzumi 1999; Khan 2003) have shown a reduction in peak-hour trips, which means a modification in the travelling time. Thus, there is a possibility that they will use the time they save for recreational purposes or social travelling (Gepts 2002), which means that their destinations – and subsequently the travelling patterns – will have changed.

Another possible effect is that telecommuters will migrate further away from their workplace in search of an affordable place to live in an attractive environment, which means that the overall distance they travel remains the same (Nilles 2001). In 1995, the average commuting distance in the Netherlands for regular commuters was 21 kilometres (CBS 1995). For telecommuters, Reisen (1997) found an average commute distance of 38 kilometers (nearly double of average for regular commuters).

Mokhtarian and Bagley (2000) also indicated that the commuting distance of telecommuters may be greater than the average commuting distance for regular commuters. Based on several studies, she reports that the average telecommuting distance is 1.8 to 2.3 times that of the regularly commuted average distance.

Telecommuting also seems to lead to a reduction in the number of multi-purpose trips (shopping and picking up and dropping of children at school etc. during the return trip from home to workplace), which previously was common practice, as a result of people no longer have to drive to work. This will also modify the shopping destinations for telecommuters. The main modification in the case of teleshopping is that now the trip is from store to home (home delivery service), or it can be from the home to the delivery centre instead of from home to store and back. Although teleshoppers still make trips from home to store, more and more they do so in the settings of leisure activities (Douma *et al.* 2004; Farag 2006).

2.3.4 Generation

In some cases the use of ICTs to access opportunities generates more traffic. Due to the flexible timing of commuting it is not possible to provide public transport for every one according to their schedule, so there will be a tendency for people to use private transport. Thulin and Vilhelmson (2004) found that in Sweden ICTs are being used by youngsters to make new contacts, which can also result in movements in physical space, which may increase the number of vehicle miles, resulting in higher costs and environmental effects. ICTs are also making people aware of attractive new destinations, inviting and motivating them to travel.

There are various other ways in which ICTs will tend to generate more rather than less traffic, as the emphasis on fast, guaranteed delivery leads to more delivery trucks not being fully loaded (Nilles 2001). Virtual contacts generate physical contacts. Although people expand their network of contacts through e-mail and the Internet even worldwide, but still the need and desire to meet someone in person stays. As a result they travel greater distances. With e-commerce, goods are being delivered at home and traffic from producer to retailer is reduced, which means that more goods will be delivered in smaller batches, resulting in more traffic from store to home (Casas & Bricka 2001; Ferrel 2004).

A recent Dutch research by Visser and Lanzendorf (2004) found that e-commerce leads to a growing number of displacements due to processes of decentralization and sub-urbanization of distribution systems. For business-to-business traffic, a growth of 8% is expected, and for business-to-customer 4%. And, as mentioned earlier, traffic may even increase as people will tend to use the time they have managed to save to visit relatives or places of interest (Handy & Mokhtarian 1996; Mokhtarian 1998; Shen 1998a; Shen 2000).

To conclude, we believe that the first thing Graham Bell said to his assistant refer to when he used the telephone for the first time is relevant here: "Watson, come here". Virtual communication causes people to move in physical space (Graham & Marvin 1996; Mokhtarian 1998; Shen 2000; Hjorthol 2002; Plaut 2004; Sheller & Urry 2004).

2.3.5 Enhancement

ICTs optimize the efficiency of transport systems. Intelligent Transport System (ITS) are often used to solve problems like congestion and traffic jams, to manage traffic in such a way that more cars are able to use the same infrastructure without causing traffic problems (Khan 2003; Khan & Armstrong 2005). By using Advanced Transportation Information Systems (ATIS), which are part of ITS, people can get advanced warning about traffic jams as well as information about alternative routes and the best possible time to travel. Fast, automatic, electronic fee collection at parking facilities, on toll bridges and freeways also saves time and encourages people to be mobile (Nilles 2001; Plaut 2004).

Advancements in ICTs will also improve the efficiency and attractiveness of mobility sharing programmes (Golob & Amelia 2001). It is also used to ameliorate the capacity of vehicles, for example, by car sharing (Handy & Mokhtarian 1996; Gepts 2002). Car sharing has flourished in Europe, where in 1999, over 200 organizations in 450 cities involving 130,000 persons took part (Sperling *et al.* 1999). Specialized applications will undoubtedly include providing access for handicapped travellers and anyone with unusual requirements.

All these developments will facilitate the mobility of the people and goods, either by providing them with up-to-date information about conditions on the road or through car sharing, to reduce traffic volume. Thus, the effects of ICTs on the accessibility depend not only on physical aspects but also on the socio-economic characteristics of the people involved. Highly educated people, who are skilled ICTs users, will benefit more than people who are less skilled. It also depends on the opportunities that are available, which means that government policies concerning ICTs also play a significant role. According to Dijst (2001), ICTs may have an impact on the following three components of accessibility:

The reference location, from which, access to destinations is determined. Telecommuters may have the opportunity to live further away from where offices are located, because they no longer commute or do so less frequently.

Attraction of destinations, when people manage to save time because of telecommuting, new destinations will have attraction for the people and make them to travel in physical space.

Impedances, by using ICTs not only for telecommuting, but also for planning trips, impedances, which in most cases are related to distance, time and cost, will be modified, and in addition planned trips will be more relaxed as compared to the hectic circumstances of unplanned ones.

To these three components we can now add two more: *the personal characteristics* (education level, ICTs skills) of the people involved and *the nature of the opportunities* (less physical contact and fewer special facilities are needed to carry out an activity).

Handy and Mokhtarian (1996) have considered different factors, including the trend among employers and employees and U.S government policies, that will affect telecommuting. They found, for instance, that some people will telecommute not regularly, but occasionally. Some professions will benefit more from telecommuting than others, for instance management and sales (Handy & Mokhtarian 1996). Although ICTs have penetrated most areas, some activities still require physical commuting (for instance those that require face-to-face contact). Even most telecommuters still make work-related trips every week to maintain a certain frequency of face-to-face interaction with management, co-workers and clients. This is essential for establishing and sustaining good working relationships, which enables telecommuters to function more efficiently while working at home. Furthermore, many telecommuters must travel to their workplace from time to time because some tasks require special facilities or close interactions with co-workers, which means that they cannot be carried out at a distance. Thus telecommuting on the one hand substitutes physical commuting, and on the other hand complements it. Thus it does in some ways substitute, generate and increase physical mobility (Shen 2000; Hjorthol 2002).

Hence, ICTs play an enabling and co-evolutionary role (Occelli 2001). This means that, in order to determine what the effects of ICTs are on the job accessibility, one needs to know what the trend will be with regard to telecommuting, whether people will telecommute fulltime or on a part-time basis, for instance on different weekdays or whether they will alternate between telecommuting and physical commuting.

The next section further considers the effects of ICTs on accessibility. In particular the discussion on ways to measure the accessibility in this hybrid space where many activities that people used to access in physical space, now are also being accessed in virtual space, will be discussed.

2.4 Measuring the accessibility in hybrid space

The idea of accessibility has to do with reachability, obtainability, and attainability. In the pre-virtual (physical) world, access was considered in terms of the ability of people to reach and use, or take advantage of spatially dispersed activity sites providing jobs, goods, and services like medical care, recreation, entertainment etc., (Hanson 2000).

A hybrid blend of physical and virtual space may constitute the new geography of the information age (Janelle & Hodge 2000). It may reinforce patterns of physical infrastructure that may impinge on the comparative levels of physical accessibility for different regions; for example, on-line purchases still require transhipment facilities to accommodate the physical movement from producer to consumer (Batty & Miller 2000).

Although ICTs are now playing a critical role in determining the strength and extensiveness of various geographical relationships, all existing accessibility measures continue to focus on transportation, without taking into account other means of spatial interaction (Shen 1998a). On the other hand, because most activities still take place in physical space, the existing models for measuring the accessibility need to incorporate the virtual component.

According to Scott (2000), accessibility is not a distinct physical entity that is easily counted or measured, but it is a concept, a perception, something we all experience, evaluate or judge differently. Accessibility is indeed a relative and contextual notion and the correct definition largely depends on the scope and context of investigation. Hence, unlike Scott's predecessors ((Hansen 1959; Wilson 1970; Weibull 1976; Handy 1994), who focused more on gravitational aspects), his model can be extended to the study of accessibility to employment in hybrid space, where gravitational forces do not play a role.

Nagurney and Dong (2002) have used a multi-class, multi-criteria network equilibrium approach to interpret the effects of telecommuting on urban location and transportation in the information society. Moss and Townsend (2000) have designed a model that combines a traditional spatial interaction model with the Gi local statistics (Getis and Ord's Gi statistics measure the degree of association or spatial clustering associated with a single variable distributed over a spatial surface) to shed new light on the notorious spatial mismatch phenomenon. Heikkila (2000) has combined fuzzy logic with club theory (which examines the economic rationale by which individuals voluntarily form groups or clusters in order to derive tangible or intangible benefits through mutual association) to model accessibility in both the geographic and non-geographic context.

Shen (1998a; 2000) used a composite measure (by categorizing the population according to their job type and means of transportation) of job accessibility for Boston residents, which seems quite promising. According to Mokhtarian (1998), telecommuting is not a continuous process, people sometimes like to switch between telecommuting and commuting physically. As such, people may also tend to commute at convenient hours to avoid traffic jams.

According to Couclelis (2000), Hajer and Zonneveld (2000), and Shen (2000), in this hybrid space opportunities can be divided into three categories:

- Opportunities that are accessed fulltime or at least in part by using ICTs. ICTs are an indispensable component of these opportunities.
- Opportunities that can be accessed either through transportation in physical space or through ICTs in virtual space. ICTs are the preferred way to access these opportunities, but are not an indispensable component of these opportunities.
- The traditional type of opportunities that belong exclusively to the physical space, and therefore are accessed by physical means only.

On the other hand, people can also be divided into two categories, based on whether or not they possess the ICTs skills required. Even people who do possess the necessary skills will decide whether or not to telecommute on the basis of their personal preferences and or on the nature of the opportunities. On the basis of these observations a model for measuring the accessibility of opportunities in hybrid space is formulated (see Figure 2.3).

Opportunities can be divided into a number of categories. For example in the case of jobs, people can commute and telecommute. If they telecommute, a subdivision into two classes can be made, either home-based or in telecentres, which are usually located near residential areas or at easily accessible sites (ICTs will change destinations). In both cases the opportunities can be part-time, fulltime or occasional (Alexakis *et al.* 2006). These are opportunities that only people

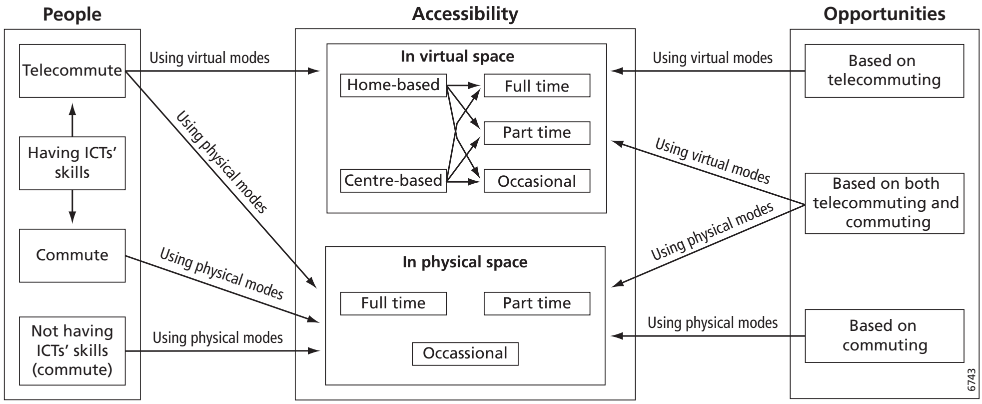

Figure 2.3 Model for measuring the accessibility of opportunities in hybrid space

with ICTs skills have access to, unlike opportunities in physical space, which can be accessed regardless of the skills people possess. The same is true for other activities like shopping, leisure etc.

There are several types of activity-based accessibility measures, among which there are five that are widely used: a contour measure, a potential accessibility measure, the accessibility measure with competition, the inverse balancing factor and accessibility measures from space time geography (Geurs & Ritsema van Eck 2001). Among these, the potential accessibility measure, with the gravitational model provided by Hansen (1959) with some modifications (by introducing a competition factor), has widely been used.

It was found that the measure given by Hansen (1959), accounts only for supply side. The spatial distribution of demand for available opportunities is limited in capacity and if the demand is not uniformly distributed across space, then the competition factor needs to be incorporated. This competition factor takes the compatibility between type of opportunities and the personal characteristics of the opportunity seekers into account. By cross-matching the characteristics of opportunities and opportunity seekers, the average commuting distance can be computed. By using this statistic, the respective distance decay parameter can be computed, which will be helpful in shaping the accessibility surface in hybrid space.

2.5 Conclusions

In literature, most of the authors agree that more information is needed on the implications for accessibility of ICTs to draw definitive conclusions. Nevertheless, it can be said ICTs are causing an information revolution that is changing our everyday lives. People have a desire to live safe and relaxed lives, and as a result activities like telecommuting and teleshopping are becoming more and more important.

Cities are getting new fibre-optic networks that stay close to the existing infrastructure. These networks allow people to access both the physical and the virtual space. People who can access virtual space are in a position to make use of opportunities at greater distances than are available to regular commuters. On the other hand, telecommuters may move away from where they work in search for more affordable and more attractive living environments.

The need for physical contact remains however. In part due to the fact that some jobs require people to work together in the same physical space, but also as a result of the human need to have face to face contact. In addition, virtual interaction also induces physical contact. Thus, telecommunications tend to lead to an overall increase in interaction in both physical and hybrid space.

In this way, the use of ICTs to access opportunities substitutes, modifies, generates and enhances the accessibility of people in hybrid space. Consequently, the use of ICTs will not result in the death of distance, but in new places are emerging in virtual space. People with ICTs skills are better able to access opportunities in both the physical and the virtual space. This means that the accessibility can no longer be measured solely in terms of physical separation, as the virtual component also needs to be incorporated. In this virtual component, people's personal characteristics, like type of education, and capabilities, and the nature of the job play a bigger role. This means that not all people will be able to fully access opportunities in virtual space, but only the ones with the capabilities required. And even then most opportunities will require a certain level of physical contact, due to the nature of the opportunity or to our social nature. Thus, in order to incorporate the virtual mode of communication in measuring job accessibility, the personal characteristics of the opportunity seekers and the nature of the opportunities become more important.

Many opportunities still require people to move in physical space; hence, physical distance will not disappear, but it will become less important as the emergence of new places in the virtual space creates other forms of proximity become more significant. Most opportunities that are available in virtual space still need to be accessed in physical space, albeit with a lower frequency. Rather than talk about the death of distance, we should recognize that distance acquires a new meaning. For instance, telecommuters will not commute all the time, but less frequently than regular commuters, while at the same time travelling greater distances when they do commute in the physical space. This means that to measure job accessibility the distance decay parameters for the telecommuters should be relaxed according to the possible average distance they commute.

Because ICTs' infrastructure adheres to the existing hierarchy of urban settlements, the existing inequalities will not vanish, although they may be reduced a bit, as in some regards the friction of distance decreases. This means that even people living at great distances from existing main cities will be able to access opportunities located there, through virtual space. This means that the use of ICTs will enhance the accessibility of the people to an increasing array of their opportunities.

3 Job Accessibility in Hybrid Space

Muhammad, S., T. de Jong & H.F.L. Ottens (2007), Job accessibility under the influence of information and communication technologies, in the Netherlands. Forthcoming in Journal of Transport Geography. Copyright © Elsevier Science, Ltd.

Abstract
Information and Communication Technologies (ICTs) are enabling people to access opportunities in virtual space without facing the friction of distance and travel time alongside the long-existing opportunities in physical space. Hence, society is now dealing with hybrid space circumstances, in which new meanings of distance and accessibility are developing. In physical space, accessibility is measured on the basis of the spatial separation between the locations of opportunities and opportunity seekers. In virtual space, spatial separation loses its importance, but the nature of jobs (whether they can be accessed in virtual space or not) and the personal capabilities of workers (having ICT skills or not) gain more importance. This study explores how this virtual component can be incorporated into existing accessibility models. The influence of the use of ICTs on job accessibility is analysed with two models, the Hansen and the Shen model. The outcomes of this measuring exercise show that job accessibility in hybrid space is likely to improve, but this improvement shows distinct patterns of regional variation. Of the two accessibility measuring models, the classic Hansen potential accessibility approach performs best in quantifying job accessibility in hybrid space.

3.1 Introduction

Job accessibility is a key concept in land-use and transport policies in many western countries. In Dutch national spatial policy, job accessibility has also played a key role in the planned allocation of new urban developments to brownfield locations within existing built-up areas and to new greenfield locations directly adjacent to existing cities. The main aim is to provide good access to urban employment and facilities and reducing car mobility growth (Verburg *et al.* 2004; Geurs 2006). With the increasing use of ICTs for accessing opportunities in virtual space, job accessibility is taking on a new meaning, as people can access opportunities without facing the friction of distance (travel time, costs, and effort), which is the measure of job accessibility in physical space (Janelle & Hodge 2000; Shen 2000). Thus virtual space will enhance the accessibility of people to jobs, shopping, recreation, education, and so forth (Gould 1997; Martens *et al.* 1999; Janelle & Hodge 2000; Johnston & Nolan 2002). But opportunities will never be exclusively accessed in virtual space. This is caused by both the nature of opportunities and people's preferences of and need for face-to-face interaction (Graham & Marvin 1996). For example, many people who telecommute will additionally commute physically for a certain number of days per week or month (Mokhtarian & Salomon 1997). Thus a *hybrid space* emerges, where distances still matter, but for an increasing number of jobs to a lesser extent (Shen 2000).

The current practice in measuring job accessibility at the Netherlands Environmental Assessment Agency (Milieu en Natuur Planbureau (MNP) in Dutch) and the Transport Research Centre (Adviesdienst Verkeer en Vervoer (AVV) in Dutch) of ministry of transport, public works and water management mostly follows the original or modified destination-constrained potential model of Hansen (1959) but without taking a virtual component into consideration. Accessibility being an important element of land use allocation models in the Netherlands, with this increasing use of ICTs for accessing opportunities there is a need to incorporate this virtual component in job accessibility measurements.

The first aim of this research is to examine how the changing meaning of home-work distance can be incorporated into different accessibility models and to answer the question which accessibility model is best suited for this modification. A subsequent aim is to apply the modified job accessibility models in order to estimate and project how the use of ICTs will influence job accessibility in the Netherlands.

When measuring job accessibility in hybrid space, either the traditional Hansen model can be split into a physical space and a hybrid space component, or a dedicated integrated model can be developed. The later approach is taken by Shen (2000), who has developed a potential model with a competition factor. Both approaches are appropriate for this research, because both are based on a potential accessibility measure, which is more suitable for land-use and transportation interaction studies than measures based on transportation infrastructure characteristics only (Geurs 2006).

The two models (modified Hansen and Shen) are applied to study the effects of ICTs on job accessibility in the Netherlands for four different years in the period 1986-2020. The outcomes are used to test which model performs better and how the use of ICTs affects spatial patterns of job accessibility in the Netherlands. In order to implement these models first, we discuss the theoretical effects of ICTs on commuting and the way in which job accessibility can be measured in hybrid space.

3.2 The effects of the use of ICTs on commuting

The term telecommuting was first coined by Nilles in 1973 (Nilles 1988) and it was popularised by the futurist Francis Kinsman (1987) in his book *The Telecommuters*. The term telework has been promoted in Europe through its use by the European Commission (EC), which sponsored a number of research projects on this topic from the late 1980s to the early 1990s. The aim of the projects was to explore how telework can contribute to developing economic activity and creating work opportunities in rural areas or places with economic problems (ETO 2005). The common element in all definitions is: *the use of computers and telecommunications which allows workers to execute their tasks away from the traditional fixed office or workshop location* (Johnston & Nolan 2001).

In recent years, the interaction between ICTs and human activity (especially in travel behaviour) is getting more attention. Researchers have recognized that an increased use of ICTs may lead to changes in the location, timing and duration of people's activities. This will most probably lead to new patterns of activity and travel in time-space (Kwan *et al.* 2007). Hence, in order to assess the effect of ICTs on travel behaviour (like the effect of telecommuting on physical commuting), individual-level analyses would be able to identify relationships that are more difficult to assess at the aggregate level. However, currently available data sets lack individual-level detail at fine spatial and temporal scales (Kwan 2002) and therefore do not allow for such a micro-level approach.

Aggregate level analyses have revealed that telecommuting is effecting physical commuting not only in terms of commuting frequency but also commuting distance (Mokhtarian & Krishna 1998). According to Mokhtarian and Bagley (2000), telecommuting is not a continuous process. People who telecommute often continue to be traditional physical commuters, but only for a certain number of days per week or month and using flexible timings. Overall the effects of telecommuting on commuting are complex as processes of substitution, generation, enhancement and modification, all can lead to new synergies of development (Graham & Marvin 1996).

Couclelis (2000), Hajer and Zonneveld (2000), Shen (2000), and Muhammad (2006) identify personal capabilities and preferences of opportunity seekers and the nature of jobs as important variables explaining telecommuting behaviour. Following this reasoning, in hybrid space opportunities such as jobs can be divided into three categories:

- Opportunities in virtual space that can only be accessed through ICTs,
- Opportunities in hybrid space that can be accessed by using physical means of transportation as well as making use of ICTs and
- Opportunities in physical space that can only be accessed by physical means of transportation.

Opportunity seekers, in this case workers, can be divided into two broad categories based on whether they have ICT skills (education, training, experience) or not. In this research, a worker who has ICT skills and accesses opportunities in virtual space is termed a *telecommuter*. In order to differentiate in this research jobs that, to a large extent, are being carried out away from the employer's premises, but often in combination with commuting trips with a frequency of at least once a month (*by monthly commuters*), are termed *jobs in virtual space* while other *jobs in hybrid space* combine virtual commuting with physical commuting at least once a week (*by weekly commuters*). Rest of the jobs are being accessed in physical space by commuting regularly (*by daily commuters*).

3.3 Measuring job accessibility in hybrid space

In a pre-virtual world, referred to Castells (2000) as a *space of places*, access was considered in terms of the ability of people to reach and use, or take advantage of, spatially-dispersed activities, such as sites providing jobs, goods, and services of medical care, recreation, entertainment, and so forth (Hanson 2000). In hybrid space, accessibility has to do with *reachability* (reaching an activity at a location by using physical or virtual means of transportation or communication), *obtainability* (personal skills and capabilities to be able to make use of an opportunity in physical or virtual space), and *attainability* (the temporal component, at what time and how long an opportunity can be accessed, virtual space makes it more flexible).

Despite the fact that ICTs now play an important role in determining the patterns and strengths of various geographical relationships, most existing accessibility measures only take physical transportation (like commuting) into account and do not consider other means of spatial interaction (like telecommuting). Although, still the major part of human activity takes place in physical space, the existing models for measuring accessibility need to be adapted to incorporate this virtual component as well.

Accessibility modelling is a well-developed field of scientific research. Several types of activity-based accessibility measures are available. The most widely used ones are: contour measures, potential measures, competition-based measures, the inverse balancing factor, and accessibility measures based on space-time geography (Geurs & Ritsema van Eck 2001; Hensher *et al.* 2004). Of these, the potential-accessibility measure, best known as the gravitational-accessibility model developed by Hansen (1959), has been the most widely used and refined.

According to Hansen's original gravity formula, the potential accessibility value is calculated as:

$$A_i = \Sum j O_j f(t_{ij}) \qquad \text{(Eq. 3.1)}$$

Where:
A_i is the accessibility for zone i
O_j is the number of relevant opportunities in zone j
$f(t_{ij})$ is the distance-decay function, measuring the spatial separation between zone i and j, for an urban or regional system with N zones, $i = 1,2\ldots N$, and $j = 1,2\ldots N$, with travel time t_{ij}, commonly specified as an exponential function:

$$f(t_{ij}) = \exp(-\beta(t_{ij})) \qquad \text{(Eq. 3.2)}$$

Where:
β (beta) is distance decay parameter, which converts actual travel time to perceived travel time as shown in Equation 3.2.

In the course of time, urban researchers have modified Hansen's accessibility measure by incorporating other factors that affect accessibility (like mode of transport and competition among opportunities and opportunity seekers) in order to improve understanding of the complicated relationship between transportation technologies and the changing geography of opportunities. A large volume of literature has resulted. Most researchers agree that the level of accessibility for an opportunity seeker is a function of the total number of relevant opportunities, the spatial distribution of these opportunities, the spatial location of the individual, and the individual's ability to overcome these spatial separation. When opportunities are relatively scarce, competition with other opportunity seekers must also be taken into account (Shen 1998a; Ritsema van Eck & De Jong 1999; Van Wee *et al.* 2001). To incorporate these competition effects, several authors have developed alternative accessibility measures based on the potential accessibility concept. Among those, the balancing factors of the doubly constrained interaction model introduced by Wilson (1970) is best known. Here the competition effects occur at both origin (among opportunity seekers) and destination (opportunity providers). Workers compete with each other for jobs and employers compete with each other for employees (Geurs & Ritsema van Eck 2003). For applying this approach in our research, the balancing factors for origin (daily, weekly and monthly commuters) and destination (the jobs being accessed in physical, virtual and hybrid space), need to be calibrated with real time origin and destination survey data having the necessary spatial and respondent details. This type of survey data is not available for the Netherlands. Furthermore, Geurs and Ritsema van Eck (2003), have found that job accessibility for 1995 for physical commuters in the Netherlands, computed using balancing factors in a doubly constrained interaction model, are very similar to the ones computed by the potential accessibility model. Given the above-mentioned facts, instead of a doubly constrained interaction model with balancing factors, Hansen's destination-constrained potential accessibility model was adopted in this study.

A second relevant approach for measuring job accessibility with competition is developed by Shen (2000). It is also based on the potential accessibility model given by Hansen (1959) which was modified by Weibul (1976). Recently, Shen (2000) has generalized this approach. In this modified model, each available opportunity is weighted by a demand factor, which represents the competing demand generated by other opportunity seekers.

According to Shen (2000), if there are O total opportunities and P is the total number of opportunity seekers, then ϕO opportunities in the virtual space will be accessible to the δP people (δ is the proportion of the total number of opportunity seekers P), who have ICT skills and c is the necessary means of accessing these opportunities. The λO opportunities are accessible either by physical or virtual means of communication to δP opportunity seekers who use ICTs to access them (c, communication means) and $(1-\delta)$P to those who use physical means (v, mode of transport in physical space). While $(1-\phi-\lambda)O$ are the opportunities, these can only be accessed by using physical modes of transportation, m; those are available to all opportunity seekers P. The accessibility for different groups of opportunity seekers (distinguished in section 3.2) can be measured using Equations 3.3 and 3.4. Further details about the specification of these equations are given by Shen (2000).

- For opportunity seekers who do not have ICT skills:

$$A_i^v = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m) + \delta_k P_k^m f(t_{kj}^{cm})]} \qquad \text{(Eq. 3.3)}$$

- For opportunity seekers who have ICT skills:

$$A_i^{cv} = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m) + \delta_k P_k^m f(t_{kj}^{cm})]} +$$

$$\Sigma_j \frac{\phi_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k \delta_k P_k^m f(t_{kj}^{cm})} \qquad \text{(Eq. 3.4)}$$

The distance-decay function $f(t_{ij})$, defined in Equation 3.2 is the most sensitive component of a potential accessibility model, specified for each mode of transport and communication (c, v, and m, in Equations 3.3 and 3.4). It should be noted that if the denominators (competition factor) in the Equations 3.3 and 3.4 are ignored, one arrives at the Hansen's destination-constrained potential measure for hybrid space.

To make Hansen and Shen potential accessibility models specific and operational, distance-decay parameters for physical, virtual and hybrid components must be defined. The usual approach is to derive the distance-decay parameter from the Mean Trip Length (MTL) for each means of access. Hence, for the physical component, travel time by physical Mode of Transport (MoT) can be used straightforwardly. For the virtual component, travel time can only be defined if people who use ICTs to access opportunities, still make at least some complementary trips to workplaces in physical space. As discussed in section 3.2, this is indeed the case and as a result, the commuting distance of telecommuters is longer than of regular commuters.

In 1995, the average commuting distance in the Netherlands for regular commuters was 21 kilometres (CBS 1995). Van Reisen (1997) found an average trip distance of 38 kilometres for telecommuters. Mokhtarian and Salomon (1997) and Giuliano (1998) also show that commuting distance is larger for telecommuters than for regular commuters. Based on several studies, they report that the average telecommuting distance is 1.8 to 2.3 times the traditional commuting distance. Hence, the distance-decay parameter needs to be relaxed for telecommuters, depending on their commuting distance. This commuting distance is inversely proportional to commuting frequency, which depends on both the nature of the job and commuting distance.

In this research, we have applied both Hansen's destination-constrained potential accessibility model and Shen's potential-accessibility model with the incorporated competition factor. In order to facilitate the implementation of these models and the interpretation of the model outcomes, a literature study of the status of telecommuting in the Netherlands was undertaken. Results are summarized in the next section.

3.4 Telecommuting in the Netherlands: past, present and future

Since the mid 1970s, the phenomenon of telecommuting has been given a great deal of attention in the literature (De Graaff & Rietveld 2007). Telecommuting is practised in the Netherlands for many years, but official statistical data are only available from 1995 onwards. To estimate the magnitude of telecommuting, Willigenburg and Van Osch (2000) conducted a survey (Electronic Commerce and Telework Trends, ECaTT) among both employers and employees. In order to ascertain the start of telecommuting in the Netherlands, firms were asked how long they had been practising it. For only 1.65 percent of all respondents the reply was: for more than 10 years. The firms surveyed were above average in terms of number of employees. Unfortunately, the report does not mention the business sectors to which they belong, nor does it give any information about the nature of the jobs held by the people who were telecommuting. On the basis of literature survey, for hybrid space the figures adopted for the share of jobs in physical, virtual and hybrid space for the years 1986, 1995, 2000 and 2020 are shown in Table 3.1.

For the coming years, the development and use of ICTs is generally assumed to be growing rapidly. The number of telecommuters in the Netherlands is also expected to grow significantly as reported in many publications. At the moment, the Netherlands has a high percentage of telecommuters: 21 percent of the total employed population. In comparison, in the USA this percentage is 17 and in the European Union 7 (Todd 2006). The highly services-oriented Dutch economy makes 45 percent of all jobs suitable for telecommuting. Those percentages for the European Union (EU) and the USA are 31 and 37 respectively (Empirica 2003).

Table 3.1 Distribution of jobs in hybrid space (in percent)

Year	Physical Space	Virtual Space	Hybrid Space
1986	98.0	0.75	1.25
1995	93.0	1.75	5.25
2000	85.0	6.00	9.00
2020	55.2	10.51	34.29

Source: Figures in this table are based on these documents (Hamer *et al.* 1991; Van der Wielen *et al.* 1993; Van Reisen 1997; Martens *et al.* 1999; Johnston & Nolan 2000; Korte 2000; Werdigier & Niebuhr 2000; Willigenburg & Van Osch 2000; Bates & Huws 2001; Huws & O'Regan 2001; Johnston & Nolan 2001; Johnston & Nolan 2002; MuConsult 2003; ETO 2005; Todd 2006).

Nilles (1988) discusses the factors that will drive telecommuting in future. He argues that the key to understanding telecommuting lies in the nature of technological substitution and social change. Telecommuting should be considered a classic example of the effect of the substitution of an old technology by a new one. Mokhtarian and Salomon (1997) undertook extensive studies into the driving factors and constraints concerning telecommuting. The actual use of telecommuting is dependent on the (perception of) opportunities rather than on intrinsic preference. Several constraints apparently limit the actual take-up of telecommuting. However, the main necessary condition is still the possibility of telecommuting. Jobs that need daily interaction with colleagues or fixed equipment are not suitable for telecommuting and most jobs still face this constraint (Martens *et al.* 1999).

It is also argued that ICTs will reconstruct the labour market. The structural changes will lead to a considerably higher share of telecommuters. Ultimately, 40 percent of all jobs could be telecommuted (Van der Wielen *et al.* 1993; Van der Wielen & Taillieu 1995). Van Reisen (1997) for the Netherlands, expects telecommuting to grow from 23 percent in 1997 to 46 percent in 2015.

The Netherlands Central Planning Bureau (CPB) has formulated three scenarios for year 2020 by taking into consideration various options for international economic politics, technological development, and socio-economic and demographic changes. The first scenario is *Divided Europe*, characterized by a slow pace of development. The second is *European Coordination* with a medium pace of development and the third is *Global Competition*, with the fastest rates of growth and change. Martens and colleagues (1999) have used these CPB scenarios along with the drivers and constraints for telecommuting listed by Mokhtarian and Salomon (1997) for the prediction of the number of commuted and telecommuted jobs in the Netherlands for 2020 for the three scenarios. The European Coordination scenario, in fact the 'middle scenario', can be considered the most realistic one and is used in this research as the basic reference to estimate telecommuting participation in future. Other sources provide additional evidence and projections are listed under Table 3.1.

3.5 Data preparation for measuring job accessibility

A job-accessibility model has data requirements regarding the amount and spatial distribution of jobs and working population, the relevant transport system (travel times or distances), and the intensity of distance decay perceived. In order to measure job accessibility in hybrid space, these jobs and workers needs to be split into physical, virtual and hybrid components as described in section 3.2. This section describes data acquisition and pre-processing according to those criteria.

Table 3.2 Distribution of telecommuted jobs in the Netherlands, according to type and size of economic sector (figures for 2000)

Type of Economic Sector	Size of the Sector (No. of Employees)	Telecommuted Jobs (% of Total No. of Telecommuted Jobs)
Agriculture & Fisheries	5 to 20	0.88
	20 to 100	0.19
	More than 100	0.23
Mineral Extraction	5 to 20	0.01
	20 to 100	0.04
	More than 100	0.03
Trade	5 to 20	1.94
	20 to 100	1.91
	More than 100	11.22
Energy & Water	5 to 20	0.00
	20 to 100	0.01
	More than 100	0.75
Building Industry	5 to 20	1.22
	20 to 100	0.48
	More than 100	1.93
Retail	5 to 20	4.67
	20 to 100	2.43
	More than 100	6.37
Transport & Communication	5 to 20	0.82
	20 to 100	0.86
	More than 100	4.07
Financial Business & Services	5 to 20	6.18
	20 to 100	6.40
	More than 100	35.08
Remaining Services	5 to 20	2.16
	20 to 100	2.60
	More than 100	7.52
Overall	5 to 20	17.88
	20 to 100	14.92
	More than 100	67.20

Source: Figures in table 3.2 are estimated on the basis of statistics based on information from these documents: (Gareis & Kordey 2000; Johnston & Nolan 2000; CBS 2001; Huws & O'Regan 2001; CBS 2002; CBS 2003; MuConsult 2003; Van Oort *et al.* 2003a; CBS 2004; CBS 2005a; CBS 2005b).

Job data:
Telecommuting is an attractive option for jobs in which use of computers and communication networks are an important component of daily activities. Mostly administrative, management and communication jobs fulfil this criterion. For example, in Europe, 15 percent of all managerial jobs are conducted by telecommuting (Johnston & Nolan 2002). Unfortunately, no detailed data having the information about nature of the jobs at management level is available. Along with the nature of jobs, type and size of the industry also influence the adoption of telecommuting (CBS 2001; MuConsult 2003). Large organizations offer more telecommuted jobs. Based on the data search and literature survey, the share of telecommuted jobs according to the type and size of the economic sector for year 2000 adopted for this study are given in Table 3.2.

In order to implement the share of telecommuted jobs according the type and size of industries mentioned in Table 3.2, employment data for the years 1986, 1995, 2000 and 2020 available at sub-zone level from AVV in their national modelling system (in Dutch, *Landelijk Model Systeem*, LMS) is used. LMS zones are standard transport analysis zones in the Netherlands. The country is divided into 345 LMS main zones and 1308 LMS sub-zones (shown in Figure 3.1). In this research LMS sub-zones are taken as analysis units. The Employment data from AVV has the details about the economic sector but missing information about size of those sectors. In order to recover this shortcoming, the database of the national employment register LISA (*Landelijk Informatiesysteem Arbeidsplaatsen*) for year 1996 and 2000, which has details about the type and size of the economic sector at 4-digit Postal Code (PC) level, is additionally used. The LMS sub-zones are spatial aggregate of PCs. Based on type and size of economic sector (Table 3.2) both the LISA and AVV databases were used to split the jobs into physical, virtual and hybrid space categories at LMS sub-zone level.

Working population data:
The spatial distribution of the overall working population is also available from AVV at LMS sub-zone level, but without information about telecommuters. The socio-economic characteristics of the working population are therefore used to distribute telecommuters spatially at LMS sub-zone level. The Housing Demand Survey by MVROM (2002) (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, (MVROM) in Ducth), shows that the share of telecommuted jobs in the Netherlands is well above average for highly educated people with a high income level and residing in upscale urban residential environments. Based on literature survey, the criteria used for the spatial distribution of telecommuters according to education, income, and the urbanization level of their residential areas are given in Table 3.3. The urbanization level is derived from CBS (2005b), which calculates this indicator based on address density.

For the year 1986, 1995, 2000 and 2020, the criteria adopted in Tables 3.2 and 3.3 were used for estimation of overall telecommuted jobs and number of telecommuters at LMS sub-zone level. In order to implement job accessibility models for hybrid space, according to the figures adopted in Table 3.1, these telecommuted jobs were further distributed into hybrid and virtual components and telecommuters as weekly and monthly commuters. Rest of the jobs are in physical space and accessed by daily commuting as described in section 3.2.

Table 3.3 Distribution of telecommuters according to their education, income, and urbanization level of their residential location in 2000 (in percent)

Urbanization Level	**High Income**			**Middle Income**			**Low Income**		
	High Edu.	Middle Edu.	Low Edu.	High Edu.	Middle Edu.	Low Edu.	High Edu.	Middle Edu.	Low Edu.
Less Urbanized	6.67	3.33	3.33	3.33	1.67	1.67	0.00	0.00	0.00
Moderately Urbanized	6.67	3.33	3.33	3.33	1.67	1.67	3.33	1.67	1.67
Highly Urbanized	13.33	6.67	6.67	10.00	5.00	5.00	3.33	1.67	1.67

Source: Figures in this table are adopted from these documents (Johnston & Nolan 2000; Willigenburg & Van Osch 2000; CBS 2002; Goetgeluk *et al.* 2002; Van Oort *et al.* 2003b).

Travel time data:
AVV has calculated intra and inter LMS-sub zone travel times for each Mode of Transport (MoT) based on the existing infrastructure for (1986, 1995, and 2000) and for the future (2020) by incorporating the planned new transportation infrastructure. In the Netherlands, multi-mode commuting (walking/cycling plus bus, tram or train) is very common (Martens *et al.* 1999; Van Wee *et al.* 2001). Along with that people who telecommute normally can avoid rush hours for their occasional physical trips to work. Thus for their flexible commute timings, public transport

Figure 3.1 Netherlands' LMS sub-zone boundaries

will not be available so frequently. It is therefore likely that they have a tendency to make more use of private MoT or a combination of private and public MoT (Graham & Marvin 1996; Sheller & Urry 2004). For both the private and the combination of (private and public) MoT (will be referred as public MoT in this research) the shortest intra and inter LMS sub-zone travel times were adopted for years 1986, 1995, 2000, and 2020.

Perceived Intensity of Distance Decay:
The last component to be estimated is the intensity of distance decay. Commuting data from the Origin and Destination Transportation Survey (ODS) was available for the years 1986, 1995, and 2000 from Statistics Netherlands. For the year 1986, the ODS data was collected at municipal level and subsequently disaggregated to LMS sub-zones by using the working population and number of jobs both at the LMS sub-zone and municipality level.

The data for the years 1995 and 2000 were collected at 4-digit PC level. The LMS sub-zones are a spatial aggregate of PCs, so the commuters were aggregated based on their origin and destination PCs and according to their MoT. For the year 2020, ODS data for 2000 was extrapolated using the change in the number of trips by each mode of transport projected for year 2020 by Martens and colleagues (1999).

The exponential function (Equation 3.2) was used to compute the distance-decay parameters (β in Equation 3.2) when it provided a better fit than other functions with the empirical commuting data. The distance-decay parameters for both private and public MoT for different Mean Trip Lengths (MTL) for the years 1986, 1995, 2000, and 2020 were computed. These value were further refined for physical, virtual and hybrid components of the model.

The *'Law of Constant Travel Time'* ('Brever-wet' in Dutch) states that, notwithstanding changes in modal split, the individual's total time spent on transport will remain more or less unchanged (Hupkes 1982). This rule is verified at aggregate level by Mokhtarian and Chen (2004) and Schaffer and Victor (1997). Therefore, the assumptions made for increased commuting time

Table 3.4 Selected distance-decay parameter, beta (β) values

Year	Type of Commuters	Private Mode of Transport		Public Mode of Transport	
		Mean Trip Length (Minutes)	β Value	Mean Trip Length (Minutes)	β Value
1986	Daily	22.2	0.10478	29.7	0.10260
	Weekly	33.3	0.06102	44.6	0.06988
	Monthly	44.4	0.03905	59.4	0.04853
1995	Daily	22.0	0.10891	29.0	0.10681
	Weekly	32.9	0.06182	43.5	0.06988
	Monthly	43.9	0.03957	58.0	0.04853
2000	Daily	23.5	0.10248	30.4	0.10032
	Weekly	35.2	0.06111	45.6	0.05853
	Monthly	47.0	0.03961	60.7	0.03715
2020	Daily	25.5	0.09322	30.4	0.10022
	Weekly	38.3	0.06211	45.6	0.04853
	Monthly	51.1	0.03975	60.8	0.03105

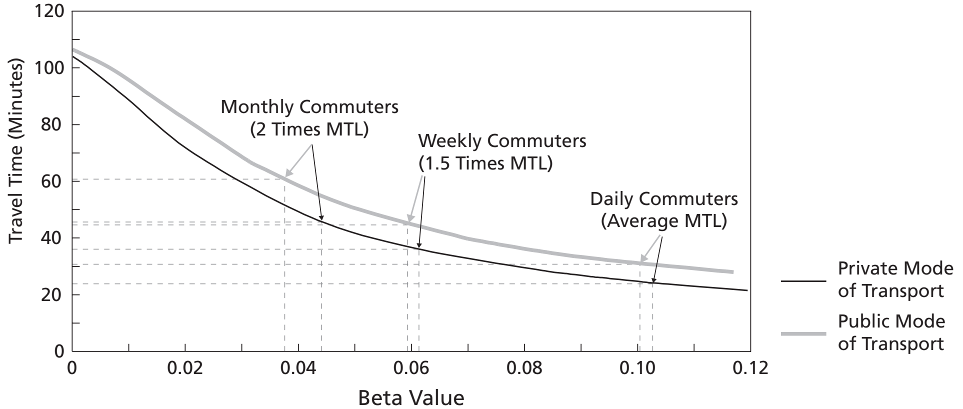

Figure 3.2 Selection of distance-decay parameter, beta (β) values for the year 2000

per trip for telecommuters while having lesser commute trips, are not unrealistic. Empirical data and analyses in the Netherlands support them (Van Reisen 1997; MVROM 2002). By taking into consideration the *Law of Constant Travel Time*, it is estimated that, for jobs in hybrid space, weekly commuters commute 1.5 times the MTL of regular *daily commuter*s in physical space and, for jobs in virtual space, *monthly commuters* commute twice the MTL of *daily commuters*.

The distance-decay parameter values for *daily*, *weekly*, *and monthly commuters* have been generated from the computed distance-decay parameters, using the relevant MTL for both private and public MoT for the years 1986, 1995, 2000, and 2020 (Table 3.4). How those values were implemented is shown graphically in Figure 3.2 for the year 2000. These distance-decay parameter (β) values for daily, weekly and monthly commuters for both private and public MoT were applied to compute job accessibility.

3.6 The model results compared

Both Hansen's model (destination-constrained potential-accessibility model) and Shen's model (potential-accessibility model with competition factors) are applied to explore future changes in job accessibility due to increasing telecommuting. A scenario-based approach is followed. In the Physical Space Scenario (PSS) jobs are only accessed in physical space, and in the Hybrid Space Scenario (HSS) jobs are accessed in both physical and virtual space. Job accessibility was calculated by applying both models for PSS and HSS of 1986, 1995, 2000 and 2020 at LMS sub-zone level.

The performance comparison of the two models presented here is based on the job accessibility measured for the years 2020. For year 2020, it is projected that 45 percent of the total job will be telecommuted. Hence, a significant influence of virtual space on job accessibility can be expected as compared to other years. Further, three cities are selected to compare the PSS and HSS job accessibility values by both models: Amsterdam, Groningen and Terneuzen. They represent urban nodes with a large, medium and small population – 731,288, 173,139 and 34,539 respectively in 2000 (CBS 2005b) – and different geographical contexts. Amsterdam is part of the heavily urbanized Randstad region, Groningen is a medium-sized centre of a large region

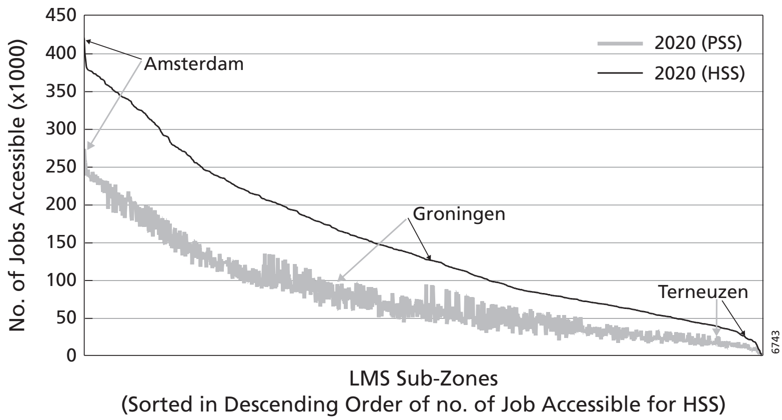

Figure 3.3 Number of jobs accessible in the Netherlands in 2020 (PSS and HSS) at LMS sub-zone level by the destination-constrained potential model (Hansen)

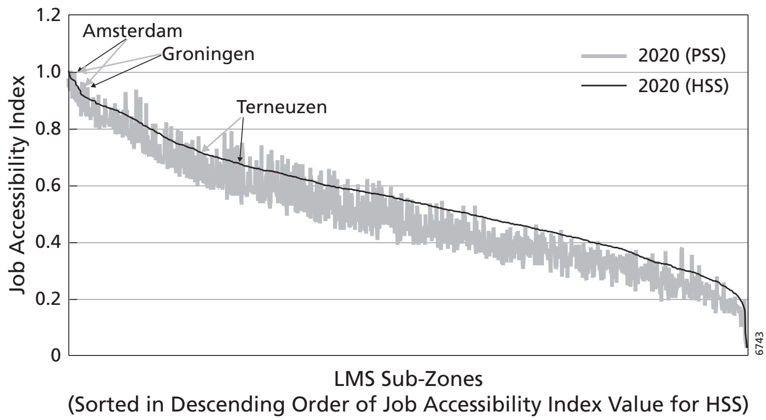

Figure 3.4 Job accessibility index in the Netherlands in 2020 (PSS and HSS) at LMS sub-zone level by the potential model with competition factors (Shen)

with a relatively low population density and Terneuzen is a small centre of a small region (Figure 3.1). Analyzing the results for these three different types of cities will provide insight into the plausibility of the outcomes of these two models.

It is clear from Figures 3.3 and 3.4 that, as could be expected from the input parameter settings, job accessibility scores higher in hybrid space than in physical space. The trend of improvement in job accessibility is consistent and plausible for the Hansen model, while for the Shen model this is much less the case. Moreover, the Shen model produces unrealistic levels of job accessibility for Groningen and Terneuzen. Especially Terneuzen gets much higher job accessibility values than expected for both PSS and HSS. Moreover, the accessibility values calculated by the Shen model are unrealistic given the size of the city regions studied. Especially Terneuzen, a peripheral and small region, gets job accessibility levels well above the national average for both the PSS and HSS scenario. This result is derived from the ratio nature of the Shen model, for which uniform spatial distribution of opportunities and opportunity seekers is a prerequisite. If that condition is not met, which is the case here, such effects can be expected. Almost same trends were found for Teneuzen for the year 1986, 1995 and 2000. Since all factors are the same for all the years for the computation of accessibility by both models, hence, the Shen model is more sensitive to spatial distribution of jobs and working population in a local context.

An additional option for assessing the performance of the two models is to compare the results for the year 1995 with the job accessibility measured for the Netherlands by Geurs and Ritsema van Eck (2003). The spatial pattern of job accessibility estimated for the year 1995 by applying the Hansen model for PSS is very similar to the results reported by them. The outcomes of the Shen model are substantially different. Further, the performance of the both models is assessed by analysing the spatial patterns of job accessibility measured by both models for PSS and HSS.

3.7 Spatial patterns of job accessibility

Given the outcomes of the performance comparison of the two applied models (Section 3.6), the spatial variation in job accessibility for the years 2000 and 2020 based on the estimates calculated by both models are presented: for year 2000 (Figures 3.5 to 3.8) and 2020 (Figures 3.9 to 3.12). Along with 2020, the year 2000 is selected, because by this year a sizable share of jobs (15 percent of the total) are being held by telecommuters and around this year the growth rate of the ICTs sector was also at its peak (Paul *et al.* 2003). The comparison of job accessibility for year 2000 and 2020 will assess the development of spatial patterns of job accessibility.

It is apparent from Figure 3.5 and 3.6 that job accessibility computed by Hansen model for PSS and HSS for year 2000 is highest in and around the Randstad region in the west-central section of the country (comprising the four main city regions of Amsterdam, The Hague, Rotterdam, and Utrecht). However, the low-density areas between these largest cities, the *Groene Hart* (Green Heart), bands of cities in the eastern and southern parts of the country, and individual regional urban centres in the periphery also show higher accessibility values. Compared with the PSS, overall accessibility values in the HSS are higher over the whole country. The Randstad maintains its strong position; the transition zone between the Randstad and the periphery of the country benefits particularly.

In contrast, in the outcomes of the Shen model (Figure 3.7 and 3.8), the favourable position of the Randstad is less pronounced. A much more regionalized pattern appears with high scores for job accessibility around small- and medium-sized cities, like Terneuzen, Emmen, and Heerenveen. In the HSS, this configuration is even more pronounced than in the PSS. It becomes clear that the Shen model, by incorporating competition, gives much more weight to local labour market circumstances, which has made a number of small and medium sized cities favourable.

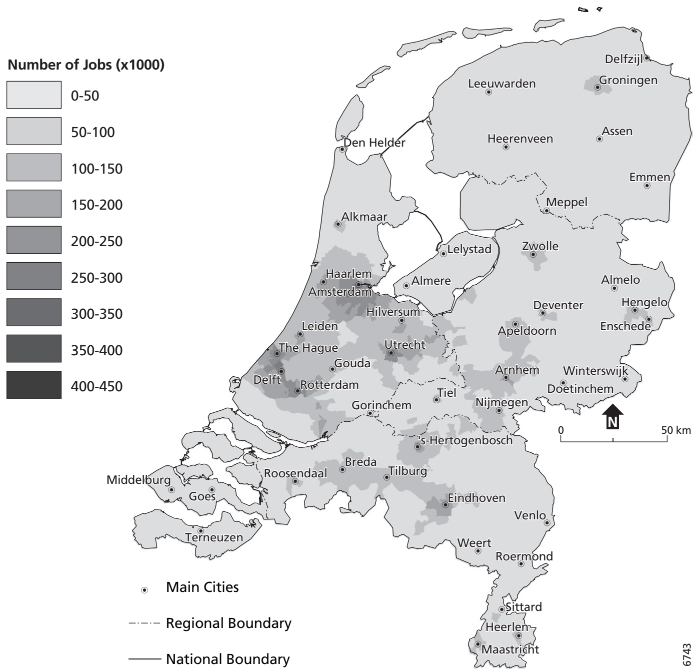

Figure 3.5 Jobs accessible in PSS of 2000 by destination-constrained potential model (Hansen)

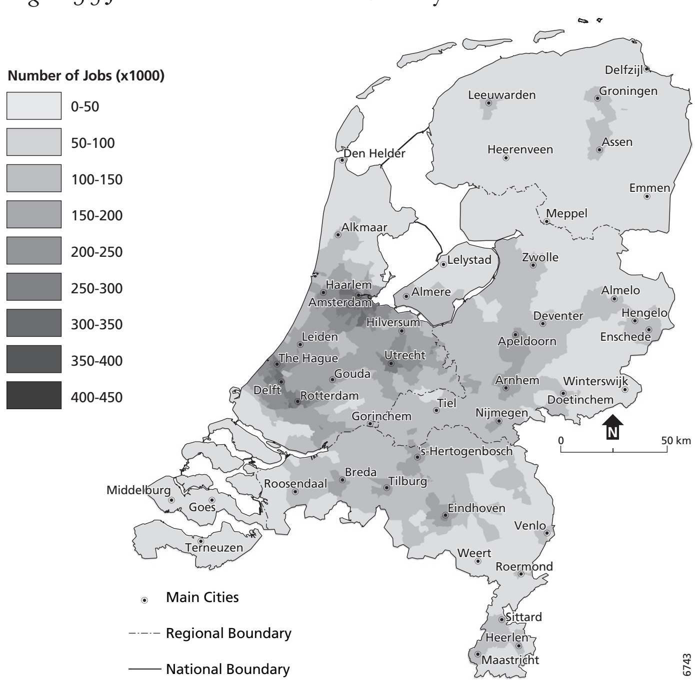

Figure 3.6 Jobs Accessible in HSS of 2000 by destination-constrained potential model (Hansen)

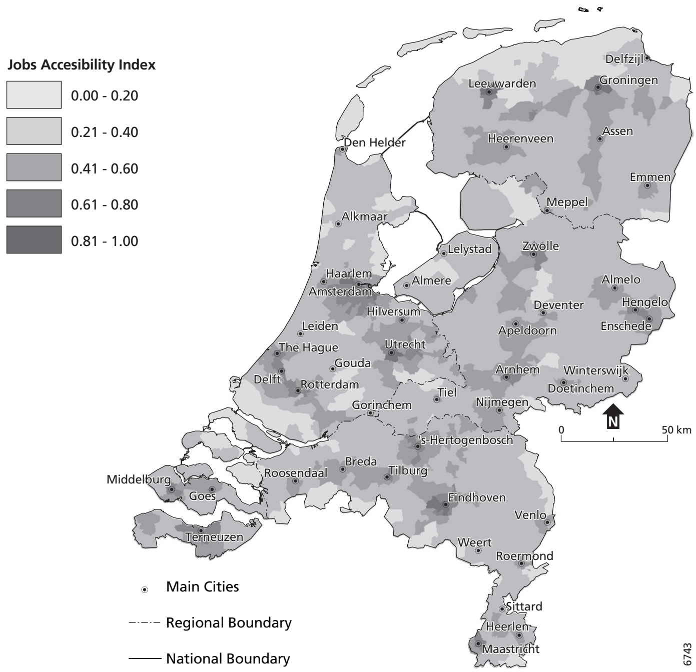

Figure 3.7 Job accessibility in PSS of 2000 by potential model with competition factor (Shen)

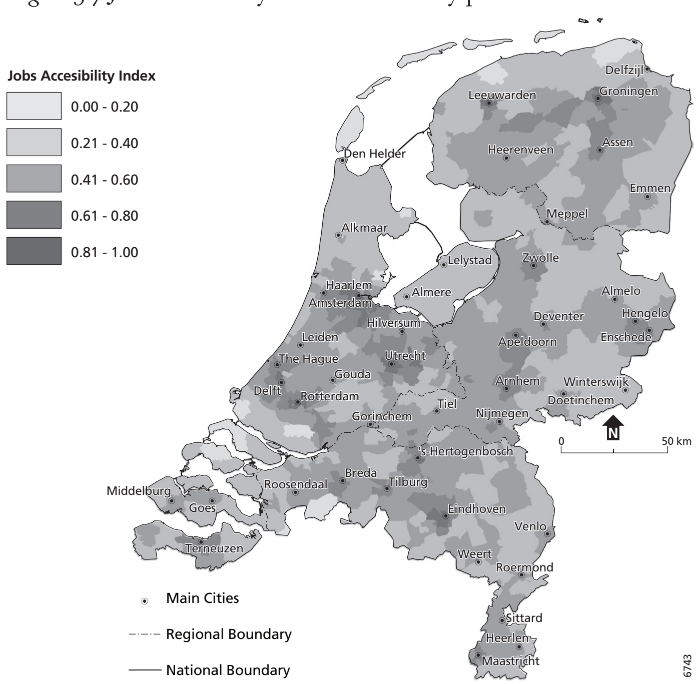

Figure 3.8 Job accessibility in HSS of 2000 by potential model with competition factor (Shen)

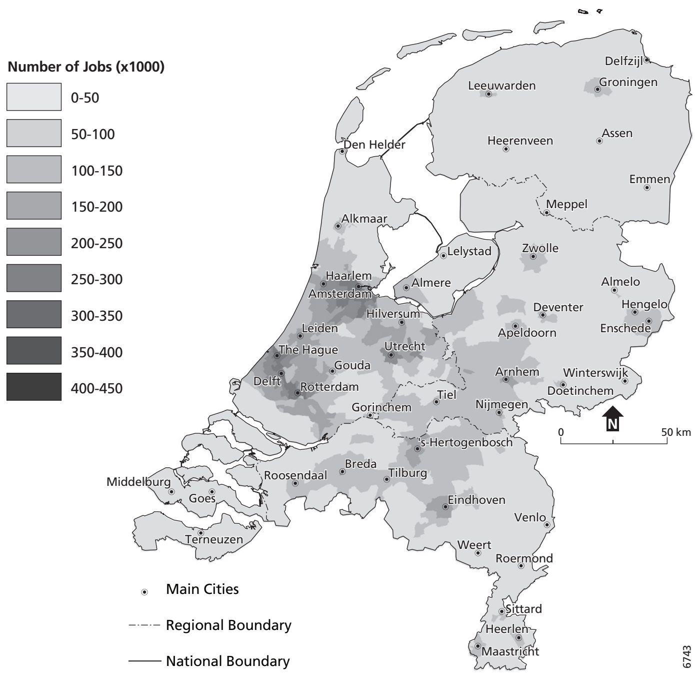

Figure 3.9 Jobs accessible in PSS of 2020 by destination-constrained potential model (Hansen)

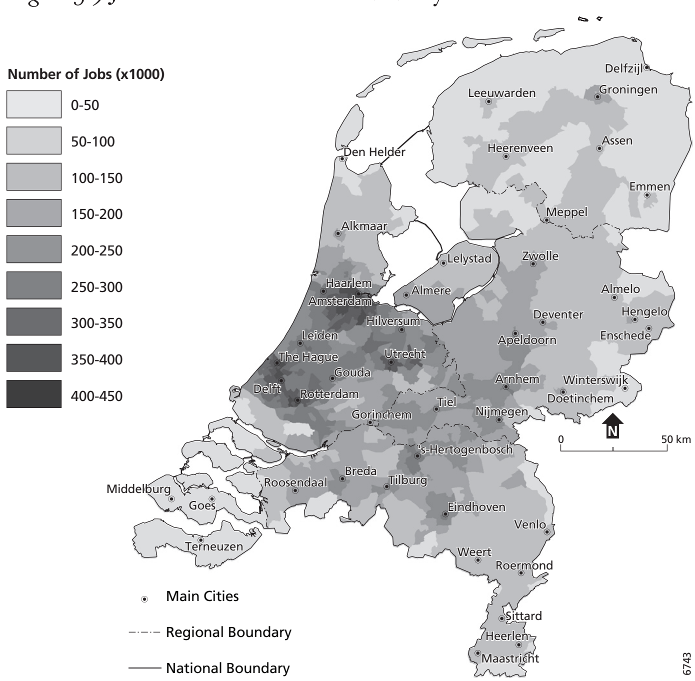

Figure 3.10 Jobs accessible in HSS of 2020 by destination-constrained potential model (Hansen)

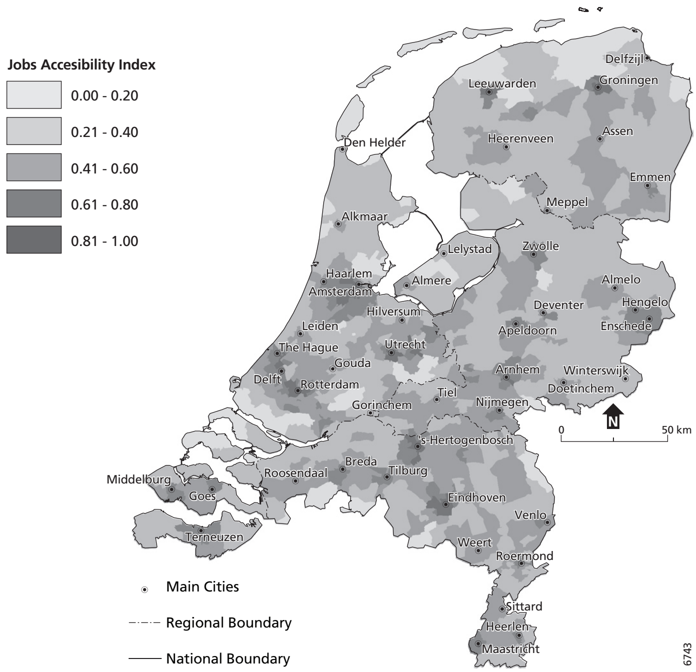

Figure 3.11 Job accessibility in PSS of 2020 by potential model with competition factor (Shen)

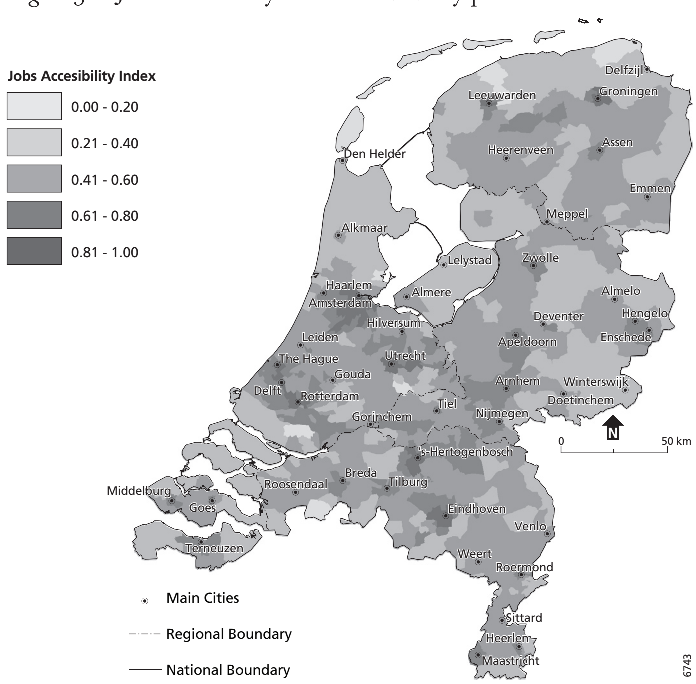

Figure 3.12 Job accessibility in HSS of 2020 by potential model with competition factor (Shen)

Not surprisingly, outcomes of both model for PSS and HSS of the year 2020 yield comparable differences between the two models and the two scenarios. As mentioned earlier, it is assumed that, in 2020, 45 percent of all jobs will include some sort of telecommuting. This would cause a major overall improvement in job accessibility, as was already apparent in Figures 3.3 and 3.4. The general spatial patterns of the Hansen model outcomes (Figures 3.9 and 3.10) are, at first sight, quite similar to those for year 2000. It is however important to note that, in 2020, the majority of the low-density areas in the country will also enjoy relatively high job accessibility. Only the northern and south-western parts of the Netherlands are clearly lagging behind. However, it is also clear that the Randstad area remains the dominant region for better job accessibility in the Netherlands.

The Shen model (Figures 3.11 and 3.12) again produces a localized picture, even more strongly than for the year 2000 (Figures 3.7 and 3.8). Compared with the results of the Hansen model, the Shen model outcomes have no clear focus on the Randstad. Job accessibility is again high within a relatively short range around small- and medium-sized cities in the Netherlands.

Summarizing, both the Hansen and Shen model compute a major improvement in job accessibility in hybrid space compared with a physical space scenario. The spatial patterns of accessibility are, however, quite different. Since the same data is used and parameter settings are comparable, the differences in results for the Hansen and Shen models must lie in the competition factor incorporated in the Shen model. Thus, competition emphasizes differences in the demand and supply of jobs at local level over accessibility at a regional scale. This emphasis is not appropriate for land use transportation interaction studies at regional or national level, where the regional disparities also need to be considered. Concluding, the Hansen model computes scenario outcomes that are plausible, interpretable, and in line with other research on this topic.

3.8 Conclusions

ICTs are enabling people to access their jobs in virtual space. This resource complements traditional physical commuting and removes the friction of distance and time to some extent. Consequently, a hybrid space (comprising of physical and virtual space) is emerging in which many workers will commute both physically and virtually (telecommute). The travel time saved by telecommuting will most likely be partly spent on longer, but less frequent commuting trips than for the traditional commuter in physical space. Thus telecommuters will still have a certain commuting frequency per week or month.

In hybrid space, new meanings of distance and accessibility are evolving. This trend will probably give more weight to the personal preferences and capabilities of the working population and the nature of jobs over the spatial separation between the locations of jobs and workers as the major determinants for measuring job accessibility. However, many opportunities remain in physical space. Moreover, hybrid jobs will continue to require physical interaction with localized personnel and the facilities of the employer. The nature of human beings also makes face-to-face social and environmental interaction an essential component of life.

Of the two models assessed, Hansen's destination-constrained potential-accessibility model gave better (more plausible and better interpretable in given geographical context) results for job accessibility patterns in the Netherlands. In the Shen model, the expected accessibility value of a location is the ratio of the total number of accessible opportunities to the total number of opportunity seekers in the area concerned. Thus, Shen's model assumes more or less closed regional labour market. Moreover, the strong influence of regional labour market conditions on the final accessibility value is not consistent with the argued assumption that telecommuting will allow and stimulate interregional commuting.

From these results, it can be concluded that under the influence of ICTs, job accessibility in the Netherlands has improved and will further improve in the future. The western heartland of the country has always been the most attractive for job seekers and this situation will continue, even in hybrid space. However, in the hybrid space more opportunities in the Randstad can also be accessed from adjacent medium-sized city regions and rural areas, not only by telecommuting in virtual space, but also with a limited frequency of commuting in physical space. In the longer term, this situation with respect to geographical accessibility might also further widen the residential locational margins for telecommuters. For northern and south-western regions, which have the lowest levels of job accessibility in physical space, job accessibility will improve in hybrid space, but they will become even more peripheral in relative terms. All these findings validate the expectation that an accessibility model that incorporates use of ICTs, produces useful information for planning and decision making purposes for the Netherlands' spatial planning and policy making institutions.

4 Distance-Decay Parameter Behaviour while Modelling Telecommuting

De Jong, T. & S. Muhammad, 2007. Distance-decay parameter behaviour while modelling telecommuting. Manuscript submitted for publication.

Abstract

While assessing the effects of telecommuting on job accessibility, the distance-decay parameter, as an impact of this, must somehow be relaxed. Usually there is a clear notion of an increase in mean commute trip length for telecommuters in case they commute. Hence the question of how to adopt the distance-decay parameter's value of this changed mean trip length while not having available the real-time origin-destination commute-frequency data for telecommuters becomes important in accessibility modelling. In this research it was found that the options were restricted to certain minimum and maximum values of the distance-decay parameter, with a non-linear relationship between mean trip length and the distance-decay parameter values. Furthermore, the distance-decay parameter is also influenced by the geographical extent of area concerned.

4.1 Introduction

As a consequence of the massive use of modern, computer-based Information and Communication Technologies (ICTs) a *hybrid space* situation has emerged in many countries of the world. Hybrid space is composed of two spatial 'modes'. First the traditional physical space, where distance and accessibility by physical means of transport play an important role in the spatial organization of society. The new *virtual space* has become interwoven with physical space where distance has taken on a new meaning. In this spatial mode, people can work from home (telecommute), shop from home (teleshop), and so forth.

In physical space the effect of distance was modelled by using various distance-decay functions in potential/gravitational models (Weibull 1976; Ritsema van Eck & De Jong 1999; Thorsen *et al.* 1999; Geurs & Ritsema van Eck 2001; Van Wee *et al.* 2001). By using these models in physical space accessibility was measured in terms of the spatial separation of opportunities and opportunity seekers, but in virtual space this friction of distance is reduced to such a level that people can access opportunities at a distance of thousands of kilometres in a matter of seconds. To access those opportunities in physical space would have required many hours of travelling. However, the majority of opportunities are still only being accessed in physical space and even those accessed in virtual space are often also partly accessed in physical space. According to Mokhtarian (1998), telecommuting is not an exclusive process. People sometimes prefer to telecommute and later (also) to commute. There may be a trend for people to commute for a certain number of days per week or month using the flexible timings for travelling in order to reduce travel time. To accommodate this behaviour in spatial modelling, adaptations must be made to the existing opportunities-accessibility models.

According to Couclelis (2000), Hajer and Zonneveld (2000), and Shen (2000), the influence of ICTs allows opportunities to be divided into three categories:

- Opportunities that are accessed through virtual space, at least in part: ICTs are an indispensable component of these opportunities.
- Opportunities that can be accessed either through physical space or virtual space: ICTs are the preferable means of accessing these opportunities, but are not an indispensable component.
- Traditional type opportunities that belong exclusively to the physical space: these are only accessed by physical means of transportation.

Opportunity seekers can also be divided into three broad categories, based on whether they have ICT skills or not and whether they use them for accessing opportunities in virtual space. People with ICT skills in principle have the choice between commuting or telecommuting. If they telecommute, they can be further categorized into two main classes: full-time telecommuters (accessing opportunities exclusively in virtual space); part-time telecommuters (accessing opportunities in both physical and virtual space). The full-time telecommuters are few in number, and distances in physical space are not important for them. For them, the ICTs infrastructure (the capabilities of desktops, mobile devices and Internet) matter more than means of commuting in physical space. In the Netherlands, even these full-telecommuters also commute in physical space, although with less frequency. But they commute over longer distances than regular commuters (Van Reisen 1997; Martens *et al.* 1999; Mokhtarian & Bagley 2000). Thus, telecommuters who partly commute in physical space need to be incorporated in the existing job-accessibility models. As a result, to accommodate the effects of ICTs, the existing models would have to be disaggregated for the use of different values of distance-decay parameter (for commuters and telecommuters) in a hybrid space. This was done for the traditional potential accessibility model, by Shen (1998a; 2000). In the next section, the Shen-model is briefly described. Then, the factors affecting the distance-decay parameter are discussed. Subsequently, the effects of telecommuting on the parameter values are analysed with real world and artificial examples. Finally, conclusions are drawn.

4.2 A potential accessibility model accommodating telecommuting

According to Shen (2000), both opportunities and opportunity seekers can be divided into three categories. In that way, if there are O total opportunities and P is the total number of opportunity seekers, then the ϕO opportunities (ϕ being the appropriate proportion of the total opportunity O) available in virtual space will be accessible to the δP people who have ICT skills (δ being the appropriate proportion of the total opportunity seekers P) and c is the necessary means of accessing these opportunities. The λO opportunities are accessible either in physical or virtual space to δP opportunity seekers who use virtual space to access them and to $(1-\delta)P$ opportunity seekers who use physical space. While $(1-\phi-\lambda)O$ are the opportunities, these can be accessed only in physical space and are available to all opportunity seekers P. The means of accessing these opportunities are the transportation modes m. The accessibility for different groups of opportunity seekers can be measured using the following equations.

- For opportunity seekers who do not have ICT skills (accessibility of opportunities in physical space):

$$A_i^v = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m)+\delta_k P_k^m f(t_{kj}^{cm})]} \tag{Eq. 4.1}$$

- For opportunity seekers who have ICT skills (accessibility of opportunities in hybrid space):

$$A_i^{cv} = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m)+\delta_k P_k^m f(t_{kj}^{cm})]} + \Sigma_j \frac{\phi_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k \delta_k P_k^m f(t_{kj}^{cm})} \tag{Eq. 4.2}$$

The details of these equations can be found in Shen (2000). To make these formulas specific and operational, the distance-decay functions $f(t_{yz}^x)$ must first be defined. In physical space, the zone-to-zone travel times (or travel distance) for each mode of transport can be used in a straightforward manner. However, for telecommuters, travel time can also be defined, if they make at least some complementary trips in physical space. The literature on telecommuting suggests that this is indeed the case (Van Reisen 1997; Shen 1998a; Martens *et al.* 1999; Couclelis & Getis 2000; Mokhtarian & Bagley 2000). To calculate the average travel time for telecommuters, Shen (2000) assumed that these people typically travel to a certain type of opportunity once every τ days instead of every day and so calculated the perceived average daily travel time as:

$$t_{ij}^{tc} = \beta(1/\tau)t_{ij}^c \tag{Eq. 4.3}$$

Where:

t_{ij}^{tc} is the commute time for *telecommuters* when they commute between zone i and j

t_{ij}^{c} is the commute time for *commuters* between zone i and j

and β is the distance-decay parameter

There are two variables that determine the distance decay for telecommuters when they commute in physical space. One is the commuting frequency in physical space; the other is the zone-to-zone travel time for the transportation mode used. Thus there are M different specifications of distance-decay parameters for telecommuters, each corresponding to a transportation mode used in physical space.

Different distance-decay functions such as power, exponential, Gaussian, and log-logistics are used in computing accessibility (Geurs & Ritsema van Eck 2001). In these functions, the effect of distance is represented by one or more parameters known as *distance-decay parameters*

(Hansen 1959; Fotheringham 1981; Petersen 2001), and also as *deterrence parameters* (Batty 1976). The distance-decay function itself is also known as the *inverse distance function* or *impedance function* or *distance lapse rate*. A distance-decay parameter measures the relationship between the distance and the size of the observed interaction when all other determinants of the interaction are constant. This relationship is assumed to be an accurate reflection of the perception of distance as a deterrent to interaction. Thus, when an estimate of a distance-decay parameter is obtained through the calibration of a gravity model, the traditional interpretation of this estimate is that it is a purely behavioural measure of the relationship between distance and interaction (Fotheringham 1981). This implies that, unlike the traditional Newtonian gravity formula, the distance-decay parameter is not a constant, but varies with the context in which interaction is measured and that care must be taken when the empirically-derived distance-decay parameters are used in the evaluation of alternative scenarios describing a spatial distribution of activities and travel patterns very different from the current situation.

In addition to this, in the literature on gravity-based spatial-interaction models, several authors (Fotheringham 1981; Fotheringham 1983; Sheppard 1984; Gordon 1985; Tiefelsdorf 2003) indicate that distance-decay functions depend on the spatial configuration of the area concerned and the interaction behaviour of the population (commuting patterns for jobs). Thus, if we want to apply our models successfully, we must estimate the distance-decay parameters accurately. To do so usually involves the mean or overall trip length statistic, since on the one hand it is closely related to the distance-decay parameter (Hyman 1969) and on the other hand its values are easily interpreted by scientists and decision makers alike.

To estimate job accessibility in hybrid space where people can both commute and telecommute, disaggregated potential models (like the Shen model described earlier) are often used. They need different distance-decay parameter values for jobs being accessed in both physical and virtual space. It is found in practice that the average commuting distance for telecommuters is longer than for daily commuters, when telecommuters commute for a certain number of days per week or month (Mokhtarian 1988; Mokhtarian & Krishna 1998). These authors report, on the basis of several empirical studies, that the average telecommuting distance is 1.8 to 2.3 times that of the average regular commuting distance. In the Netherlands, this would equate to an average of 21 kilometres for daily commuters and 40 kilometres for telecommuters when they also commute (Martens *et al.* 1999). Hence, to model the effects of telecommuting (that is, a longer Mean Trip Length (MTL) in order to reduce the influence of distance decay in this particular situation), a smaller value must be chosen for the distance-decay parameter. But the question remains of the extent to which the value of this parameter should be relaxed and what other factors need to be considered.

4.3 Factors affecting the distance-decay parameter

In this research, gravity models (which have a strong analogy to potential models) have been used to investigate whether the relationship between the distance-decay parameter and the mean trip length statistic is continuous and linear or non-linear and, whether the value of the mean-trip-length statistic is influenced by the extent of the area concerned. At the same time we investigate whether there is a sound theoretical case for an upper limit on the mean trip length statistic that is always below its maximum practical value has also been investigated. For these

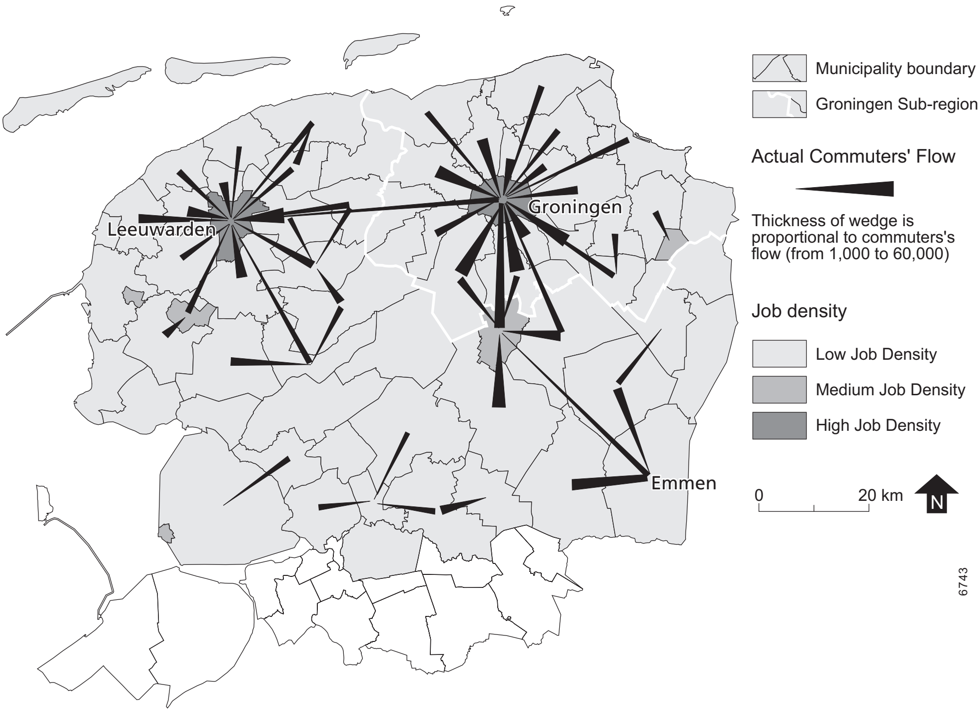

Figure 4.1 Job density and actual commuters' flows in the North-Netherlands in 2001

purposes, a commuting survey at municipal level (Origin Destination Survey) commissioned by the Statistics Netherlands (CBS) in (2001) has been used.

This dataset is the only recent official source for commuting data, but regrettably it is not complete (only the origins/destinations of the thirty most important commuter flows to other municipalities are registered for each municipality). This deficiency has the least effect in the relatively isolated northern part of the Netherlands, hence this was the area chosen for the case study. Figure 4.1 shows in the background the job density for the 68 municipalities that together make up the North-Netherlands region. The job density, measured as jobs per square kilometre, varies from 11 to 868. The city of Groningen, the region's prime urban centre has the highest density. The major (1000 commuters or more) daily inter-municipal commuter flows are shown by arrows, the width of which is proportional to the number of commuters. Most of these daily commuter flows clearly focus on Groningen and Leeuwarden, the two major cities in the region. At this level there seems to be very little overlap in the catchment areas of these two cities, indicating that commuting is still a very local phenomenon confined to a certain commuting distance (in this case within the sub-regions' boundaries). The distribution of commuters' flows is shown in Table 4.1 along with the intra municipal and inter municipal commuters' flows; the commuters' flow from other region is also included.

Within the North-Netherlands, commuters travel (including the intra municipal flows) an average distance of 16.5 minutes from home to work daily. To analyse the effects of the extent of the area concerned apart from the North-Netherlands region, the Groningen sub-region has been examined separately. This sub-region is indicated in Figure 4.1 by a thick white borderline.

Table 4.1 Commuters flow distribution and Mean Trip Length (MTL) (in minutes)

Region	North-Netherlands			Groningen		
	Abs.	Rel.	MTL	Abs.	Rel.	MTL
Intra municipal	402833	55.29	10.7	122874	47.79	8.7
Inter municipal	272279	37.37	25.2	83566	32.50	21.2
Subtotal	675112	92.66	16.5	206440	80.30	13.7
Extra regional	53482	7.34	71.8	50647	19.70	53.3
Total	728594	100.00	20.6	257087	100.00	21.5

Over 200,000 commuters within this sub-region travel on average 13.8 minutes per day. When the inter-regional commuters are also taken into account the two mean–trip–length statistics are more alike: both around 21 minutes. Therefore, to give the best comparison of the two regions, modelling should include inter-regional flows as well.

In order to calibrate the distance-decay parameter using the MTLs given in Table 4.1, the commuter flows shown in Figure 4.1 were used in a doubly-constrained gravity model to select the distance-decay function with the best fit for both the North-Netherlands region and the Groningen sub-region Three models were applied: one without any distance decay; a second with an exponential distance decay function; and a third with a power-distance decay function. By using the calibrated distance-decay parameters from these functions, commuter flows among all the municipalities were predicted. These predicted flows were compared with actual commuter flows. Table 4.2 shows the results in the form of goodness of fit statistics between predicted and actual flows. To make these statistics comparable, they have all been scaled from zero to one hundred, where zero represents a perfect match and one hundred stands for a total mismatch.
The two statistical measures, σ (sigma) and χ^2 (chi square) explained in Equation 4.4 and 4.5, give an indication of how well the observed and calculated flows correspond. They are called the 'Goodness of Fit Statistics'. However, these values are strongly influenced by the absolute values of the data set that was used. This is why percentage, which indicates an exact fit of observed and expected flows is used. The advantage of relative values is that different numbers are comparable. Even values of different data sets can be compared (Van der Zwan *et al.* 2005).

$$\sigma = \sqrt{\frac{\sum_i \sum_j \left(E_{ij} - O_{ij}\right)^2}{N}} \qquad \text{(Eq. 4.4)}$$

$$\chi^2 = \sum_i \sum_j \left(\frac{\left(E_{ij} - O_{ij}\right)^2}{O_{ij}} \right) \qquad \text{(Eq. 4.5)}$$

Where:
E_{ij} is expected trips between origin i and destination j
O_{ij} is actual past trips between origin i and destination j
N is the number of origins times the number of destinations

From the goodness-of-fit statistics presented in Table 4.2 it is clear that distance decay still plays an important role in commuting patterns. The statistics for the run of the model without

Table 4.2 Goodness-of-fit statistics between actual commuters' flows and the predicted commuters' flows with different distance decay functions

Region	**Distance decay function**	**Goodness of fit statistic (in percent)**		
		Flow difference	σ	Chi-square
Groningen	None	38.2	42.5	31.6
	Exponential	17.6	18.0	13.6
	Power	11.9	11.6	8.9
North-Netherlands	None	65.7	84.9	61.9
	Exponential	16.4	22.4	16.6
	Power	7.4	17.4	11.5

distance decay are far worse than for those which include distance decay functions. This is even more valid in every aspect for the North-Netherlands region. It indicates that spatial extent does influence the distance-decay parameter value. It is also apparent that, for all statistics, the power function gives consistently better results than does the exponential function. The values of the distance-decay parameters found (2.97 for Groningen and 3.47 for North-Netherlands) support this view, since the value for the larger area is substantially greater.

Gravity models are based on the concept of entropy maximization (Wilson 1970) on the one hand and the concept of distance decay on the other. Since these concepts tend to work in opposite directions, entropy can only be fully maximized when distance decay is not taken into account. In the case of an even distribution of jobs and residential locations over space, entropy maximization will lead to a greater mean trip length for a larger area. Model predictions without distance decay show that the mean trip length for Groningen would be less than 30 minutes, whereas for the North-Netherlands it would be well over 50 minutes.

Thus, in the case of a larger region, the distance-decay parameter also has to be larger to ensure an identical mean trip length of 21 minutes. On the other hand, most of the previous studies that resulted in distance-decay parameter values between 1 and 2 were at single-city level (Shen 1998a; Thorsen *et al.* 1999). This is consistent with the notion that relatively small parameter values go hand in hand with relatively small areas. That is the reason why in practice values between 1 for modest and 2 for strong distance-decay effects are often applied without considering the spatial extent of the area concerned.

4.4 Effects of telecommuting on distance-decay parameter values

The effects of telecommuting are usually expressed in an expected increase in the mean trip length (Mokhtarian 1988; Mokhtarian 1998; Mokhtarian & Krishna 1998). The models require a different distance-decay parameter. Before adapting such a new parameter, the nature of the relationship between mean trip length and distance-decay parameter has to be examined first. Following the results reported in the previous paragraph, further analysis used the power function, since this appeared to fit the situation best.

Figure 4.2 shows the relationship between the distance-decay parameter computed by using the power function for the mean trip length estimated with a gravity model for North-Netherlands and Groningen. This figure confirms that the relationship is complex and far from linear, as Batty (1976) explained. Both graphs stay between the upper and lower limits that are determined by minimum and maximum travel times to and from each municipality in the study area. The lower limits of MTLs are reached with high distance-decay parameter values that simulate the effect of commuters staying within their home municipality as much as possible. Hence, lower limits are dependant on the zoning unit.

In both cases, the zoning unit is the municipality. Since municipality sizes in the region are fairly similar, the lower limits should also be comparable. The two upper limits are far apart because they are determined by the longest distances within the area concerned, so these also depend on the spatial extent of the area. Although the two graphs start from an almost identical position at the lower end and are similarly shaped, the effect of the difference in the extent of the study area is clearly visible in the whole graph. The non-linearity of the relationship in the graph shown in Figure 4.2, makes it necessary to translate a predicted change in mean trip length into a matching value of the distance-decay parameter. Thus, to model a five percent increase in mean trip length, it would not be logical merely to lower the distance-decay parameter by five percent.

For future situations involving telecommuting, an increase in mean trip length would generally be expected. This rise would not be unlimited. In each case there is a maximum limit that is determined by the spatial spread of employment and the maximum distance to each employment centre within the area concerned.

Figure 4.2 shows, assuming that the distribution of employment remains unchanged, it would be technically possible to raise the mean trip length to about 60 minutes in the Groningen case and to about 90 minutes in the North Netherlands case. The question remains, however, whether the matching distribution of commuter flows would be realistic. Figure 4.3 shows the major commuter flows as predicted within the North-Netherlands region when the mean trip length reaches the maximum limit (in the case of telecommuting). The variations in residential attractiveness are shown in the background. Of course, many more flows than those shown in Figure 4.1 qualify, because virtually no intra-municipal interaction is left. But, on the other hand, hardly any commuter flows towards the municipality of Groningen are present.

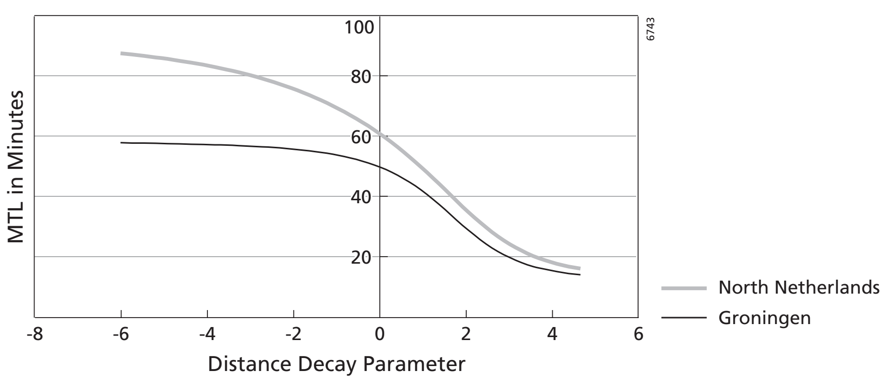

Figure 4.2 The relationship between the distance decay parameter and the estimated mean trip length for North Netherlands and Groningen

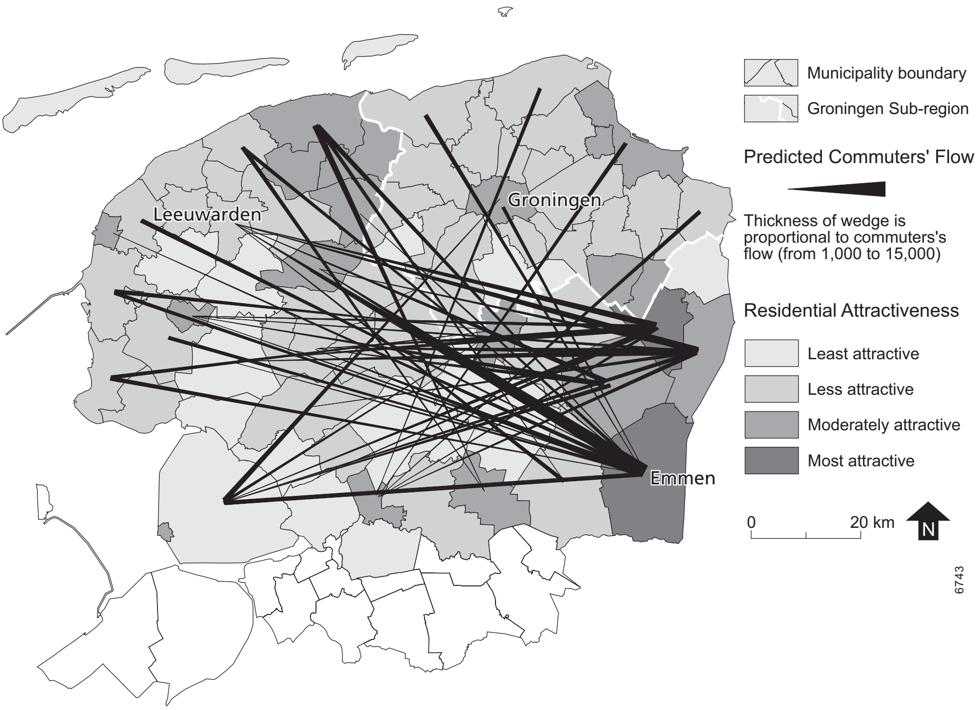

Figure 4.3 Prediction of commuters' flows with distance maximized (in the case of telecommuting), with residential attractiveness in background

The flows shown in Figure 4.3 all seem to connect residential locations at one end of the region to an employment location at exactly the opposite end. Maximizing the mean trip length models a telecommuter's behaviour that ignores any intervening opportunity, but simply seeks a residence at the location that is far away from the job location, and *vice versa*. This situation would be possible when everybody telecommutes, but that is not the case in reality.

Therefore, it can be concluded that fulltime telecommuting would lead to a situation in which distance from the working area no longer played any part in the search for a residence and only the attractiveness of the residential locations determined the choice. This effect can be modelled by setting the distance-decay parameter to zero; this value eliminates any influence of distance from any gravity/potential model. When the effect of distance is removed from the equation, the situation modelled will be one in which entropy is fully maximized (as shown in Figure 4.4). Comparison with Figure 4.1 reveals that clear catchment areas have disappeared and many commuter flows towards Leeuwarden and Groningen cross each other as many commuters now choose to live in areas with high residential attractiveness, such as the southeast of the region near the city of Emmen.

The commuter patterns shown in Figure 4.4 seem to represent the situation of telecommuting at its peak. There is no good reason for commuters to choose to ignore areas of high residential attractiveness simply to live further away from their work location. The practical implication is that the left hand side of the graph in Figure 4.2 should be ignored; the distance-decay parameter should not be set to values equal or below zero. Consequently, we can read from the graph what

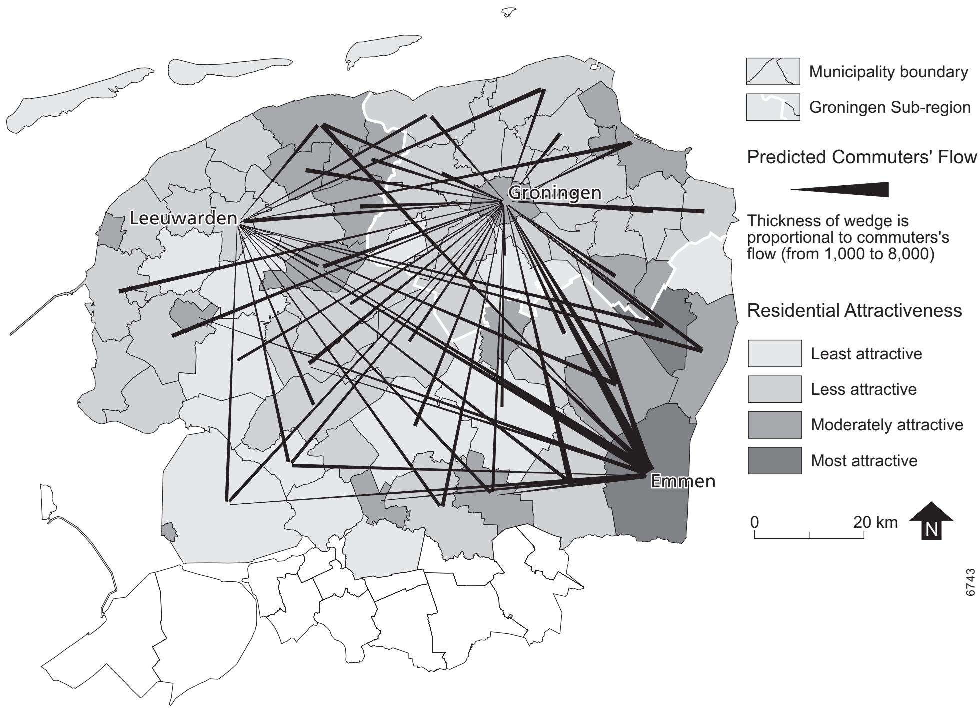

Figure 4.4 Entropy maximized prediction of commuter flows (in the case of telecommuting), with residential attractiveness in background

the maximum values for the mean trip length in that case would be. So effectively, under the influence of telecommuting, the mean trip length for the North-Netherlands region could rise from 21 to 60 minutes, but the comparable maximum for the Groningen sub-region would be only 50 minutes. Again, this figure is an indication of the effect of the spatial extent of the area concerned.

4.5 Experiment outside the real world

In a real world situation, this kind of analysis is always influenced by such factors as the quality of the dataset, the uneven spatial distribution of jobs and residences, irregularities in the transport network, and the size and shape of the area concerned. In order to test the effect of the extent of the area concerned on the distance-decay parameter, the following experimental/utopian region was set up to eliminate all these factors. Figure 4.5 shows a schematized urban region where all area units are identical hexagons.

What can be seen in Figures 4.5 and 4.6 is that in a schematized actual interaction pattern in which this interaction is modelled with a singly constrained gravity model, the relationship between the mean trip length and the distance-decay parameter can be estimated in each case. Figure 4.7 shows these results and reveals the strong effect of the extent of the area concerned on the distance-decay parameter as all other conditions are equal. The actual mean trip length is set to zero on the vertical scale, so Figure 4.7 shows the deviation from the actual mean trip length as the distance-decay parameter changes. Because the shortest distances are the same everywhere, all graphs end at the same level on the right hand side. The huge variations on the left hand side of Figure 4.7 are only the result of the variation in the size of the area concerned.

It is clear that applying the usual distance-decay parameters of 1 or 2 would result in very different mean trip lengths (overestimations of up to 300 percent). Thus, in order to model the distance-decay parameter's value, the correct mean trip length is required. This, together with the dynamics of commuters' flow, largely depends on the geographical extent of the area concerned. The larger this is, the larger is the distance-decay parameter that needs to be adopted so that it results in the same mean trip length.

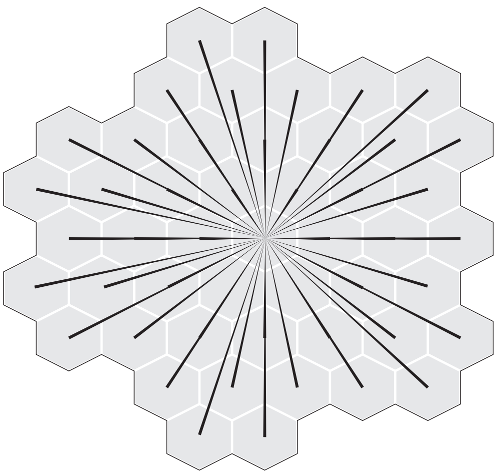

Figure 4.5 Single region system

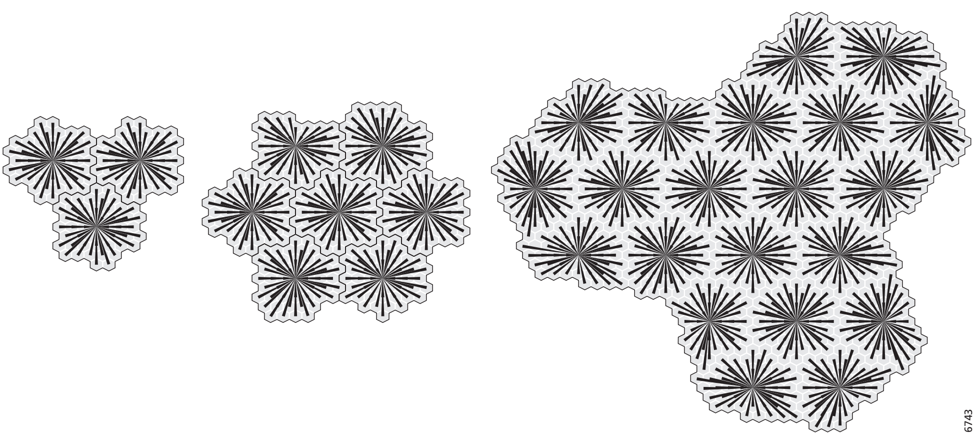

Figure 4.6 Triple, seven, and twenty-one region systems

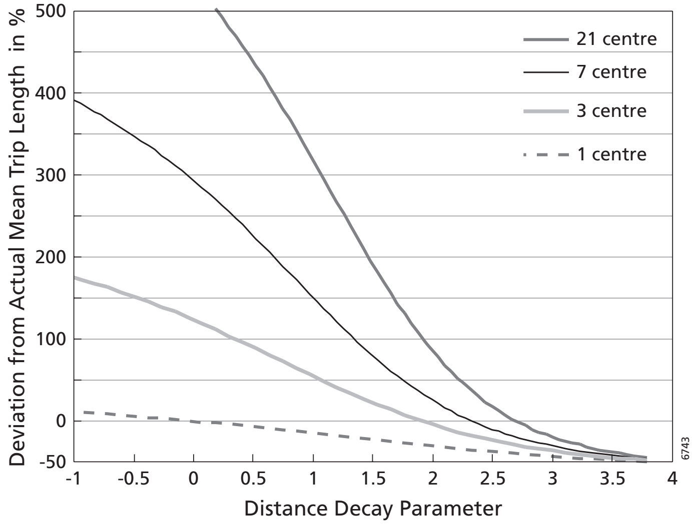

Figure 4.7 Relationship between distance-decay parameter and estimated mean trip length for four areas of different spatial extents

4.6 Conclusions

In practice, when using potential accessibility models, a distance-decay parameter with a value between one and two is often chosen regardless of the spatial extent of the area concerned. The distance-decay parameter is thought to be a proxy for distance behaviour, since the parameter reflects the willingness of people to overcome distance. In this research it has been found that the value of the distance-decay parameter depends strongly on the extent of the area concerned. The larger the area, the greater is the value of the distance-decay parameter needed to keep the modelled mean trip length at the same level.

Moreover, it is clear that, owing to the non-linearity of the relationship between mean trip length and distance-decay parameter, modelling the effect of telecommuting is not simply a matter of reducing the value of the distance-decay parameter. The maximum value of the mean trip length that could technically be realized does not produce very likely commuter patterns. It seems justified to argue that the distance-decay parameter should never be set to a value equal or below zero, which further limits the maximum mean trip length that could be achieved.

In this research, it has been clear that the extent of the area concerned influences the (maximum) mean trip length and also the value of the distance-decay parameter. Hence the notion that a distance-decay parameter is an otherwise independent reflection of distance behaviour should be abandoned. At the same time, the parameters found in different studies for different areas cannot be used by simply applying some conversion factor. A calculated relationship between distance-decay parameter and mean trip length should be the base of conversion of expected mean trip length into a matching distance-decay parameter's value.

5 Telecommuting and Residential Locational Preferences

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Abstract

Traditionally, along with stages of the life cycle and changes in people's financial status and their household composition, the commute distance has been identified as one of the main explanatory factors for residential locational preferences and subsequent migration flows. In the Netherlands, telecommuting is rapidly becoming popular and is expected to affect residential locational preferences. A hypothesis that can be raised is that telecommuting has an impact on the effect that commute distance has on residential preferences. Based on this hypothesis, this paper investigates the role of telecommuting alongside the traditional factors currently explaining residential locational preferences. This research provides evidence that, in the Netherlands, telecommuting has enabled people to commute longer distances. Currently the effect of telecommuting on the probability of relocating, however, is not significant. Telecommuting appears to have a limited effect on residential location preferences, but traditional factors, such as life cycle stages, remain the dominant explanatory factors.

5.1 Introduction

During the last three decades, in particular since 1995, Information and Communication Technologies (ICTs) have evolved to a level that enables people to access opportunities such as work (telecommuting), shopping (teleshopping), and education (e-learning) in virtual space, complementing the traditional access in physical space. Hence, a hybrid space has emerged as a mode for spatial activities. This is part of a general trend in the post-industrial society, where human activities have become increasingly person-based in the sense that a growing number of them are no longer firmly linked to fixed geographic locations (Couclelis 1998). ICTs have strengthened this trend by offering opportunities on networked personal computers, notebooks, and other mobile devices. As a consequence, people can now access opportunities in virtual space without facing the friction of spatial separation (distance). Based on this paradigmatic shift in the meaning of distance, different schools of thought have developed regarding the impact of ICTs on spatial development. Some examples are the "death of distance" by Cairncross (1998), the "rise of the new place" by Malecki and Gorman (2001) and Wilson and colleagues (2001), "feed off and fuel" by Graham and Marvin (2000) and "an old script replayed with new actors" by Mitchell (2000). Thus, the effects of ICTs on human spatial activities and resulting spatial structures are still the subject of academic discussion. Consequently predictions are diverse, particularly with respect to future urbanization trends (Couclelis 2003).

In the context of the spatial organization of work, the ICT revolution has had a strong impact on opportunities to work in places other than the employer's premises. The term *telecommuting* was first used by Nilles in 1973 to refer to "the partial or total substitution of telecommunications with or without the assistance of computers for the daily commute to work" (Mokhtarian 1991). Telecommuting is in fact a special form of teleworking. Teleworking is a broad term defined as "substitutions of all work-related travel by telecommunication and related information technologies" (Nilles 1988).

The rapid development and use of ICTs has had a strong impact on the number of people telecommuting, which has increased markedly in the last few decades (Bates & Huws 2001; Huws & O'Regan 2001; Johnston & Nolan 2002; TWF 2004; CBS 2005a). In the Netherlands in 1995, the share of all jobs that were fully telecommuted with a formal contract was 2.3 percent and another 6.3 percent were mobile, with travelling workers using telecommunication for their occupation. In the year 2000, the share of all jobs in the Netherlands that were being telecommuted from home had risen to 6 percent, with a further 6 percent mobile telecommuted, of which 3 percent by self-employed people (Willigenburg & Van Osch 2000).

Comparative international statistics indicate that the Netherlands is a forerunner. In the year 2002, 9 percent of the total employed population telecommuted for more than one full day per week, while for the European Union this percentage was 2 and for the USA 5. In 2005, these percentages were 21, 7, and 17 respectively (Todd, 2006). International statistics also reveal that in the Netherlands 45 percent of all jobs are suited for telecommuting, with 31 percent for the EU and 37 percent for the USA (Empirica 2003). This large percentage is caused by the strong services orientation of the Dutch economy.

Traditionally, along with other socioeconomic, demographic and environmental factors, job accessibility in terms of commuting distance in physical space has been important in understanding residential location choices in the Netherlands (Van Ommeren *et al.* 1997; Van Ommeren *et al.* 2000). This relationship can be understood from the preference of workers to limit their commuting distance and time (Horner 2004). Since, in the case of telecommuting, physical commuting trips are made less frequently, a longer commuting distance may be less problematic. Thus, the opportunity to telecommute may affect a telecommuter's perception and evaluation of distance, and thereby the residential location priorities and decisions (Mokhtarian *et al.* 2003). Hence, with the mentioned growth of telecommuting and other activities in virtual space, locational preferences for different types of residential environment are expected to change in a sense that different trade-offs are made between commuting time and characteristics of the dwelling and its amenities. In general terms, telecommuters will have a spatially wider range of options than traditional physical commuters. It can therefore be expected that commuters and telecommuters will have different residential locational preferences.

In order to understand the trends in urbanization dynamics in an ICT-based society, it is necessary to investigate the geographical residential preferences of both commuters and telecommuters, as well as the factors affecting these preferences. This research investigates the role of telecommuting alongside the traditional factors responsible for residential locational preferences. Although it is too early to come up with definitive answers, first indications can be found in large-scale housing surveys, especially in countries that already have a sizeable share of telecommuters. To that end, this paper presents the outcomes of analyses based on the official Netherlands' housing demand survey (Woning Behoefte Onderzoek (WBO) 2002).

In order to investigate the impact of telecommuting on residential location preferences, a series of hypotheses are developed and will be tested. Following Van Reisen (1997) and Mokhtarian *et al.* (2003), we hypothesize that the lower commute frequency, made possible by telecommuting, allows workers to accept longer commute distances. Therefore, we expect commute distances of telecommuters to be longer than those of regular commuters. In addition, since longer commute distances will be acceptable, telecommuters have better opportunities to live in suburban or rural areas that are further away from employment centres. Consequently we expect that their current and desired residential areas are more likely to be suburban or rural. Finally, the question is to what extent the decision to telecommute is made jointly with the location decision or afterwards. In the first case, telecommuting is a permanent status that is deliberately chosen to accommodate living in a suburban or rural area. Telecommuters would then be equally likely to relocate as regular commuters. In the second case, telecommuting is seen as a temporary measure to deal with an undesired long commute. Telecommuters would then be more likely to relocate in order to have a shorter commute distance. In this paper, we hypothesize that the first case holds, implying that the telecommuting decision is made in connection with the relocation decision.

To test the above hypotheses, the paper is structured as follows. First, the major determinants of residential location preferences are discussed and the selected methods for statistical research are described. We then report our exploration of whether telecommuting played any part in the selection of the location of the current residence. Next, the analysis of whether telecommuting affects the commuting distance is reported. Moreover, along with other traditional factors, the relationship between telecommuting and intentions to move in the near future is analysed. Finally, it is explored whether telecommuting will have an influence on future residential location preferences. The article concludes with a discussion of the results.

5.2 Residential locational preferences

In general, it is assumed that residential locational preferences are influenced by housing characteristics such as cost, size, and amenities and by the socioeconomic characteristics of the occupants, such as age, income, gender, and household composition (Renkow & Hoover 2000). According to Nijkamp and colleagues (1993), the life course rather than economic motives is the predominant factor in residential relocation decisions. Needs and values change over the life course and these changes are presumably reflected in changes of residential priorities (Dokmeci & Berkoz 2000; Sirgy *et al.* 2005). Along with those changes, mobility decreases with increasing age. Middle-aged households are less likely to move than younger households, and the elderly are the least prone to relocate (Michaelson 1977).

In empirical research, life cycle stages have consistently been found to correlate with locational preferences (Hansen 1959; Lamanna 1964). Lindberg and colleagues (1992), Clark and Onaka (1983) and Speare and colleagues (1975) have shed light on the relationship between reasons for moving and age. They found that housing type and size adjustment according to the composition of the household largely explain mobility over all age groups. Young couples with small households need smaller houses than older couples with more children, and the elderly with shrunken households move to smaller houses. Along with these socio-demographic characteristics, the economic status of the household and the amenities of the dwelling are also important determinants in the relocation decision. For young people, whether married or not, housing costs and tenure are important factors in deciding where to live. For those in the midlife stage, tenure, housing unit size, and housing quality are the most important determinants (Hansen 1959). Children in the household also have an effect on residential location choice. People in the childrearing stage trade-off the quality of the residential environment against job accessibility (Kim *et al.* 2005).

A second set of factors is related to the interrelation between residential and workplace location decisions of workers. The outcome of the two decisions determines workers' commuting pattern (Simpson 1987; Van Ommeren *et al.* 2000; Horner 2004; Naes 2005; Van der Laan *et al.* 2005). For example, a job change or move can make the new home-workplace combination sub-optimal, meaning that either a new move or a new job location is needed in the medium to long term (Horner 2004).

Telecommuting, either working from home or at a telecentre, can change the role of the commuting distance. For the Netherlands, Van Reisen (1997) found an average commute distance of 38 kilometres for telecommuters while in 1995, the average commuting distance in the Netherlands for regular commuters was 21 kilometres (CBS 1995). Mokhtarian and Salomon (1997), Mokhtarian and Krishna (1998) and Giuliano (1998) also show that commuting distances are larger for telecommuters than for regular commuters. Thus, telecommuting facilitates longer commuting distances in physical space with a lower commuting frequency than regular commuters (Ellen & Hempsted 2002). This increased commuting distance for telecommuters is expected to change the interrelation between the locations of workplace and residence. Thus, for telecommuters who wish to avoid the high costs and other perceived drawbacks of urban living, moving to more peripheral, low-density residential environments becomes an option (Mokhtarian 1998; Raspe & Van Oort 2004).

Although socioeconomic, demographic, and environmental characteristics still largely determine residential locational preferences (Kim *et al.* 2005), this may change as a result of recent socioeconomic changes caused by ICTs, especially the use of ICTs for telecommuting (Castells & Hall 1994; Mohammad *et al.* 2003; Van Oort *et al.* 2003b).

The Netherlands is a densely populated country with a relatively compact but decentralized urbanization pattern. Although spatial planning has had a relatively powerful influence on urban development, in the last few decades, housing prices have increased considerably. Moreover, spatial policies were recently decentralized and relaxed, increasing the influence of market forces (Healy 2004). The mass adoption of ICTs, which relaxes spatial binding, is assumed to increase the desire to have relatively less expensive residences in green environments. This possible effect of telecommuting on residential locational preferences has not yet been fully explored. Therefore, this paper will present an analysis of the effects of telecommuting on residential locational preferences.

5.3 Data and research methods

The WBO 2002 database has been analysed to address the questions posed in this research. WBO is a quadrennial survey among households covering all aspects of housing in the country (MVROM 2002). It is commissioned by the Ministry of Housing, Spatial Planning and the Environment (Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (MVROM) in Dutch). In the 2002 version, 75,000 household were successfully interviewed. The final database includes variables related to housing situation, preferences, housing expenditures, residential mobility, and a large number of socio-cultural and socioeconomic background variables.

The WBO 2002 aims at identifying the overall residential locational preferences in the Netherlands. The survey includes the question whether the respondent worked at home in combination with a fixed working address elsewhere. Unfortunately, such details as how many hours per day or week or month the respondent worked at home, and whether or not ICTs were used for that purpose, were not asked. In this study, "telecommuting therefore has the broad meaning of working at home along with a fixed work address other than the house address". A comparable operationalization was used by Mokhtarian and Bagley (2000). The definition will certainly exaggerate the number of telecommuters, but a large share of the selected group will most likely use ICTs to communicate regularly with the employer's base. Moreover, the whole group will share the option of having relatively wide housing-location margins. All workers not belonging to the category of telecommuters as defined above are further referred to as *commuters*.

For telecommuting to have an impact on residential locational patterns, two conditions must hold. First, a substantial number of workers must telecommute; second, these telecommuters must have locational preferences that differ from those of commuters (Ellen & Hempsted 2002).

The frequencies of commuters and telecommuters are shown in Table 5.1. In the year 2002, 7.3 percent of the total working population in the survey was engaged in some sort of telecommuting. This proportion is substantial enough to support the investigation of telecommuters' differences from commuters in their residential locational preferences. The proportion is also in line with the percentages reported in the studies on telecommuting reviewed in section 5.1.

The same criterion was used for determining whether the partners of the main respondents were commuters or telecommuters. In the case of double-income households, most of the respondents who telecommute had partners that (still) commute (Table 5.2).

There are relatively more telecommuters who have telecommuting partners as compared to commuters as main respondent. Although the majority of the partners commute, there are also many who do not work. Furthermore, a considerable share of the telecommuters are single.

Table 5.1 Composition of main respondents as commuters and telecommuters

Category	Frequency	Percent
Telecommuters	2930	7.3
Commuters	37039	92.7
Total	39969	100.0

Source: (WBO survey 2002)

Table 5.2 Composition of households: commuters and telecommuters (in percent)

Main Respondent	Single	Partner		
		Telecommuter	Commuter	Do not work
Telecommuter	22.5	16.2	43.3	18.0
Commuter	26.7	4.2	44.3	24.8
Overall	26.4	5.1	44.2	24.3

Source: (WBO survey 2002)

The statistical analysis starts with descriptive analyses of the general characteristics of commuters and telecommuters. Then, the effects of telecommuting and traditional factors related to residential locational preferences are studied to find out their relative importance by applying multivariate analyses through linear regression and (binary and multinomial) logistic regression models. As discussed in section 5.2, the indicators with respect to residential location, commute distance, education, household composition, employment, and household net monthly income will be included as explanatory variables in the statistical analyses. Along with these traditional variables, the telecommuting status of both main respondent and partner were added to assess the effects of telecommuting on residential locational preferences.

5.4 General characteristics of commuters and telecommuters

In order to compare the main socioeconomic characteristics of commuters and telecommuters, both of them were subdivided into five age and three income groups. Low income households have a net monthly income of less than 1500 euros; medium income households have a net monthly income of 1500 to 2500 euros; and high income households have a net monthly income of more than 2500 euros. In general, telecommuters are older and have higher incomes (Figures 5.1 and 5.2). There are more telecommuters in the age category of 36 to 65 years as compared to other age categories. The commuters are almost equally divided among the income groups distinguished. The telecommuters, however, are overrepresented in the highest income group.

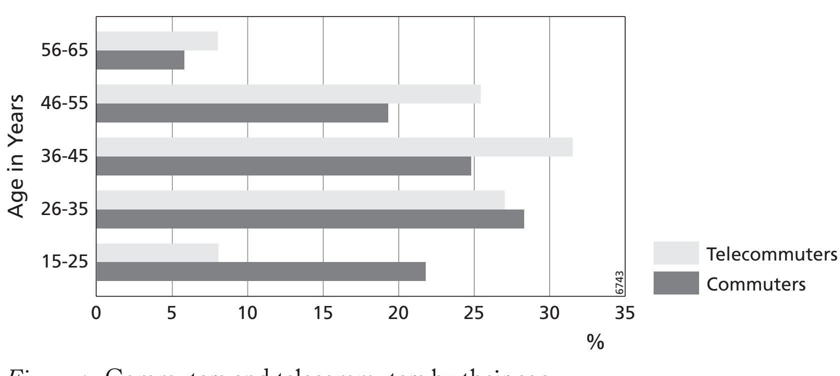

Figure 5.1 Commuters and telecommuters by their age

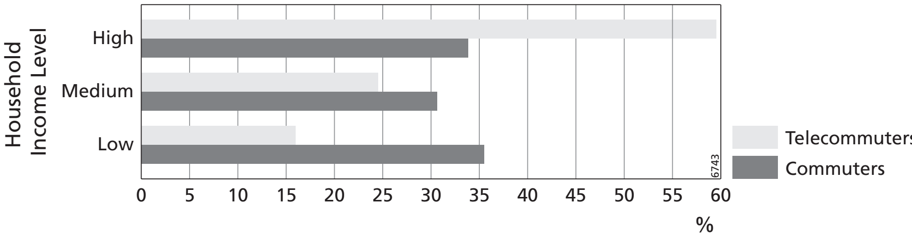

Figure 5.2 Commuters and telecommuters by their monthly household income level

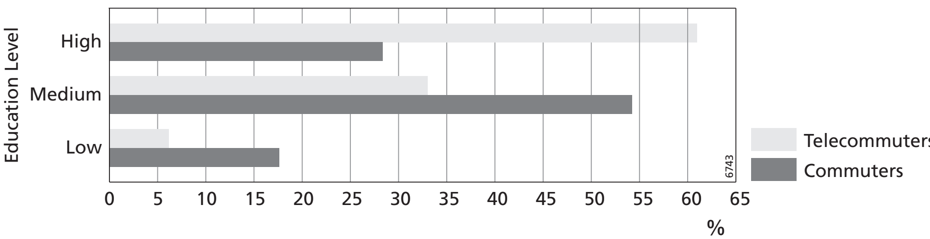

Figure 5.3 Education level of commuters and telecommuters

Both commuters and telecommuters are also categorized according to their educational level. Primary education is considered as low level education, secondary or higher secondary as medium level, and vocational or university education as high level education. The educational level of both commuters and telecommuters is shown in Figure 5.3. It is clear that telecommuters on average have a higher educational level than commuters. This finding confirms that telecommuting jobs require relatively high qualifications, competencies and substantial work experience, as reported by several authors (Willigenburg & Van Osch 2000; Ellen & Hempsted 2002; Goetgeluk *et al.* 2002; Johnston & Nolan 2002; Van Oort *et al.* 2003a; Van Oort *et al.* 2003b).

5.5 Factors explaining current location of residence

As shown in Figure 5.4, in 2002 both commuters and telecommuters were residing in all types of residential environment. However, the distributions of commuters and telecommuters across all residential environments were significantly different, according to both binomial and chi-square tests ($p < 0.001$). The most frequent residential type of both commuters and telecommuters is the outer city area, the planned and unplanned post-war suburbs, in regional urban centres and in rural areas. Although the differences in residential location between commuters and telecommuters are minute, in relative terms telecommuters are slightly more oriented towards living in green rural environments and inner cities than commuters. This may point at two segments of telecommuters with different residential preferences.

Broken down by age groups (Figure 5.5), the general patterns of shares of residential environments for commuters and telecommuters are quite different. This finding is statistically significant according to both binomial and chi-square tests at $p < 0.001$. Figure 5.5 suggests that older telecommuters appear to be responsible for the overrepresentation in rural environments,

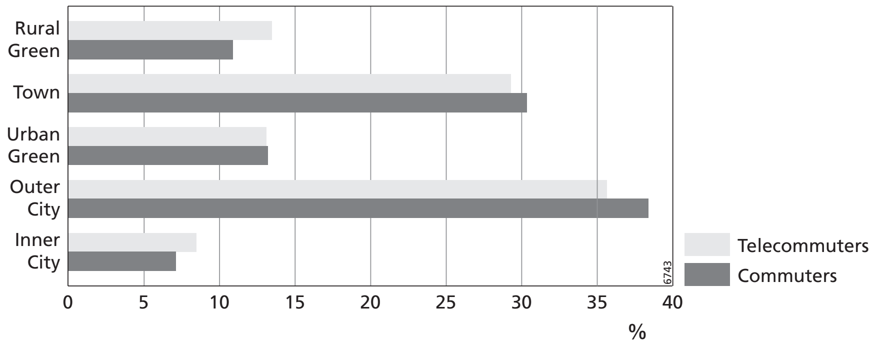

Figure 5.4 Current location of residences of commuters and telecommuters

while old age commuters account for their above-average presence in outer city environments. Furthermore, there are relatively more telecommuters residing in the inner city as compared to commuters belonging to all age groups except middle age.

Not surprisingly, a comparable picture is found when looking at differences among income subgroups in the distribution of commuters and telecommuters across residential environments. This finding is also statistically significant at $p < 0.001$. Figure 5.6 indicates that middle and higher income telecommuters are overrepresented in rural green environments, while the low and medium income ones are overrepresented in the inner city. On the other hand, low and middle income groups of commuters are overrepresented in outer city environments. There are also an above average number of low income commuters residing in urban green environments.

In order to reveal the contribution of telecommuting, along with traditional factors (mentioned in section 3) for their current location of residence, a multinomial logistic regression model was estimated (Table 5.3). The dependent variable is the current location of residence. The

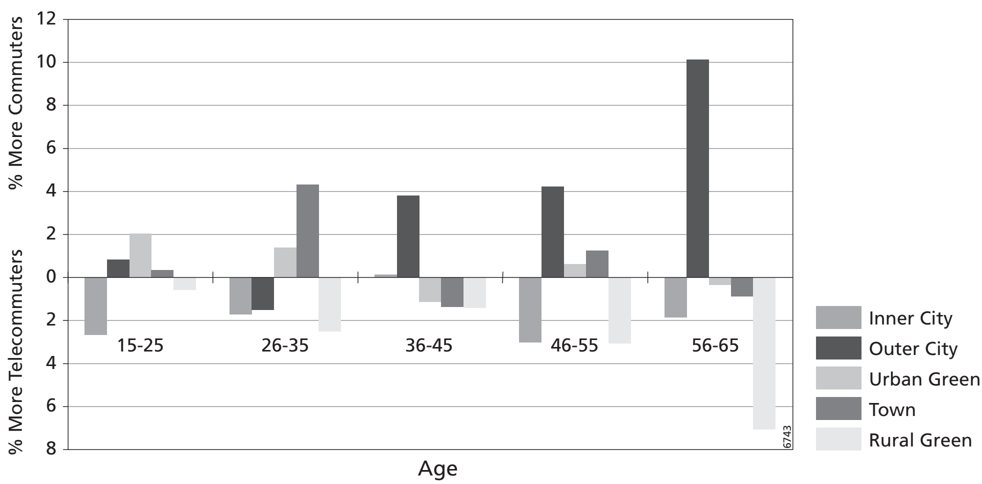

Figure 5.5 Differences in current location of residences of commuters and telecommuters according to their age

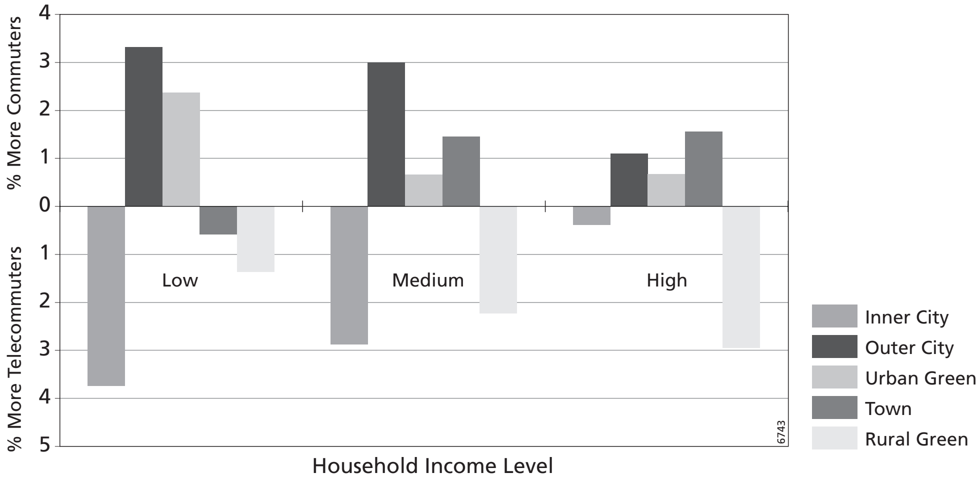

Figure 5.6 Differences in current location of residences of commuters and telecommuters according to their household income level

inner city serves as the reference category, implying that effects are interpreted relative to this residential environment.

The results show that if the main respondent telecommutes, he/she is more likely to live in a rural environment as compared to the inner city. If the partner telecommutes, the household is less likely to live in the outer city, an urban green area or town, implying a larger probability to reside in rural green or inner city environments. It should be noted, however, that the causality of the relationship is uncertain. Although it is possible that a preference for telecommuting leads to a choice to live in a rural environment, it is also possible that the fact of living in a rural environment makes one decide to telecommute, in order to deal with the longer commute distance. A different type of data (longitudinal data or qualitative interviews) would be required to solve this problem.

Relative to single households without children, all household types are more likely to live in areas outside the inner city. Compared to all types of couples, single workers with children are less likely to live in towns or rural greens areas, which can be explained by the worse accessibility of schools and jobs, making it more difficult to combine work and child care tasks. As a separate factor, the presence of children leads to a larger probability of living in suburban and rural areas.

Furthermore, the analysis confirms the pattern that the youngest age groups and the medium and higher income level groups are overrepresented in the urban-type environments, while middle aged and old age people prefer to reside in more peripheral rural environments. The 'green urban environments' clearly hold an intermediate position, being attractive to households with a high income and high education. This result is hardly surprising, since green urban environments are a luxury setting, having relatively low density residential districts both within and at the edges of the large and medium-sized cities.

Overall, it can be concluded that along with other traditional factors (household composition, number of children in the household, and age), telecommuting is associated with the location of residence, in the sense that telecommuters are more likely to reside in rural areas. The analysis

Table 5.3 Multinomial logistic regression model of current location of residence

Variables	**Current Location of Residence**															
	Outer City				Urban Green				Town				Rural Green			
	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio
Constant	1.581	**	0.101		0.143		0.117		0.844	**	0.104		-0.410	**	0.121	
Household Type																
Single (Worker) without Children *(Ref.)*																
Couple (Both Worker) without Children	0.576	**	0.121	1.779	0.913	**	0.135	2.491	1.092	**	0.123	2.982	0.969	**	0.140	2.634
Couple (One Worker) without Children	0.424	**	0.074	1.529	0.900	**	0.084	2.459	1.246	**	0.076	3.477	1.512	**	0.088	4.534
Single (Worker) with Children	0.500	**	0.135	1.648	0.372	*	0.154	1.450	0.158		0.142	1.171	-0.152		0.176	0.859
Couple (Both Worker) with Children	0.776	**	0.148	2.174	1.059	**	0.163	2.882	1.150	**	0.150	3.158	0.946	**	0.167	2.576
Couple (One Worker) with Children	0.522	**	0.126	1.686	0.701	**	0.139	2.016	0.951	**	0.127	2.588	1.084	**	0.142	2.957
Number of Children in Household of Age																
01-12	0.140	*	0.056	1.151	0.210	**	0.061	1.234	0.332	**	0.056	1.393	0.363	**	0.061	1.438
13-18	0.046		0.070	1.047	0.192	*	0.075	1.212	0.324	**	0.070	1.383	0.347	**	0.075	1.414
Household Income Level																
Low *(Ref.)*																
Medium	0.047		0.062	1.048	0.122		0.073	1.130	0.039		0.065	1.040	0.107		0.076	1.113
Higher	-0.094		0.083	0.910	0.176		0.095	1.192	-0.172	*	0.086	0.842	-0.188		0.099	0.828
Age																
18-25 *(Ref.)*																
26-35	-0.061		0.066	0.941	-0.073		0.078	0.930	-0.212	**	0.069	0.809	-0.115		0.081	0.891
36-45	0.015		0.073	1.015	0.027		0.085	1.027	-0.063		0.076	0.939	-0.020		0.089	0.980
46-55	0.106		0.075	1.112	0.196	*	0.086	1.216	0.195	*	0.077	1.216	0.294	**	0.089	1.341
56-65	0.088		0.104	1.092	0.193		0.118	1.213	0.260	*	0.106	1.298	0.421	**	0.120	1.524
Education Level																
Low *(Ref.)*																
Medium	-0.218	**	0.068	0.804	-0.116		0.077	0.891	-0.274	**	0.069	0.761	-0.272	**	0.077	0.762
Higher	-0.566	**	0.072	0.568	-0.462	**	0.082	0.630	-0.924	**	0.074	0.397	-1.006	**	0.085	0.366
Commuting Status																
Commuting (Ref.)																
Telecommuting	-0.139		0.077	0.870	-0.161		0.088	0.852	-0.057		0.079	0.945	0.195	*	0.090	1.216
Partner's Commuting Status																
Commuting *(Ref.)*																
Telecommuting	-0.336	**	0.096	0.714	-0.282	**	0.108	0.754	-0.228	*	0.097	0.796	-0.137		0.110	0.872
Number of Working Hours per Week	0.001		0.002	1.001	-0.001		0.002	0.999	0.005	**	0.002	1.005	0.006	**	0.002	1.006
Partner's Number of Working Hours per Week	-0.003		0.003	0.997	-0.007	*	0.003	0.993	-0.001		0.003	0.999	0.006	*	0.003	1.006
Chi Square	2436**															
-2 Loglikelihood Intercept Only	64911															
-2 Loglikelihood Final	62475															
Nagelkerke R Square	0.063															
N	39777															

Reference Category = Current Location of Residence at Inner City, B is Regression Coefficient, S.E. is Standard Error
* Significant at $p < 0.05$, ** Significant at $p < 0.01$

Table 5.4 Linear regression model of commute distance

Variables	**LN (Commute Distance in Kilometers)**			
	B		S.E.	Standardized Beta
Constant	2.375	**	0.885	
Household Type				
Single (Worker) without Children *(Ref.)*				
Couple (Both Worker) without Children	4.476	**	0.844	0.062
Couple (One Worker) without Children	1.191	*	0.527	0.013
Single (Worker) with Children	-1.183		0.928	-0.007
Couple (Both Worker) with Children	3.888	**	0.939	0.055
Couple (One Worker) with Children	2.116	**	0.775	0.021
Number of Children in Household of Age				
01-12	-0.722	*	0.306	-0.020
13-18	-1.912	**	0.382	-0.035
Household Income Level				
Low *(Ref.)*				
Medium	6.482	**	0.472	0.096
Higher	10.384	**	0.601	0.161
Age				
18-25 *(Ref.)*				
26-35	3.094	**	0.502	0.045
36-45	1.213	*	0.536	0.017
46-55	-1.036		0.535	-0.013
56-65	-3.082	**	0.736	-0.024
Education Level Low *(Ref.)*				
Medium	3.394	**	0.424	0.055
Higher	10.260	**	0.485	0.153
Current Location of Residence				
Inner City *(Ref.)*				
Outer City	2.037	**	0.599	0.032
Urban Green	2.347	**	0.684	0.026
Town	5.544	**	0.618	0.082
Rural Green	7.592	**	0.712	0.077
Commuting Status Commuting *(Ref.)*				
Telecommuting	3.132	**	0.583	0.026
Partner's Commuting Status				
Commuting *(Ref.)*				
Telecommuting	0.569		0.701	0.004
Partner's Commute Distance	0.131	**	0.007	0.107
Number of Working Hours per Week	0.345	**	0.014	0.131
Partner's Number of Working Hours per Week	-0.340	**	0.020	-0.204
F	**178****			
R Square	**0.097**			
Adjusted R Square	**0.096**			
N	**39967**			

B is Regression Coefficient. S.E. is Standard Error. * Significant at p < 0.05. ** Significant at p < 0.01

does not make it clear whether telecommuters have a higher preference for rural areas or whether rural residents are more likely to adopt telecommuting.

5.6 Factors affecting commuting distance

As explained in section 5.1 and 5.2, telecommuting is expected to have major consequences for commuting practices, in particular for commuting distance and frequency. Therefore, we tested whether commuting distance is being affected by telecommuting along with traditional factors, which could influence the future residential locational preferences. To this end, a linear regression model was estimated, with commute distance as the dependent variable. We used a logarithmic transformation (*ln(d)*) of distance, since we expect that the relationship between the explanatory variables and distance is non-linear. The coefficient of determination (R Square) is 0.097, so a relatively small amount (9.7%) of the variance in commute distance was actually explained by the variance in the independent variables. As could be expected, a positive association between this distance and telecommuting appears, confirming that telecommuters do indeed have longer commute distances. People living in rural environment are travelling a longer distance as compared to people living in urban environments. Relative to single workers without children, all types of households except single workers with children have longer commute distances. The number of children of all ages in the household has a decreasing effect on commute distance. With increasing educational and income levels, the commute distance also increases. This can be explained by the more specialized jobs held by these categories.

The most important negative relationships relate to age categories. The commuting distance tends to decline gradually for old age categories. The respondents who work more hours per week have longer commute distances. The telecommuting status of the partner does not have a significant effect on the commute distance of the main respondent, while a higher number of working hours of the partner tends to reduce the commute distance of the main respondent. Overall, the regression analysis confirms the findings of other studies such as those by Martens and colleagues (1999), Mokhtarian (1998), and Van Reisen (1997) that telecommuters still commute physically as well, but with a lower frequency and a longer distance than regular commuters.

5.7 Factors explaining intended change of residence

In the WBO 2002 survey, detailed information about the intention to change residence in the coming two years was collected. The pre-coded answer options included: “have no intention, have intention (subdivided into: maybe, like to, yes, ready), and don’t know”. To keep the analysis manageable, these options were categorized into two classes: either having the intention (maybe, like to, yes, ready) to change residence or not (no intention or don’t know). This dichotomization creates a binary type of variable which allows the use of a binary logistic regression model for analysing the factors (mentioned in section 5.3) related to an expressed intention to move within the next two years (Table 5.5). The chi-square value is highly significant, which means that the null hypothesis that all effects of the independent variable are zero can be rejected. The Nagelkerke R square value (0.177) is moderate.

Table 5.5 Binary logistic regression model of intention for change of residence in coming two years

Variables	B		S.E.	Odds Ratio
Constant	0.161	*	0.068	1.175
Household Type				
Single (Worker) without Children *(Ref.)*				
Couple (Both Worker) without Children	-0.332	**	0.073	0.717
Couple (One Worker) without Children	0.187	**	0.040	1.205
Single (Worker) with Children	0.078		0.071	1.082
Couple (Both Worker) with Children	-0.509	**	0.079	0.601
Couple (One Worker) with Children	-0.125	*	0.061	0.882
Number of Children in Household of Age				
01-12	-0.043		0.026	0.958
13-18	-0.020		0.033	0.980
Household Income Level				
Low *(Ref.)*				
Medium	-0.211	**	0.037	0.810
Higher	-0.376	**	0.049	0.687
Age				
18-25 *(Ref.)*				
26-35	-0.521	**	0.036	0.594
36-45	-1.128	**	0.041	0.324
46-55	-1.693	**	0.044	0.184
56-65	-1.996	**	0.069	0.136
Education Level Low *(Ref.)*				
Medium	0.095	**	0.035	1.100
Higher	0.332	**	0.040	1.393
Current Location of Residence				
Inner City *(Ref.)*				
Outer City	-0.010		0.045	0.990
Urban Green	-0.246	**	0.052	0.782
Town	-0.441	**	0.047	0.643
Rural Green	-0.710	**	0.057	0.492
Commuting Status Commuting *(Ref.)*				
Telecommuting	0.071		0.047	1.074
Partner's Commuting Status				
Commuting *(Ref.)*				
Telecommuting	0.028		0.060	1.028
Commute Distance	0.002	**	0.000	1.002
Number of Working Hours per Week	0.006	**	0.001	1.006
Partner's Commute Distance	0.001	*	0.001	1.001
Partner's Number of Working Hours per Week	0.001		0.002	1.001
Chi-square	5326**			
-2Loglikelihood at Convergence Level	43770			
Nagelkerke R Square	0.177			
N	11867			

Reference Category = No intention to change residence in coming two years, B is Regression Coefficient, S.E. is Standard Error
* Significant at p < 0.05, ** Significant at p < 0.01

Table 5.6 Multinomial logistic regression of future desired location of residence

Variables	Future Wanted Location of Residence															
	Outer City				Urban Green				Town				Rural Green			
	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio	B		S.E.	Odds Ratio
Constant	-0.925	**	0.152		-1.981	**	0.172		-3.124	**	0.212		-3.590	**	0.252	
Household Type																
Single (Worker) without Children *(Ref.)*																
Couple (Both Worker) without Children	0.419		0.233	1.521	0.267		0.242	1.306	0.863	**	0.264	2.370	0.610	*	0.295	1.840
Couple (One Worker) without Children	0.072		0.084	1.075	0.016		0.094	1.016	0.083		0.104	1.086	-0.118		0.130	0.889
Single (Worker) with Children	0.162		0.183	1.176	0.042		0.199	1.043	0.346		0.223	1.414	-0.451		0.306	0.637
Couple (Both Worker) with Children	0.314		0.258	1.369	0.181		0.269	1.198	0.895	**	0.290	2.448	0.504		0.325	1.656
Couple (One Worker) with Children	-0.158		0.156	0.854	-0.228		0.170	0.796	-0.178		0.184	0.837	-0.275		0.218	0.760
Number of Children in Household of Age																
01-12	0.340	**	0.084	1.405	0.365	**	0.088	1.440	0.373	**	0.093	1.452	0.322	**	0.104	1.379
13-18	0.137		0.098	1.146	0.111		0.104	1.117	-0.052		0.111	0.950	0.087		0.126	1.091
Household Income Level Low *(Ref.)*																
Medium	-0.029		0.089	0.971	0.112		0.096	1.119	0.064		0.109	1.066	0.197		0.131	1.218
Higher	-0.300	*	0.131	0.741	-0.061		0.139	0.941	-0.134		0.157	0.875	0.321		0.182	1.378
18-25 *(Ref.)*																
26-35	0.094		0.080	1.099	0.362	**	0.088	1.436	0.414	**	0.100	1.513	0.498	**	0.120	1.645
36-45	0.434	**	0.107	1.544	0.746	**	0.114	2.109	0.768	**	0.130	2.155	0.785	**	0.153	2.192
46-55	0.258	*	0.123	1.294	0.816	**	0.128	2.261	0.891	**	0.145	2.437	0.738	**	0.173	2.092
56-65	0.300		0.203	1.350	0.759	**	0.212	2.137	0.679	**	0.244	1.971	0.722	*	0.281	2.059
Education Level																
Low (Ref.)																
Medium	-0.230	*	0.099	0.795	-0.077		0.106	0.925	-0.154		0.115	0.857	-0.117		0.137	0.890
Higher	-0.425	**	0.107	0.654	-0.412	**	0.116	0.662	-0.490	**	0.128	0.612	-0.382	*	0.151	0.682
Current Location of Residence Inner City *(Ref.)*																
Outer City	1.188	**	0.085	3.279	1.014	**	0.098	2.757	0.734	**	0.146	2.084	0.716	**	0.166	2.046
Urban Green	0.883	**	0.111	2.418	1.684	**	0.117	5.388	1.140	**	0.173	3.125	1.178	**	0.194	3.247
Town	0.775	**	0.115	2.171	1.115	**	0.126	3.051	4.026	**	0.152	56.028	2.478	**	0.177	11.921
Rural Green	0.417	*	0.170	1.517	0.852	**	0.181	2.344	2.733	**	0.191	15.379	4.177	**	0.197	65.198
Commuting Status Commuting *(Ref.)*																
Telecommuting	-0.163		0.116	0.849	-0.284	*	0.127	0.753	-0.449	**	0.148	0.638	-0.322		0.168	0.725
Partner's Commuting Status Commuting *(Ref.)*																
Telecommuting	-0.020		0.194	0.980	-0.041		0.199	0.959	0.030		0.219	1.030	0.059		0.236	1.061
Commute Distance	0.001		0.001	1.001	0.001		0.001	1.001	-0.002		0.001	0.998	-0.001		0.001	0.999
Number of Working Hours per Week	0.018	**	0.003	1.018	0.024	**	0.003	1.024	0.026	**	0.003	1.027	0.025	**	0.004	1.026
Partner's Commute Distance	0.003		0.002	1.003	0.002		0.002	1.002	0.002		0.002	1.002	0.001		0.002	1.001
Partner's Number of Working Hours per Week	0.005		0.006	1.005	0.012		0.006	1.012	0.001		0.007	1.001	0.005		0.007	1.005
Chi Square	6615**															
-2 Loglikelihood Intercept Only	36326															
-2 Loglikelihood Final	29710															
Nagelkerke R Square	0.442															
N	12070															

Reference Category = Future wanted location of residence at inner city, B is Regression Coefficient, S.E. is Standard Error
* Significant at $p < 0.05$, ** Significant at $p < 0.01$

The estimation results indicate that, relative to single workers without children, one worker couples without children are more likely to relocate. Couples with children and dual income couples without children are less likely to change residence.

On the other hand, age, household income, number of children in the household, and currently living in a non-urban residential environment are factors that are negatively associated with a relocation intention. Respondents with higher incomes and in older age categories are less likely to change residence, whereas higher educated respondents are more likely to change residence.

Looking at residential location, it is found that households currently residing in urban green areas, towns, and rural areas are less likely to relocate. If the respondent works more hours, this increases the relocation probability. With respect to commute distance, it is found that both the main respondent's and the partner's commute distance positively affect relocation probability. But the telecommuting status, both of the respondent and of the partner, do not have a statistically significant effect on relocation probability.

Altogether, this regression confirms the importance of commute distance in relocation decisions. At the same time, telecommuting does not lead to a higher relocation probability, suggesting that telecommuting is a permanent state in which a longer commute distance is balanced against a more attractive residential area, rather than being a temporary measure to deal with a long commute in anticipation of a residential relocation.

5.8 Factors explaining future residential locational preferences of commuters and telecommuters

The last analysis was undertaken to unravel the statistical relationships of the factors explaining the preferred location of future residences for commuters and telecommuters. This task is far from straightforward, as we have to deal with small sample sizes of subgroups. Some 70 percent of all the main respondents (both commuters and telecommuters) had no intention to change residence in the next two years, leaving less than 800 cases of telecommuters in the analysis. In the previous section, it was found that telecommuting has a neutral effect on intention for change of residence. However, this does not necessarily prevent telecommuters from having different preferences once they decide to relocate. This is tested in a multinomial logistic regression model, in which the future desired location of residence was the dependent variable. The inner city area served as the reference category (Table 5.6).

Telecommuting status has a statistically significant association with residential locational preferences for urban environments and towns. The partner's telecommuting status does not have a significant effect. With a larger number of working hours, preference for all residential environments increases relative to the inner city.

With respect to the effect of current residential location, it is found that those planning to relocate prefer to find their new residence in the same residential environments where they are currently living, followed by spatially 'adjacent' types. For instance, those living in a town prefer to stay living in a town, with rural and urban green areas as second best options. There are no clear relationships between the household type and the preferred residential environment, except for dual income couples without children, who prefer towns or rural environments, and dual income couples with children, who prefer towns. The presence of children in the household leads to a higher preference for all residential environments as compared to the inner city.

All the age groups have preferred all residential environments. The outer city urban environment is relatively more strongly preferred by the middle age groups. The urban green and rural environment will attract relatively more middle and old aged people. Young people have a higher preference for rural environments than urban ones. Overall there is trend in all age groups to have their future residence in a rural environment, which slightly increases among young age groups and decreases for middle and old age groups. In addition, highly educated people will have a higher preference for rural living environments as compared to urban ones.

On the basis of this analysis, it can be concluded that telecommuters are more likely to prefer their future residence to be located in an urban green environment or a town as compared to other living environments. This differs slightly from their current residential environments, which were more likely to be located in rural areas. Among the traditional factors, age, number of children in the household and current location of residence were the main ones affecting the future desired location of residence.

5.9 Conclusions

In this research we have explored the potential effects of telecommuting on residential preferences and relocation decisions. A first outcome is that in the Dutch context, telecommuters also have longer commute distances than regular commuters. This implies that telecommuting leads to a different valuation of commute distance in relocation decisions, implying that a widespread adoption of telecommuting may lead to changes in residential patterns. In addition, telecommuters are not more likely to intend to change residence, suggesting that telecommuting is adopted as a rather permanent state, which allows one to overcome a longer commute and live in a more peripheral area with higher quality surroundings. Finally, an analysis of both the current and the preferred residential environment indicates that, as hypothesized, telecommuters have a higher probability than commuters to reside in more peripheral areas, such as urban green settings, towns, and rural areas.

With respect to the potential effect of telecommuting on residential patterns, it is noted that although telecommuting facilitates longer commute distances, a dramatic shift in the meaning of distance, as announced by some researchers, is not fully substantiated in this study, especially for the future preferred location of residence. Thus, traditional factors like household type, number of children in the household, and especially the stages of life cycle still play a dominant role in residential locational preferences. Along with that, the majority of the people wish to have their future residence in the same residential environment as the one in which they are residing at present. For such a short period of two years in the future, in which telecommuting must still become established, it needs to be considered that the majority of telecommuters have partners who commute. It is difficult to assert that, for all of them, telecommuting will result in a preferred residence in a rural environment situated far away from the existing work location and not having good transport infrastructure. Taking the trends shown for current location of residence and future preferred location of residence into consideration can lead us to expect that telecommuting in the Netherlands, along with traditional factors, will play a part in somewhat more residential locational preferences in urban green and rural environments. That expectation is already reflected in the decentralization policies.

Overall, it is noted that in the WBO 2002 survey, two groups of telecommuters could be identified. By far the largest group consists of middle and old aged, well-educated professionals belonging to middle and higher income groups and living in family households. Their current residential environment is, to an above-average degree, a rural green environment. These people are not very likely to move to another type of environment in the near future. A second important group of telecommuters comprises young professionals with a high level of education but not (yet) a high income. These people clearly prefer urban residential settings, in particular inner city environments. Since it is important to distinguish different segments of telecommuters with respect to their residential preferences, future analyses will focus on identifying the specific needs and preferences of these groups, for instance using cluster analyses and latent class analysis.

6 Impact of Telecommuting on Future Urbanization

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Abstract

Information and Communication Technologies (ICTs) have evolved to such level that they can facilitate people's access to opportunities in virtual space (through telecommuting, teleshopping, e-learning, and so forth) along with accessing them in physical space. A hybrid space is therefore emerging, which will have consequences for people's spatial behaviour. In particular telecommuting is expected to change residential preferences and affect future urbanization patterns. To explore this assertion, residential land-use allocation in the 2000-2030 period is projected for the Netherlands using a dedicated model for two scenarios (Physical Space and Hybrid Space). Results indicate that urban decentralization and deconcentration are likely to accelerate because of increasing telecommuting. Attractive regions to live in at medium distances from large cities will in particular be confronted with new urban pressure of a sprawling nature. Urban policies have to be reconsidered to cope with these new spatial development trends.

6.1 Emergence and consequences of hybrid space

The Netherlands has a long tradition of national spatial planning. The focus in this planning effort has always been on (the relation between) urbanization and mobility. In particular, the densely-populated and highly-urbanized Randstad region in the western part of the country (the area including the Amsterdam, Rotterdam, The Hague and Utrecht city regions with about 7 million inhabitants) has been subjected to policy visions and measures related to urban land use (Dieleman & Musterd 1992). Dealing with future land-use demands under the condition of scarce land resources lies at the heart of Dutch spatial planning.

For many decades, the number of households in the Netherlands grew, in the European context, relatively fast and at a faster rate than the population. Although this trend is slowing down somewhat, a substantial increase in the number of households is still projected: there will be another 1.5 to 2 millions new households by 2030. Employment is also likely to increase substantially, because of population growth and higher shares of the population participating in the labour force. These developments will result in a demand for 390 to 850 additional square kilometres for residential use and 320 to 540 square kilometres for employment use (MVROM 2000; De Nijs *et al.* 2005).

In the past, a whole range of policy measures has been designed and put into action to regulate urban spatial dynamics in the Netherlands (Schwanen *et al.* 2004). All these policies have had special goals and objectives. One potentially important factor that, so far, hardly was taken into consideration in these policies is the effect of Information and Communication Technologies (ICTs) on the spatial distribution of land uses. Recently, studies have been published on the subject (Van Oort *et al.* 2003a; Raspe & Van Oort 2004). They investigated spatial trends in ICT-related employment. The main conclusion is that ICTs seem to strengthen existing agglomeration and deconcentration trends. However, model-based projections of future effects of telecommuting on the Dutch urbanization pattern have not been carried out to date. Such a reconnaissance of urban futures is important to support strategic policy and decision making.

Over the last three decades there has been a spectacular growth in the development and use of ICTs (Graham & Marvin 1996; Paul *et al.* 2003). These developments have led to the emergence of a *virtual space* alongside the familiar *physical space* as a geographical arena for human activities. As the two coexist, a *hybrid space* situation has become a reality. The hybrid space possesses new accessing opportunities (telecommuting, teleshopping, e-learning, and so forth) which are reducing the friction of distance for a range of activities (Janelle & Hodge 2000). In the Netherlands, accessibility, especially of jobs, has been a major determinant of land-use allocation (Verburg *et al.* 2004). As ICT-induced changes in socioeconomic characteristics of people (access to networks, competences) will affect the accessibility of opportunities, suitability surfaces for future residential areas will have to be adapted to include possibilities for telecommuting. As suitability is a major driver for allocating new residential land, new urbanization patterns can also be expected to emerge. Research into this phenomenon is therefore of both scientific and policy relevance.

The study reported here explores how the mass use of ICTs will change people's socioeconomic characteristics – their competences, activities and residential preferences – and the effects those changes can be expected to have on the the pattern of locations for new residential land. The resulting changes in future urbanization patterns have been analyzed applying a residential land-use projection model developed for this purpose. The model projects the allocation of Low Density Residential Areas (LDRAs, defined as having a population density of less than 6600 inhabitants per square kilometre) and High Density Residential Areas (HDRAs, over 6600 inhabitants per square kilometre) for two scenarios for the year 2030. In the first scenario, referred to as the Physical Space Scenario (PSS), it is assumed that there will be no tangible effects of ICTs on the locational behaviour of employed people. In the second scenario, referred to as the Hybrid Space Scenario (HSS), ICTs are assumed to affect spatial residential preferences and spatial policies, leading to different suitability surfaces for residential areas. In order to assess the different outcomes in the form of future spatial urbanization patterns, the mapped patterns have been analyzed visually and spatial statistical tools were applied to quantify the impacts.

The next section reviews the literature on urban land-use and ICTs and presents the conceptual model used. Next, the spatial model developed and the results of the model applications are presented. Finally, a geo-statistical analysis of the urban patterns generated is described followed by conclusions and a discussion of the research.

6.2 Urban land-use patterns in the age of ICTs

The best icon of city growth was established more than half a century ago, when enough historical evidence had been assembled to note that urban growth appeared to occur in waves. As well as raising personal wealth, each wave is connected to a revolution in transportation technology that loosened the ties to the central city (Batty 2005a). The introduction of ICTs is such a transportation revolution, but one of a special nature. With the widespread adaptation of ICTs, many human activities demand and can afford more space, while at the same time transportation has become more efficient and affordable. The combined effect is that households and firms will move into suburban locations, and cities will continue to extend into former rural land, even where the total population of metropolitan areas declines (Wegener 2005). Thus we might stand on the threshold of a new wave of socio-economic and spatial developments brought about by ICT (Raspe & Van Oort 2004).

Kotkin (2000) describes the effect of the information revolution on the cityscape as entering into the fourth dimension (virtual space). We are living in a *placeless society,* which resembles the idea of 'death of distance' put forward by Cairncross (1998). During last five to ten years, the view that a society is forthcoming where place and distance have disappeared as structuring principles are heavily challenged. Moreover, the challenge is increasingly supported by empirical evidence. Malecki and Gorman (2001) argue that, even if ICT-use does lead to the end of distance it does not mean that this also implies the *end of Geography*. According to Wilson *et al.* (2001) the death of distance is mistakenly seen as a vanishing of difference between places as people communicate in virtual space. In fact it is not so much the end of distance as it is the *emergence of a new type of space* where distance still plays a, albeit different, role. A hybrid space where virtual and physical space come together and become interwoven (Koch 2004). Hence, according to Mitchel (2000), what we see is an *old script being played by new actors*, with silicon as the new steel and the Internet as the new railroad.

Nevertheless, in current reality along with the *new forth dimension* (virtual space), the other three dimensions (those of physical space) are still influencing the spatial patterns to a considerable extent. So *hybrid space* would be the more appropriate term for the new human spatial arena. In hybrid space, among the factors that drive the decision where to locate residential and industrial areas, qualities of place will be far more important than traditional factors such as proximity to the workplace, taxes, regulations, or land cost (Van Oort *et al.* 2003b; Castells 2004). The importance of geography is therefore not dwindling into insignificance in this age of ICTs, as suggested by Kotkin (2000) and Cairncross (1998). In fact, quite the opposite is occurring. Place geography matters now more than ever before. If people, companies, or industries can truly live anywhere, or at least choose from a multitude of places, the question of where to locate becomes increasingly contingent on the particular attributes of the given location (Kotkin 2000; Mugerauer 2000; Graham 2004).

According to Batty (2005b), there are five drivers for urban change: random event, historical accident, physical constraint on development, natural advantage, and comparative advantage (like accessibility to employment, shopping, healthcare facilities, and so forth). All the mechanisms of urban development are based on the dynamics of these drivers according to local circumstances. Among these drivers, it is hard to predict the accidental and random event. Physical constraints and natural advantages will not undergo any direct effects from ICTs. In urban models, therefore, the most effected drivers by ICTs are the socio-economic activities of people. They cause them

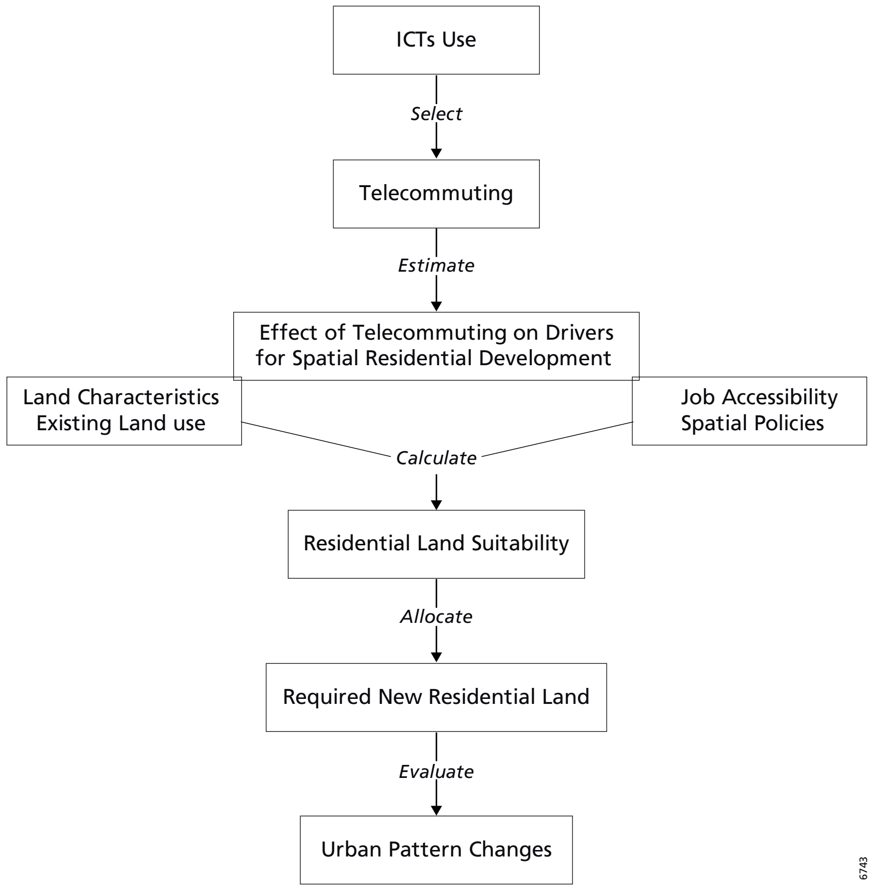

Figure 6.1 Research design

to locate and move in the landscape. Therefore, for a better understanding of land-use suitability and allocation in hybrid space, it is necessary to assess the direct and indirect impacts of ICTs on socio-economic activities. This study focuses on telecommuting as a potentially important new driver for residential location decisions. The line of reasoning and analysis is shown in Figure 6.1.

Socio-economic activities of people and spatial distribution of land uses are mutually dependent. Activities will be affected when ICTs are widely used. People who have ICT skills can communicate and access opportunities in virtual space. So, in a hybrid space environment, spatial accessibility becomes further freed from propinquity. The territorial place, ranging from the neighbourhood to the national level, is becoming less important for participating in social communities (Webber 2004).

Accessibility in terms of proximity has played a major role in the allocation of land use in physical space. The additional accessibility in virtual space is expected to have effects such as: *substitution* (like commuting replaced by telecommuting), *modification* (like changing mode of transport), *generation* (like time saved by telecommuting is spend on social or recreational travelling) and *enhancement* (like the use of ICTs in intelligent transport system enhances the efficiency of transport networks) (Muhammad 2006). It is expected that job accessibility is the component most affected by the use of ICTs. Measuring job accessibility in physical space is straightforward and based on average daily commute time. For the virtual component, commute time can only be defined if people who use ICTs to access work opportunities still make at least some complementary trips to workplaces in physical space. This is indeed the case and as a result their commute distance mostly becomes longer than that of regular commuters (Van Reisen 1997; Giuliano 1998). But their commute distance is inversely proportional to commuting frequency, which mostly depends on the nature of the job as well as on the commuting distance (Mokhtarian & Krishna 1998). In this research the telecommuters in hybrid space are assumed to commute at least once a week and those in virtual space commute still at least once a month in physical space (Muhammad *et al.* 2007a). As an overall effect, it would seem evident that ICTs are facilitating land uses at more dispersed locations in hybrid space (Howland *et al.* 1995; Cairncross 1998; Shen 1998b; Hall 1999; Hackler 2000; Kotkin 2000; Moss & Townsend 2000; Alonso-Villar & Chamorro-Rivas 2001; Van Geenhuizen & Nijkamp 2001).

Along with this changed job accessibility, still physical characteristics of locations (such as slope, landscape type, transport infrastructure) will continue to play a role in determining land-use suitability (Graham & Marvin 1996; Gillespie & Richardson 2000; Hackler 2000; Gepts 2002). Furthermore, the existing spatial configuration of land uses also is an important determinant of many ecological and socioeconomic processes and activities (Lambin *et al.* 2001). Existing land-use has an effect on the possibility of a certain new land use in their vicinity or even on replacing it. These effects are termed as neighborhood interactions, in land use modelling operationalized as *land use transition potentials* (White & Engelen 2000). Under the influence of ICTs, quite some of the telecommuters might prefer their residences located in green environments (MVROM 2002) which will influence current neighbourhood interactions.

What is stated in more theoretical literature, is also in the mean time (partly) confirmed in empirical research. When analyzing recent land-use conversions in the Netherlands, Verburg *et al.* (2004), have shown that the main factors responsible for the allocation of land use are no longer strongly related to physical suitability of the locations but that socio-economic and spatial aspects such as accessibility, existing land-use (land use transition potentials) and spatial policies have become much more important as determinants of land use changes. Therefore, these factors will be emphasized in the modelling exercise.

6.3 Residential land-use projection model

Physical suitability, existing land use, land use policies and job accessibility are considered drivers for land use changes in both the Physical Space Scenario (PSS) and the Hybrid Space Scenario (HSS). Data for the years 1986, 1995 and 2000 are used for the future (2030) land use projections. In order to implement the land use projections for the PSS and the HSS, a number of assumptions are made about the future behaviour of these drivers. They are derived from trends found in the literature which is covered in the previous section. Assumptions with respect to the shares of new high and low residential areas are inferred from an analysis of the Dutch residential preferences survey (Muhammad *et al.* 2007b). The assumptions are summarized in Table 6.1.

Table 6.1 Assumed differences of the drivers between PSS and HSS

Drivers	PSS	HSS
Job Accessibility	All the jobs will be accessible by commuting with physical means of transportation.	In year 2030 there will be 13 % jobs telecommuted in virtual space, 47 % jobs partly commuted and telecommuted in hybrid space and 40 % jobs commuted in physical space.
Commute Time	Average commute time of daily commuters in physical space	For the jobs in hybrid space 1.5 times and for virtual space 2 times that of average commute time in physical space (Mokhtarian and Salomon 1997; Van Reisen 1997)
Spatial Policies	Restrictive land use polices	Less restrictive policies, protection of the most valuable areas only
Spatial Allocation Domain	Regional level (40 COROP-regions)	Macro-regional level (4 groups of provinces)
Neighborhood land-use transition potential	Expansion concentrating in areas near existing residential areas (Muhammad 2007b).	Expansion also sprawling into rural areas, increase in low density residential areas (20% more than PSS) (Muhammad 2007b).

At first the Environment Explorer (EE), a land use projection model developed by Engelen *et al.* (2002), was applied to compute future residential development. The EE is widely used, well suited for scenario studies and a lot of input data is readily available. Unfortunately, this model was found to have a number of severe limitations for this research.

In this study job accessibility is the major phenomenon influenced by ICTs. Detailed information was desirable to be able to adequately assess its spatial effects. Therefore, accessibility has been computed at a detailed level for which the 1308 Landelijk Model Systeem (LMS) sub-zones were used. LMS is a standard for transportation modelling in the Netherlands. However, the transport module of EE appeared only be able to handle the 345 LMS standard zones. When the job accessibility values for both the PSS and the HSS were aggregated to the 345 LMS main zones a substantial loss of spatial details occurred. This limitation of EE could not be overcome, as the whole structure of a number of modules in the model would have had to be modified.

Further, future land-use requirements in the land-claim module of EE are projected for and allocated within so-called 'COROP regions', a standard regionalization of the Netherlands in 40 socio-economic regions. This is not suitable for the Hybrid Space Scenario. In the HSS, the future allocation of households in relation to job opportunities, in particular of telecommuters, can be expected to take place at both intra- and inter-regional geographical scales. Therefore macro-regions like groups of provinces are the most relevant units.

In order to avoid these limitations, a custom-made residential land-use projection model was developed and applied. The model structure and flow is shown in Figure 6.2. It is a hybrid approach combining a *cellular automata module,* a *weighted overlay module* and a *land use allocation module*. The outputs of these modules are indicated by a light grey shade.

In the cellular automata module, the neighbourhood *land-use transition potential rules* – for the transition of other land-uses to future LDRAs and HDRAs – were derived from the existing EE application that is operational at the Netherlands Environment Assessment Agency. In this application, the rules were calibrated for changes in the land use between the years 1989 and 1993 and validated for the year 2000.

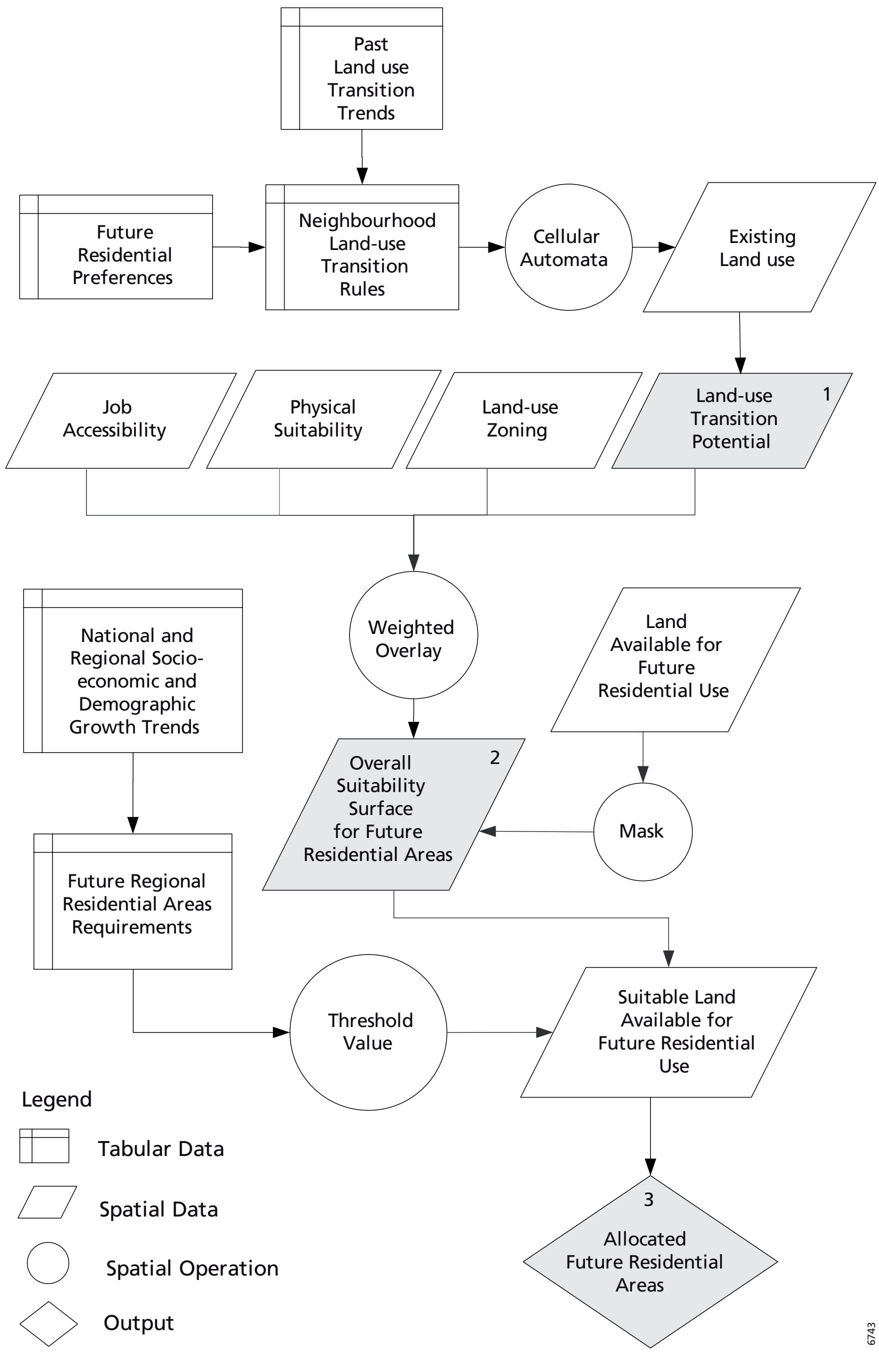

Figure 6.2 Residential land-use projection model

Note: 1 is output of cellular automata module, 2 is output for overlay module and 3 is output for land use allocation module

During this period, the development and use of ICTs accelerated and started to have an effect on land-use patterns. Furthermore, the future residential-location preferences of commuters and telecommuters revealed by the residential preferences survey commissioned in 2002 by MVROM (Netherlands Ministry of Housing, Spatial Planning and Environment) and mentioned in Table 6.1 were used to adapt neighbourhood land use transition rules for our future land-use projections. In order to compute the land-use transition potential for future LDRAs and HDRAs for the year 2030 these new neighbourhood rules were applied to the actual land use in the year 2000. The spatial units are raster cells of 500*500 meters and the iteration is on a yearly basis. For each cell, the land-use transition rules in the context area with a radius of 8 cells (totalling 196 cells) were used to compute its transition potential value.

In the overlay module, *the overall suitability* (total potential) of the cell to become residential in future is computed by weighted overlay for the PSS and the HSS. Allocation is restricted to land available for residential development after major nature and landscape protection areas have been masked. The input maps are: the computed land-use transition potential maps, land-use zoning maps (a strict zoning policy for the PSS and a more relaxed zoning for the HSS), a physical suitability map for residential land-use and a job accessibility map computed for the PSS and the HSS. The weights given to the input maps are derived from the research by Verburg *et al.* (2004), who analyzed the importance of these factors. The weights used are: 0.6 for job accessibility, 0.2 for land-use transition potential, and 0.1 for both zoning and physical suitability for the PSS. For the HSS, it is assumed that the current land use policies will be relaxed, so a 0.2 weight was used for both the land-use transition potential and physical suitability, along with 0.6 for job accessibility. This weighted overlay resulted in an overall suitability surface for future LDRAs and HDRAs for both the PSS and the HSS.

In the *land use allocation module*, considering that telecommuting can facilitate allocation of residential areas lying at a larger distance of concentrations of jobs, the allocation of future residential land for the HSS should take place at a larger geographical scale than for the PSS. In this way the wider spatial choices that telecommuters will have in future is represented adequately. For that purpose, the Netherlands is divided into four major macro-regions. We follow the official regionalization of Statistics Netherlands, although the western edge of the Flevoland province (the city of Almere), clearly is functionally part of Randstad. The regions used are:

Eastern Region: the provinces Gelderland, Overijssel, and Flevoland.
Western Region: the provinces Noord-Holland, Zuid-Holland, Zeeland and Utrecht.
Northern Region: the provinces: Groningen, Friesland, and Drenthe.
Southern Region: the provinces: Noord-Brabant and Limburg.

On the basis of the national and regional socio-economic and demographic trends analyzed for the EE application of the Netherlands Environmental Assessment Agency, future demand for low and high density residential areas for the year 2030 was allocated to the four regions as shown in Table 6.2. These totals are the input for the detailed allocation modelling within the macro-regions. For reference, the shares of workers and jobs are also given in the table. The differences between the two scenarios are predominantly due to the larger share of low residential development in the HSS. The regional shares of the macro-regions are more or less the same for the two scenarios and the density categories.

By applying these future spatial requirements in *the land-use allocation module*, future LDRAs and HDRAs for both PSS and HSS were projected for year 2030. The differences between future

Table 6.2 Allocation of required land for Low (LDRAs) and High (HDRAs) Density Residential Areas for macro-regions in the Netherlands 2030

Region	Working Population (%)	Jobs (%)	LDRAs HSS (sq. km)	HDRAs HSS (sq. km)	LDRAs PSS (sq. km)	HDRAs PSS (sq. km)
East	22	21	189.60	9.98	179.62	19.96
West	48	49	379.19	19.96	359.23	39.91
North	9	8	84.26	4.43	79.83	8.87
South	21	22	179.87	9.47	170.41	18.93
Total	100	100	832.92	43.84	789.08	87.68

HSS: Hybrid Space Scenario PSS: Physical Space Scenario
Source: Transport Research Centre (AVV: Adviesdienst Verkeer en Vervoer), and Engelen et al. (2002)

LDRAs and HDRAs for both the PSS and the HSS for the year 2030 are shown in Figures 6.3 and 6.4

From Figure 6.3, it becomes clear that pressure for residential development will grow at the inner edges of the Randstad circle of cities, seriously affecting the Green Heart, and in a number of 'half-way' zones between the Randstad and the national borders, in particular in areas along major urban and transportation corridors to the south and east. Overall, a distinctly more dispersed pattern can be seen, but no real break with the existing urban spatial structure of the Netherlands. It appears that the Randstad ring of city regions will tend to be spatially extended both internally and towards surroundings regions, but this trend has already been visible for some decades. In hybrid space, apart from having a stronger overall dispersion trend, residential growth is more clustered in attractive areas with good job accessibility at small to medium distances from the major cities than in physical space. The Utrecht-Arnhem-Gorinchem triangle, at the south-eastern edge of the Randstad heartland, is a good example of such a region. In the Physical Space Scenario, nearly all large and medium-sized cities in the country show contiguous spatial growth along with a trend in both scenarios of residential growth in small towns and villages.

The allocation of new high-density residential areas (Figure 6.4) shows growing pressure in a number of large city regions, in particular Amsterdam, Arnhem-Nijmegen, `s-Hertogenbosch, and Eindhoven. In physical space, the pressure shows up in a more pronounced fashion in the 'half-way' city regions, particularly in Eindhoven. In hybrid space, the region among Utrecht, Arnhem, and Gorinchem is apparently a hotspot area for future urbanization in the Netherlands because it will also be susceptible to more high-density residential development.

6.4 Spatial pattern analysis of new residential areas

Apart from visual interpretation, there are many spatial statistical methods and tools for measuring spatial patterns, such as the nearest-neighbour index, spatial autocorrelation, and landscape metrics (Chou 1996; McGarigal 2002). These methods can provide a systematic quantification of patterns and pattern differences in digital maps. They can supplement an objective evaluation of the spatial nature of the features represented in those maps. In this research, the focus is the potential impact of the use of ICTs, in particular telecommuting, on urbanization patterns. As shown in first section, urban sprawl, deconcentration and decentralization are often discussed in relation to the increasing use of ICTs.

A number of spatial statistical methods (like Euclidean nearest neighbourhood index, clumpiness index, proximity mean index, proportion like adjacencies, aggregation index, spatial correlation and average distance from main highway) have been explored. All these show that spatial spreading of residential areas in the HSS is more pronounced than in the PSS by 2030. Among the methods, the Spatial-Clumpiness Index (SCI) was found to be best suited for analyzing compactness and spread in spatial patterns for data in raster format. The other indices mentioned give an overall single value and are not picking up enough spatial detail.

Since the future high-density residential areas only cover a minor share of all residential land allocated by the model for the 2000-2030 period, they are combined with the low-density areas. This combined pattern of new residential land use is then analyzed with the SCI.

6.4.1 Spatial clumpiness index

For raster datasets, most spatial metrics are based on nearest-neighbour distance. This measure gives a quantitative indication of spatial spread at the patch, class, and landscape levels. The patch level is the most relevant in this analysis. The nearest-neighbour distance is then defined as the distance from a patch – represented by continuous raster cells of a common class, such as residential land use – to a neighbouring patch of the same or a different class. The nearest-neighbour distance is measured as the distance between the centres of the two cells in the two patches that are located closest to each other. On the basis of this distance, Spatial Clumpiness Index (SCI) measures the probability of neighbourhood pixels being of the same class and describes to what extent landscapes are aggregated or clumped. Formulae used to compute SCI are shown in Equation 6.1 and 6.2, further details about those can be found in McGarigal *et al.* (2002).

$$Given \quad G_i = \left[\frac{g_{ii}}{\left(\sum_{ii=1}^{m} g_{ik} - \min e_i \right)} \right] \qquad \text{(Eq. 6.1)}$$

$$SCI = \left[\begin{array}{c} \frac{G_i - P_i}{P_i} \; for \;\; G_i < P_i \;\; \& \;\; P_i < 0.5; \;\; else \\ \frac{G_i - P_i}{1 - P_i} \end{array} \right] \qquad \text{(Eq. 6.2)}$$

Where:

G_i is the proportion of like adjacencies

g_{ii} is number of like adjacencies (joins) between pixels of patch type (class) i based on the *double-count* method.

g_{ik} is number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method.

Min e_i is minimum perimeter (in number of cell surfaces) of patch type (class) i for a maximally clumped class.

P_i is proportion of the landscape occupied by patch type (class) i.

SCI equals the proportional deviation of the proportion of like adjacencies involving the corresponding class from the one expected under a spatially random distribution. Where, g_{ii} in the numerator includes only internal like adjacencies; like adjacencies involving cells in the border are not included. The sum of g_{ik} in the denominator includes all adjacencies involving the focal class, including adjacencies involving background and all adjacencies involving the landscape boundary, regardless of whether a border is present or not. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved. Thus, P_i is based on the total landscape area including any internal background present.

Given any P_i, SCI equals -1 when the focal patch type is maximally disaggregated; SCI equals to zero when the focal patch type is distributed randomly, and approaches 1 when the patch type is maximally aggregated. Landscapes consisting of patches of relatively large, contiguous landscape classes are described by a high SCI values. If a landscape is dominated by a relatively greater number of small or highly fragmented patches, the SCI is low. For example if an urbanized area is represented by one large and compact built-up area the SCI will be high. The more heterogeneous the urbanized area becomes as a result of higher fragmentation or a larger number of individual urban units, the lower the SCI value will be.

6.4.2 Urban sprawl and clustering

SCI values were calculated for each cell of the existing residential areas in the year 2000 and the new future residential areas (in 2030) for the Physical Space and Hybrid Space Scenarios by applying a moving window of a radius of 4 Kilometres (8 cells of 500*500 meter). As the differences in residential clustering among three situations studied – 2000, 2030 PSS, and 2030 HSS – are most relevant to the given research aims, several difference maps have been compiled (Figures 6.5, 6.6 and 6.7).

From a quick inspection of these maps it can be concluded that the residential areas in the Netherlands show a predominantly clustered pattern now and will continue to do so in the future (a 30 year period). This outcome is quite obvious for settlement patterns, which tend to change slowly over time. More important and interesting are the spatial differences between SCI values for scenarios and time slices. The future residential areas in the Hybrid Space Scenario are relatively less clustered than the actual residential patterns in 2000, but also to some extent relatively less clustered than in the Physical Space Scenario.

In figures 6.5 and 6.6, it can be seen that future pressure for more sprawl is most likely to occur in the heavily urbanized parts of the country: the Randstad ring of city regions and adjacent areas to the east and south. Increased sprawl is also projected in the western part of the Green Heart. This increase is visible in both the Physical Space and the Hybrid Space Scenario. In the HSS, sprawl also extends to areas at quite a distance from Randstad in the provinces of Drenthe (Assen, Emmen), Gelderland (Doetinchem) and Noord-Brabant (Eindhoven). This dispersion can be seen even better in Figure 6.7 , where the SCI values for the two scenarios are compared. The statistic reveals that the allocation modelling results mean more clustering than was discernable in 2000 for many peripheral regions in the Netherlands (north, northwest, southwest, and southeast). Here, new residential areas tend to be spatially-continuous extensions of existing towns and villages. Regions that are part of open space and nature corridors and for which strict policy controls are enforced also show this increased clustering tendency (the Gouda-Gorinchem area, for example). On the other hand, the currently not very highly urbanized region between

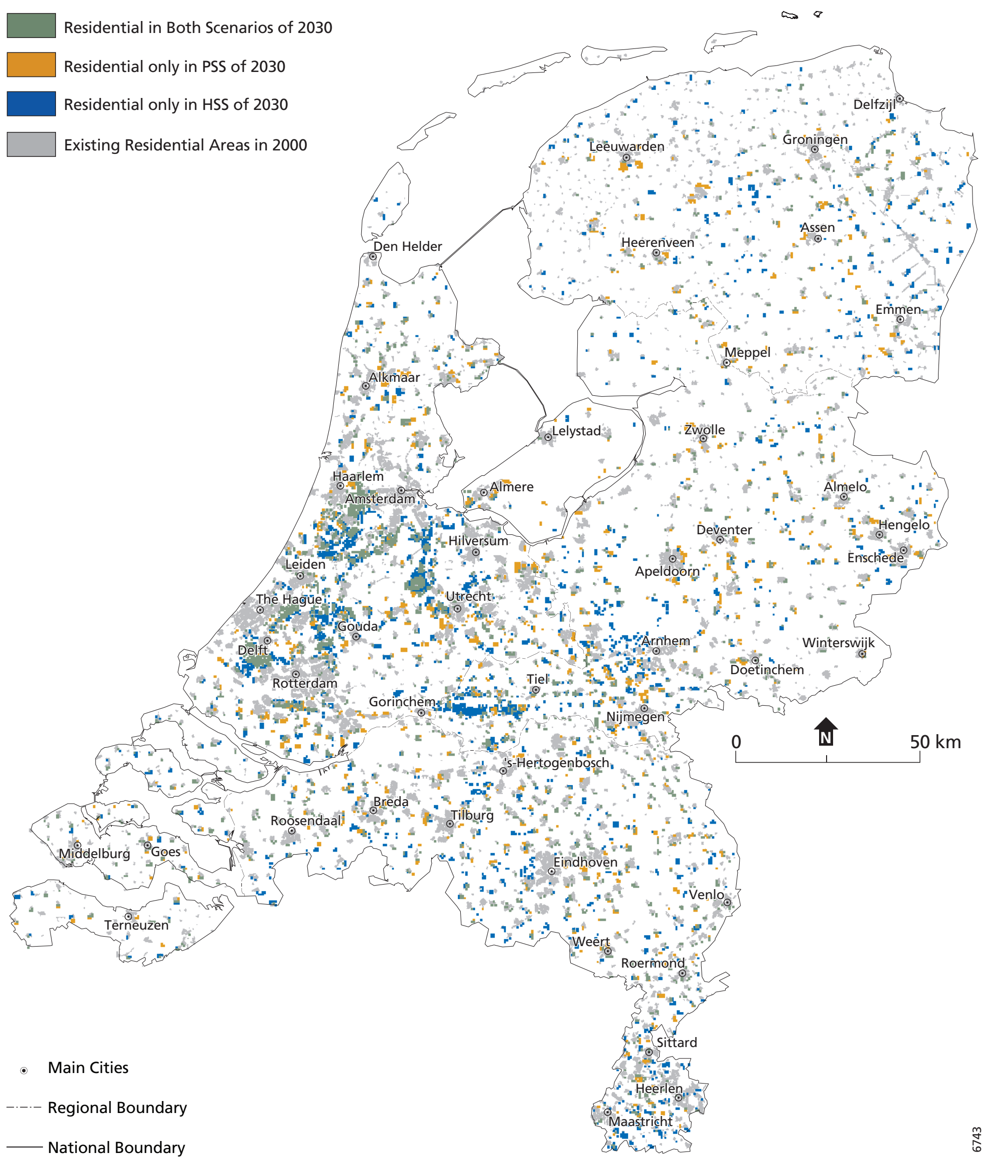

Figure 6.3 Differences between allocated new low density residential areas in PSS and HSS of 2030

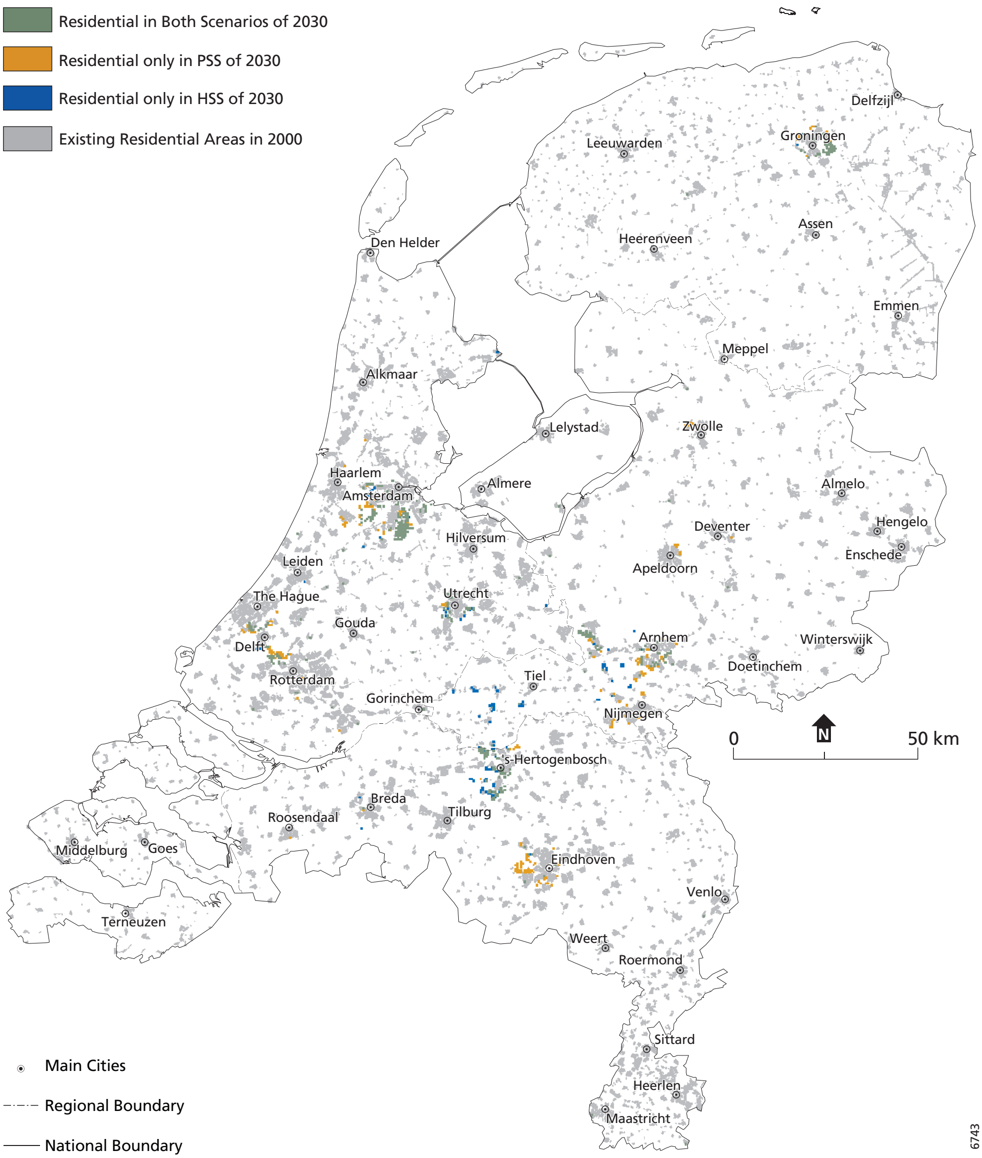

Figure 6.4 Differences between allocated new high density residential areas in PSS and HSS of 2030

Utrecht and 's-Hertogenbosch (along the main north-south transportation axis) is projected to face sprawling urbanization. The Veluwe area west of Apeldoorn and Arnhem is a special case. This area is a wooded landscape with a large protected national park. It is an attractive area for telecommuters (attractive landscape, relatively good accessibility) and it is projected to come under severe pressure of scattered urban development.

6.5 Conclusions and discussion

The Netherlands is a small and densely-populated country. Sixteen million people live on 40,000 square kilometres of vulnerable land- and townscapes, many of historic value. Land resources for a growing population and expanding economy are therefore limited and a strong national physical planning system has developed (Engelen *et al.* 2002). At present, the settlement pattern situation is characterized by polycentric urban structures, a strong urban concentration in the western and central parts of the country, but expansion to the south and east with a combination of compact growth and clustered deconcentration. The demand for new residential land use will be considerable till 2030. Current urban policy aims at continued urban containment, but at the same time spatial planning and control are being decentralized.

A major new aspect of spatial urban development is the potential impact of a widespread uptake and substantial use of modern information and communication technologies. The focus in this study is the spatial impact of telecommuting. Changing accessibility and suitability surfaces can be expected to influence residential location preferences and resulting pattern of new residential land use when telecommuting really takes off.

Scenario-based projections of likely locations of new residential land have been made with a dedicated hybrid model that combines cellular automata, accessibility modelling, and regular GIS analysis methods. In addition, the patterns generated have been screened for their contribution towards sprawling urbanization with the Spatial Clumpiness Index. The first scenario is based on the allocation of new residential land according to recent development trends. This is the Physical Space Scenario (PSS). The Hybrid Space Scenario (HSS) assumes substantial growth of telecommuting (in virtual space) with a continuous substantial role for traditional commuting in physical space.

The allocation model applications show a population deconcentration throughout the country, but no major alteration of the existing settlement pattern. The Randstad urban region is projected to grow spatially both inwards – into the western part of the Green Hart – and outwards – towards the south and east along transport axes and urban corridors. These trends are stronger in the HSS than in the PSS. But the pressure on landscapes that are attractive to live in and are located somewhat beyond the present regional labour market boundaries (of the Randstad cities) is likely to increase strongly. These areas are often protected national landscapes. The growth in urban land consumption will be heavily dominated by low-density projects, decoupling growth in residential land consumption even more from population growth than in the past decades.

The check on clustering reveals that the Randstad expansion in residential land-use will lead to an increased urban sprawl, but the (modest) growth in peripheral regions is likely to be relatively clustered. The results indicate that telecommuting, which among employed household members will often be combined with regular commuting, will not create a clean break with the past. Geography still matters, albeit with somewhat extended distances and with more attractiveness of amenity-rich locations. The results confirm theories and empirical analyses that show the two faces of ICTs have effects on urbanization. Although, a strengthening of existing agglomerations continues, but in the meanwhile a concentrated deconcentration processes is also going on. Along with those, a minor but not unimportant dispersed deconcentration to attractive regions beyond present spatial labour market borders is also observed. This last process is more residential in nature and probably has a direct relation with the increasing number of telecommuters.

Complete revision of current urban policies to accommodate these new realities does not seem to be necessary. But awareness of these new urban pressures and subsequent monitoring and timely adaptation of spatial visions and strategies is highly recommended.

The combined use of a dedicated modular hybrid allocation model and the best suited landscape statistics technique proved to be useful. This underlines the need for dedicated planning support systems that fit both the information needs and the available data and modelling facilities for a particular application.

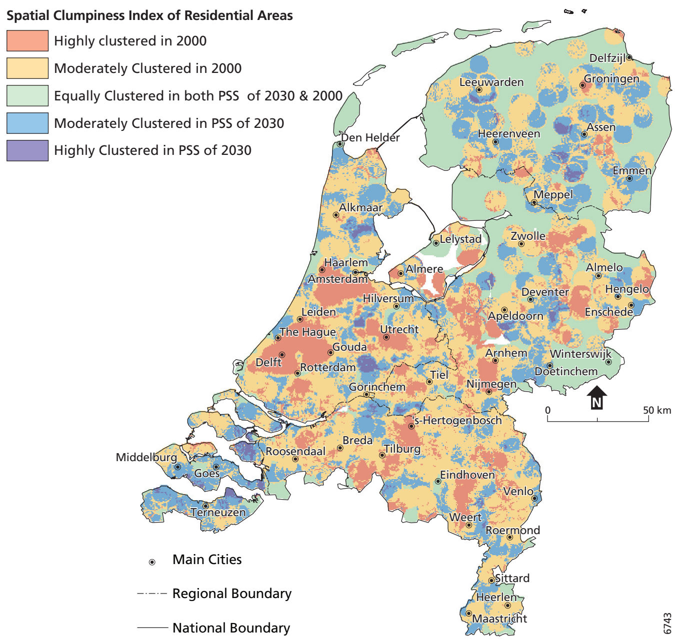

Figure 6.5 Differences in spatial clumpiness index values between residential areas in PSS of 2030 and existing residential areas in 2000

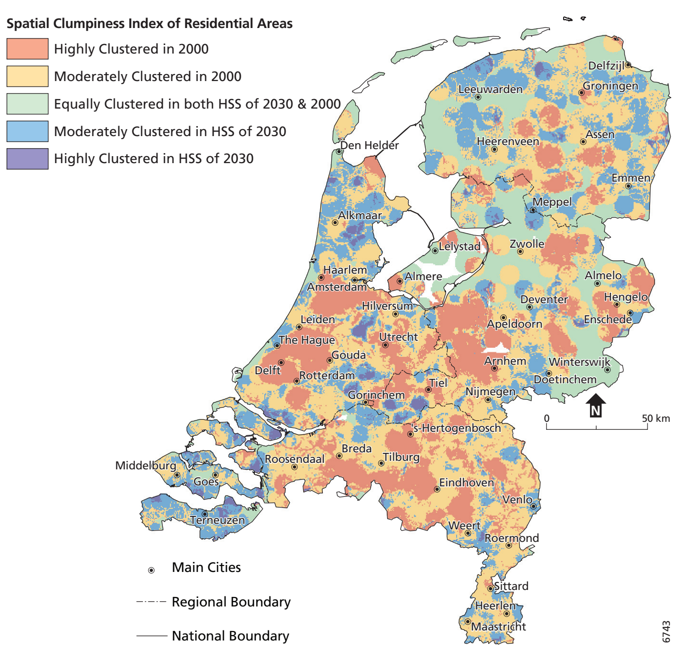

Figure 6.6 Differences in spatial clumpiness index values between future residential areas in HSS of 2030 and existing residential areas in 2000

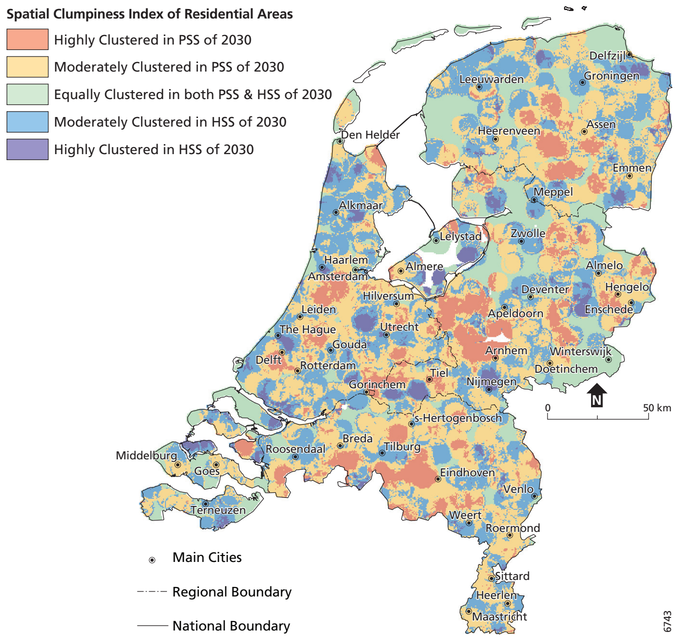

Figure 6.7 Differences in spatial clumpiness index values between future Residential areas in PSS and HSS of 2030

7 Conclusions and Discussion

7.1 Recapitulation of the research subject and questions

Many authors have emphasised the apparent disembodying of social, economic and political relations from their local preconditions, as spatial affects of ICTs on urban areas. For instance, it has been argued that the *'space of flows'* is superseding the *'space of places'* (Castells 1989; Castells & Hall 1994; Castells 2004); that *'geography itself is being dissolved'* (O'Brien 1992; Ruggie 1993), which may result in the *'end of geography'*; that national borders have become irrelevant, redundant or obsolete (Ohmae 1995); that nationally organised political-cultural identities are being *'deterritorialised'* (Appadurai 1996). Thus *'distanceless'* (Cairncross 1998), *'borderless'* (Scholte 1996) interactions in '*virtual space*' (Malecki & Gorman 2001) are '*decentring*' the role of place-based socio-institutional forms (Brenner 1999).

Whatever their differences of emphasis, research objectives and interpretations, common to these diverse analyses of effects of ICTs is a focus on the accelerated circulation of people, commodities, capital, money, identities and images through virtual space along with the long existing physical space. It means the emergence of a *hybrid space*. These accelerated, circulating flows in hybrid space are said to embody processes of suburbanization and counterurbanization through which social relations are being increasingly detached and disembodied from places and territories on sub-global geographical scales (Brenner 1999). Thus, it may be the '*death of distance but not end of geography*' (Malecki & Gorman 2001), where there is *'the rise of new places'* (Wilson *et al.* 2001), which *'feed off and fuel'* (Graham & Marvin 2000), while being *'old script replayed with new actors'* (Mitchell 2000).

Post-industrial theorists (or futurists) predict the *'death of distance'* will lead to prevailing urbanization in the form of low-density urban fields dominated by electronic cottages (Toffler 1980; Shen 2000; Ellen & Hempsted 2002). According to Webber (2004), *'spatial proximity'* continues to be considered a necessary condition, but it is now becoming apparent that it is the *'accessibility rather than propinquity'* aspect of place that is the necessary condition. In the virtual space, the accessibility becomes further freed from propinquity, cohabitation of a territorial place, whether it be neighbourhood, a suburb, a metropolis, a region, or a nation. It also is becoming less important to the maintenance of social communities. Thus a new wave of urbanization is on its way, which may turn out new spatial patterns especially those of residential and commercial areas.

The Netherlands is a small country in geographical context, but with a larger share of the working people telecommuting than the EU average and in the USA (Todd 2006). It therefore is a good laboratory to explore the spatial impacts of telecommuting. The employers organization in the Netherlands (VNO-NCW) wants the Dutch government to give more monetary rewards to telecommuters in order to reduce traffic congestion and to foster economic growth (Expatica 2007). Hence, there is a promising scope for the use of ICTs for telecommuting, teleshopping, e-recreation, e-learning etc. These new ways of conducting activities have and will continue to have profound effects on the meaning of distance. Among the e-activities, telecommuting may have the most potential for influencing job accessibility and ultimately for the allocation of land uses in future. In the Netherlands, job accessibility has been established as a major determinant of land use allocation (Verburg *et al.* 2004).

Based on these theoretical and empirical bodies of knowledge, the objective of this research was specified as 'to provide an insight into the possible effects on urbanization patterns of the changed meaning that distance (accessibility) and place quality (land use suitability) are assumed to get under the influence of the use of ICTs for telecommuting'. In order to make these effects more tangible the following research questions were formulated:

a. What will be the new meaning of distance in this age of ICTs?
b. How can job accessibility surfaces be generated that reflect the new meaning of distance in the information society?
c. What can be the effects of use of ICTs for job accessibility (by telecommuting) on residential locational preferences?
d. How can suitability surfaces for future residential areas be generated that reflect the new meaning of place quality in the information society?
e. What possible changes can be expected in future urbanization patterns under the influence of ICTs in near future?
f. What will be the implication of these possible urbanization patterns on future spatial land-use policies?

In next section, the answers found to questions a to e are summarized. Then on the basis of those results the answer to question f is given. Finally, future prospects for research in this domain are discussed in the last section.

7.2 Summary of the research results

Research question a (new meaning of distance)

In chapter 2, a literature review of the current state of affairs on the distance discussion shows that cities are getting new ICT infrastructures (fibre-optic networks, net content) that supplement the existing physical networks. These physical and virtual networks allow people to access both physical and virtual spaces. People having capabilities and resources to access virtual space, are in a position to access and use opportunities independent of distance. This will free them from physical bindings such as the need for a residence at a commutable distance from the work place. As an outcome, telecommuters will have the possibility to move away from their office location in search for more affordable living environments within their set of preferences.

However, the need for physical contact remains, in part due to the fact that some jobs require people to work together in the same physical space, but also as a result of man's social nature to often have face-to-face contact. In addition, virtual interaction also induces face-to-face contacts. Thus, telecommunications tend to lead to an overall increase in interaction in hybrid space. In this way, the use of ICTs-based access to opportunities substitutes, modifies, generates and enhances accessibility of people in hybrid space. Consequently, the use of ICTs will not result in the death of distance, but new locations or places are emerging in virtual space, where the interactions and facilities are intermingled between virtual and physical spaces. Overall, people having ICTs' competences and accessing those places in hybrid space will be privileged.

As a consequence, accessibility can no longer be measured solely in terms of physical separation, as the virtual component also needs to be incorporated. For this virtual component, people's personal characteristics, like type of education, personal skills and experiences, and the nature of the job play more important roles than before. Thus, in order to incorporate the virtual mode of communication in existing accessibility measures, these variables need to be included in these techniques.

Most of the opportunities that are available in virtual space still need to be accessed in physical space as well, albeit with a lower frequency. Thus rather than talk about the '*death of distance*', we should recognize that '*distance acquires a new meaning*'. For instance, telecommuters will not commute all the time, but less frequently than regular commuters. At the same time, they travel longer distances when they do commute in physical space. This can be explained by the '*Law of Constant Travel Time*' ('Brever-wet' in Dutch), which states that, notwithstanding changes in modal split, the individual's total time spent on transport will remain more or less unchanged (Hupkes 1982). This rule is verified at aggregate level by Mokhtarian and Chen (2004) and Schaffer and Victor (1997). It means that for measuring job accessibility in hybrid space, the distance decay parameters for telecommuters should be relaxed according to the possible average distance they commute. In this way in the model the use of ICTs will enhance the accessibility of the people to an increasing array of opportunities within wider spatial margins.

In the Netherlands, most of the jobs are located in the western part of the country called Randstad (the city regions of Amsterdam, Rotterdam, The Hague and Utrecht). Randstad has the largest population and employment volume and density in the country. So, the average commute time is relatively low both in terms of time and distance as compared to most other large metropolitan areas in Europe (Geurs & Ritsema van Eck 2003). ICTs are now facilitating residents of non-Randstad regions to access part of these employment opportunities in virtual space.

Research question b (accessibility in hybrid space)

Chapter 3 describes the work done to compute job accessibility in the Netherlands for both a Physical Space Scenario (PSS) and a Hybrid Space Scenario (HSS). In the PSS jobs can only be accessed through physical space, in the HSS jobs can be accessed in both physical and virtual space.

Two models, the traditional Hansen's destination constrained potential accessibility model and Shen's potential accessibility model with competition factors were applied. Of these two, Hansen's model gave better (plausible and interpretable) results. According to Shen (1998b), the expected value of a location is a ratio of total number of opportunities accessible to total number of opportunity seekers in the area concerned. Hence for Shen's model, it is a prerequisite to delimit more or less closed regional labour markets of about the same population size. Thus a metropolitan city region and a rural region (with a town as the centre) will have the same level of job accessibility when the numbers of jobs accessible and people who can access those jobs are proportional. This can lead to misleading outcomes. The problem propagates when the computed accessibility values are used for allocation of land use in land use projection models.

Furthermore, while modelling job accessibility, it is the distance decay parameter's value that substantially affects the computed job accessibility (Chapter 4). The distance decay parameter is thought to be the proxy for distance behaviour as it reflects the willingness of people to overcome distance. Telecommuters show a longer commuting distance than traditional commuters, hence in order to represent this phenomenon in the value of the distance decay parameter its value needs to be adapted accordingly. But, relaxing the parameter values, and taking into consideration the average commute distance, the extent of the area delimited appears also to be an important factor. In order to keep the modelled mean trip length at the same level, the larger the area the more the parameter's value needs to be adjusted.

Moreover, due to the non-linearity of the relationship between mean trip length and distance decay parameter, modelling the effect of telecommuting is not simply a matter of lowering the value of the parameter correspondingly. Further, the maximum value of the mean trip length that could technically be realised does not produce very realistic commuting patterns. Thus, the distance decay parameter should never be set to a value below zero. This puts a further constraint on the maximum mean trip length that can be achieved. These results indicate a need to abandon the notion that a distance decay parameter is an otherwise independent reflection of distance behaviour.

Overall, the results of both models for computing job accessibility show that job accessibility all over the Netherlands improves when telecommuting becomes more prominent. The western region (Randstad) of the Netherlands has always been the most attractive for job seekers and this situation will continue in a hybrid space as well. However, in hybrid space many opportunities in Randstad can also be accessed from adjacent medium-sized city regions and rural areas. Not only by telecommuting in virtual space, but also with a limited frequency of commuting in physical space. In the longer term, this pattern of geographical job accessibility will further widen the residential locational margins for telecommuters. For northern and south-western regions, which have the lowest levels of job accessibility in physical space, job accessibility will improve in hybrid space, but, in relative terms, these regions will become even more peripheral. All these findings confirm the expectation that the application of a job accessibility model that incorporates telecommuting produces useful information for planning and decision making purposes.

Research question c (residential preferences of telecommuters)

The modelled changes in job accessibility in terms of commute distance can be expected to have an impact on residential locational preferences. It is assumed that telecommuting can facilitate decentralization and as a result people will prefer to have homes located in low to medium density and physically attractive environments. This in part, could be to escape the drawbacks of high density urban settings, such as high land and house prices, small housing plots and congestion.

In order to explore the effects of telecommuting and other traditional factors on current location of residence, commute distance, intentions to change residence in the coming two years and future wanted type of residential environment, housing demand survey (in Dutch 'Woning Behoefte Onderzoek' (WBO)) data for the year 2002, was analysed using multiple regression models (Chapter 5). For telecommuting to have an impact on residential locational preferences, two conditions must hold. First, a substantial number of workers must telecommute and secondly, these telecommuters must have different locational preferences from commuters (Ellen & Hempsted 2002). Currently, the majority of the telecommuters have partners who commute. Hence, the household preference might differ from personal preferences of household members. About 16 percent of the telecommuters have a partner who also telecommutes and 22 percent live on their own. Therefore, the condition of having a sizable group is met. Further statistical analysis yielded a clear characterization of the telecommuters in the Netherlands.

It was found that among telecommuters, middle and high income and education groups are overrepresented. Currently, telecommuters above average have their residence in rural environment or a low density green urban setting as compared to an inner city location. However, the majority of the young age telecommuters, who do not (yet) have relatively high incomes do live in an urban environment.

Households currently residing in green urban areas, towns and rural environments have a low propensity to relocate. When the respondent works more hours, the relocation probability increases. Also, when both the main respondent and the partner have longer commute distance, a higher likeliness of relocation was established. But the telecommuting status, both of the respondent and of the partner, does not have a statistically significant effect on relocation probability. This suggests that telecommuting often already is a permanent state in which a longer commute distance is balanced against a more attractive residential area, rather than a temporary measure to deal with a long commute in anticipation of a residential relocation. Among the traditional factors, household composition and education level play a major role in the intention to move in the near future. A low propensity to move is connected with old age and high income categories, as was found in other studies (Lamanna 1964; Michaelson 1977; Lindberg *et al.* 1988).

With respect to preferred future location of residence, the majority of both commuters and telecommuters like to stay in the type of residential environment they live in. Within this general pattern, telecommuters are more likely to prefer their future residence located in a green urban environment and a regional town compared to other types of settings. This differs slightly from their current residential environment, where rural areas are overrepresented. Among the traditional factors, age, number of children in the household and current location of residence were the main variables correlating with the type of living environment desired in future. These results indicate that, although telecommuting facilitates longer commute distances, a dramatic shift in the preferences for types of residential environments as hypothesized by some researchers, is not substantiated in this study. In the current, premature hybrid space situation in the Netherlands, telecommuting plays a limited role in residential location decisions. Moreover, two subgroups of telecommuters can be distinguished: the 'young-high education' group with an urban orientation and the 'older-high income' group with a rural orientation. This second subgroup is now by far the largest but that may change in future.

Research question d (future suitability for residential land use)

Quite a number of land use projection models have been developed over the last decades (Appendix B). The Environment Explorer (EE), a comprehensive, dynamic land use projection model, based on a three level approach (national, regional and local) was selected to project residential land-use for both the Physical Space Scenario (PSS) and the Hybrid Space Scenario (HSS). However, the EE model, as implemented at the Netherlands Environmental Assessment Agency, has some severe limitation with respect to allocating land use requirements (computed at COROP level, 40 administrative regions in the Netherlands) and projecting future residential areas for the HSS (the allocation is calculated for each COROP separately). Further, job accessibility for both the PSS and the HSS is measured for LMS sub-zones (1308 for the Netherlands), while the transportation module in the EE is based on LMS main zone level (345 zones for the Netherlands). In the HSS it is assumed that regional labour markets will spatially widen and that allocation will also take place at interregional scales. At the other hand, allocation of residential land-use should be done with a high geographical detail to be of relevance for planning support.

In order to overcome these limitations, a residential land-use projection model incorporating job accessibility measured at LMS sub-zone level and land requirement calculation and allocation at regional level (four macro-regions for the Netherlands) was developed (Chapter 6). Its main drivers are: job accessibility, land use transition potential, physical suitability and zoning policies. They are weighted differently for the two scenarios. By applying this model, land use suitability surfaces and finally the pattern of new residential areas for both the PSS and the HSS is projected for the year 2030, compared between the scenarios and related to the situation in 2000.

Research question e (future urbanisation patterns)
At present, residential areas are scattered all over the Netherlands with concentrations in Randstad and a large number of medium-sized city regions in the other parts of the country. The processes of polycentric urban development and bundled suburbanization are typical for the Netherlands and have been supported by national spatial policies. In general telecommuting further enhances those processes. This is also suggested by Van Oort *et al.* (2003a). Nevertheless, for the HSS, the location of new residential areas in 2030 shows a more dispersed pattern than the one of both existing residential areas (2000) and the PSS-projection. Thus, in the HSS more people will have the opportunity to live in more low density, and green environments without bringing about a structural change in the urbanization pattern of the Netherlands.

More detailed regional results reveal that at the south-eastern edge of Randstad a band with relatively high but concentrated growth in residential land-use is likely to develop when the HSS assumptions become reality. This is an area with good levels of job accessibility combined with available land for residential development, attractive physical characteristics, and limited policy restrictions. On the other hand, areas to the east of Randstad will experience growth of residential land of a spreading nature, especially in the Hybrid Space Scenario. From a landscape point of view, this wooded area has a high physical attractiveness.

Within the western region, the (western part of) the Green Heart, the area encircled by the large western cities will also face a strong pressure of new residential development in both scenarios. Again, enhanced accessibility (of the Randstad jobs) will drive this pressure. The future allocated residential areas show for both scenarios a more or less clustered pattern. In the HSS this clustering will be less pronounced as compared to the PSS. This is for example clearly visible in the areas surrounding Utrecht and lying south of the Utrecht-Rotterdam line.

In the north of the country, new residential development areas will also have a more dispersed pattern in the HSS as compared to the PSS. Especially in the central part of the north, large parts of the province of Drenthe, which presently has low density figures in the Dutch context.

The southern region shows the same tendencies, with substantial growth along a number of urban/transportation axes in the province of Noord-Brabant and the Eindhoven urban region. In the HSS this growth of new residential land is in a number of sub-areas (Eindhoven, Tilburg, Roosendaal) of a sprawling nature.

With the help of the Spatial Clumpiness Index, sprawling and clustering of new residential land has been analysed statistically. In this way, the pattern differences that can be seen by visual inspection, are further geographically detailed.

The general conclusion is that telecommuting is likely to modestly facilitate more widespread allocation of future residential areas combined with more pressure for dispersed residential development. Spatial residential growth is likely to happen in large parts of the country but hot spots will be the overspill regions inside the Randstad ring of cities, the western Green Heart, and outside the ring in south-eastern and southern direction (the provinces of Gelderland and Noord-Brabant). These general spatial trends are fuelled by better and spatially expanding job accessibility and resulting residential suitability. Whether residential growth will be predominantly clustered or dispersed is dependent on regional and local circumstances with respect to existing urban pattern, physical attractiveness and zoning policies.

In order to get more insight into the effects of telecommuting on future residential land-use patterns for the Netherlands, the residential areas projected in the HSS for 2030 are compared to projected residential land-use of the Netherlands by Borsboom- Van Beurden, *et al.* (2005) and De Nijs, *et al.* (2005) (Appendix D).

Borsboom- Van Beurden used four scenarios (elaborated in Van Egmond *et al*. (2005): World Competition, World Solidarity, Safe Region and Considerate Region) for projection of future land use in the Netherlands for the year 2030 using the Land Use Scanner model. Among these, the Safe Region scenario was closest to the European Coordination scenario, the parameters of which were used for this research. The residential land-use projected for the Safe Region scenario is compared with the one projected for the HSS of 2030. Due to different criteria used for the future available land for urbanization, there are quite some differences in the allocated residential areas in both scenario projections. In our modelling, major forest areas were not considered as potential sites for future allocation of residential areas, while for the Land use Scanner they were. Hence in north and southwest of Apeldoorn, there are areas allocated as residential in future on the existing forest area. The same is the case in the eastern part of the province of Utrecht. On the other hand, in the Randstad region in the HSS-projection more residential areas are allocated around the large cities. Also, compared to the Safe Region scenario, the southern expansion of Randstad is more pronounced and residential development more scattered in the northern macro-region. These differences show the important impact that specifying drivers and their input values has on the modelling outcomes, especially at local and regional scales.

The projected future residential areas for year 2030 by the High Spatial Pressure trend scenario (De Nijs, *et al.* (2005)) are mostly located around existing residential concentrations, especially in Randstad. In comparison, the HSS pattern is more scattered. Also, De Nijs projects high urban pressure in the Arnhem/Nijmegen region, while the HSS shows an important pressure increase in regions directly south of the Randstad. Overall, the inclusion of telecommuting as a driving force for the allocation of new residential land-use, leads in the first place to a more but still limited, scattered development.

Research question f (policy implications)

7.3 Implication of telecommuting for spatial land-use policies

The current paradigm of spatial planning can best be characterized in terms of spatial concepts. A spatial plan concept is a "concise verbal or visual expression of how a planning actor views a desirable spatial structure and the interventions necessary to implement it" (Zonneveld 1991). Whether a spatial concept qualifies as new, can only be decided after comparison with existing concepts. In the Netherlands, for example, spatial planning concepts have been produced from 1920 onward. They refer to concepts of Randstad, to the relation between Randstad and the other macro-regions, to urban and rural regions, urban and green regions and urbanization and mobility and water management. Main planning actors, according to the Dutch three-tier-system, are those involved in local land-use plans, local structure plans, regional master plans and national spatial planning policy reports.

Over a period of 70 years, concepts alternate and shift (Zonneveld 1991). The concepts with regard to urban regions cover seven distinct waves:

- the concept formation without a hard core: centralization or decentralization (1920-1934),
- the completed future city (1934-1951),
- from city to conurbation (1951-1958),
- expansion and change (1958-1973),
- the threat of suburbanization (1973-1976),
- concentration and conservation (1976-1987), and
- the rediscovery of the large scale (1987-1990).

In 1988, the Fourth Spatial Planning Report (in Dutch 'Vierde Nota over de Ruimtelijke Ordening Extra' (VINEX)) has introduced the so-called 'compact city' concept. This is basically a strategic concept that applies to the regional level. The compact city implies that future housing locations are intended to strengthen existing urban agglomerations, in particular the central cities. Simultaneously, it is meant to slow-down private-car mobility growth by selecting new residential locations in the proximity of the urban core or major sub-centres. In addition, the choice of locations for companies and facilities is to be guided by rules that aim at matching mobility profiles of firms and amenities with accessibility profiles of locations.

In the recently implemented National Spatial Strategy (in Dutch 'Nota Ruimte') the central government wants to step back in favour of allowing the local authorities, in particular the provinces, to play a more prominent role. Although the liberal approach to development control is quite revolutionary, most spatial concepts in the strategy are based upon traditional ideas about spatial organization (Zonneveld 2005).

The forces that influence spatial structure today are manifold. Major driving forces are individualization, sustainability (mainly as a concern), globalization, where ICTs are playing a great role (Mokhtarian & Salomon 1997). During the last three decades, the development and use of ICTs are also interplaying with socio-economic characteristics of the society, which will influence spatial structures, as specific geo-economic and geo-political conditions favour changes in spatial patterns (Lorentzon & Paradiso 2004). Thus one can argue that a frontier of regional planning in the information society lies in understanding, visualising and redesigning the purpose, format (Townsend 2004) content (Lorentzon & Paradiso 2004) and use of ICT-networks to improve local conditions and growth.

In the Netherlands, a network society and a network economy are developing, where on the one hand, individualization continues to progress and, on the other hand, in this hybrid space, all those individuals are increasingly closely interconnected in numerous physical and virtual networks. Overall in the Netherlands, telecommuting will enhance job accessibility, not only of urban areas but also of, even remote, rural areas. This means that particular low density areas will develop a level of job accessibility in hybrid space that may lead there to more new clusters and dispersions of residential land-use than has been assumed so far.

The Netherlands, although being one of the most densely populated countries in the world, still has two thirds of all land in use for agriculture. Under the current wave of globalization of the economic relations in agriculture and the possible reduction of European price support to farmers (Koomen & Groen 2004), the residential preferences adopted by more telecommuting make those areas more attractive for people to migrate to. Hence, new spatial trends caused by activities in virtual space are challenging current paradigms of spatial planning. However, planners and practitioners are reluctant to take those on board as they prefer a 'business as usual' situation (Talvitie 2004). But the network society also can provide solutions for regional problems (peripheral regions lagging behind) and for more flexible and effective land control in a strategic and participatory style of planning. In order to be better able to incorporate uncertainties, like residential preferences of telecommuters, the legally binding land-use plans should be connected to a new institutional way of local plan making which is to be much more society based and less administrative as was also suggest by Hayer and Zonneveld (2000).

ICTs' acceptance is not only a matter of basic attitude towards the new technology, but also of daily practical use of ICTs both at work and at home. It also depends on being interested in acquiring hardware and software as well as ICTs' skills. Drewe (2000) found that ICTs acceptance among city planners on average was at a low level, although it turned out to be highly polarized between persons with a very high and those with a very low acceptance. However, ICTs were most popular among administrative actors dealing with the economic promotion of their cities, but they think that ICTs as such do not cause spatial changes. Moreover, the spatial impacts of the new technology still involve high levels of uncertainty (Mokhtarian & Salomon 1997).

According to Van Oort *et al*. (2003a), in the Netherlands spatial impacts of use of ICTs are patchy. This corresponds to some extent to what was found in this research. Their spatial planning and sectoral studies have revealed that in the Netherlands agglomeration effects, such as the incubator effect for businesses in the ICT sector and for the use of ICTs by all companies (of whatever sector), tend to spread out over larger urban areas. Cities are the traditional breeding ground for start-ups in the ICTs sector, but now it seems that the urban region, with its emerging multi-modal pattern of economic centres perform this function. Old-fashioned urban centres, more accessible suburban areas and relatively rural areas in between agglomerations, all have a role to play in the patchwork quilt of economic development. This research added insight into the 'ICT-effect' of work-home interaction to the effect of employment relocation studied by Van Oort.

In order to fulfil demands mentioned above about the style and content of spatial planning, three strategies – *intensifying land use*, *combining land use* and *transforming spaces in the cities and rural areas* in a *regional context* – should be adopted based on preferences of residents, workers and visitors. The processes of concentrated suburbanization and poly-centric development in the Netherlands have a longer tradition and along with this research, the studies (Van Oort *et al.* 2003a; Van Oort *et al.* 2003b; Weterings 2006) confirm that the spatial effects of ICTs will still favour these processes. But may be with a faster pace, as ICTs also act as catalyst (Van Oort *et al.* 2003a). Overall, it may result in an increasing pressure for urban sprawl.

7.4 Prospects for further research

Telecommuting is a person based activity (Kwan *et al.* 2007) so an increased use of ICTs may lead to changes in the location, timing and duration of people's activities. This will most probably lead to new patterns of activity and travel in time-space. Hence, in order to assess the effect of ICTs on travel behaviour (like the effect of telecommuting on physical commuting), individual-level analyses would be able to identify relationships that are more difficult to assess at the aggregate level. However, currently available data sets lack individual-level detail at fine spatial and temporal scales (Kwan 2002). Therefore they do not allow for such a micro-level approach. Future research at that level will be much valuable in exploring the effects of telecommuting on urbanization dynamics.

Also research combining studies on the interaction between employment relocation and residential relocation under the influence of the use of ICTs seems a good follow up of the research performed independently on these topics. Both processes can reinforce but also counteract each other and have direct effects on mobility as well. Therefore, close monitoring and periodical projection studies are needed.

In order to assess the spatial effects of use of ICTs for telecommuting, a good data infrastructure is indispensable. A great deal of data is collected and being collected in Europe. But different organizations have used different definitions of telecommuting which leads to confusion when results are compared. In particular in international comparative research (Raspe & Van Oort 2004; Choo *et al.* 2005). Therefore, it is required to adopt a common comprehensive theoretical and operational definition of telecommuting and related phenomena.

In order to be able to compute job accessibility with a doubly constrained interaction model, in national travel surveys, more extensive information about telecommuters should also be included. That will, among other things, help to extract exact values for the distance decay parameters for telecommuters which will improve job accessibility computation. Further in the LISA database, along with total number of jobs, information about the nature of the jobs will also be useful for measuring job accessibility and the projection of future land use. This is also valid for the housing demand survey of MVROM, as it will be helpful when information about the telecommuting is collected at household level, including the nature of the jobs being conducted by telecommuting.

Seven peripheral regions in the Netherlands are currently involved in cross-border cooperation with adjacent Belgian and German regions (within the framework of the EU's Interreg program). An inter-city network includes among others: physical connections or material links provided by infrastructure, various forms of organizational links, and non-material links of dialogue and information exchange. This is where ICTs come in (Drewe 2000). ICTs can even facilitate long-distance cooperation within trans-national perspectives on European territorial development. The *'plus'* in *'Euro-region plus'*, refers to this possibility. Thus a fresh look at familiar spatial concepts implied by ICTs should not be limited to national metropolitan city regions, but extended to an international context.

The effects of ICTs on the urban society are multi-dimensional and international. In this research one aspect, the use of ICTs for telecommuting was assessed at the national level. In order to gain more insight, a multi-disciplinary approach is desirable, preferable at the international level. The commercial, industrial and residential areas need to be projected in an interactive way. For that purpose a combination of multi-agent and cellular automata models would be a good option. Then, the scope of multi-agents would be at the macro (national and regional) level, while the focus of cellular automata would be at the micro (cell) level.

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Samenvatting

Toekomstige verstedelijkingspatronen:
In Nederland als gevolg van de informatie- en communicatietechnologie

Veel auteurs hebben gewezen op de ruimtelijke effecten van het gebruik van informatie- en communicatietechnologieën (ICT) voor de ontwikkeling van stedelijke gebieden. De basisoorzaak ligt bij de loskoppeling van sociale, economische en politieke activiteiten van hun locale context. Zo wordt aangegeven dat de '*ruimte van stromen*' de '*ruimte van plaatsen*' opvolgt (Castells 1989; Castells & Hall 1994; Castells 2004), dat de '*geografie zich oplost*' (O'Brien 1992; Ruggie 1993) wat resulteert in het '*einde van de geografie*', dat nationale grenzen onbelangrijk en overbodig worden en in onbruik raken (Ohmae 1995) en dat nationaal georganiseerde politiek-culturele identiteiten '*gedeterritorialiseerd*' worden (Appadurai 1996). Dit alles leidt tot '*afstandsloosheid*' (Cairncross 1998), '*grenzenloosheid*' (Scholte 1996), tot activiteiten in een '*virtuele ruimte*' (Malecki & Gorman 2001) en een '*decentrering*' van voorheen plaatsgebonden sociaal-economische verschijnselen (Brenner 1999).

Welke ook de verschillen van invalshoek, doelen en interpretaties in het onderzoek zijn, de gemeenschappelijke lijn is de aandacht voor de toenemende circulatie van personen, goederen, geld, identiteiten en beelden in de virtuele ruimte naast de bestaande geografische mobiliteit in de fysieke ruimte. Er is sprake van het ontstaan van een *hybride ruimte*. Het toenemend gebruik van de virtuele ruimte wordt vaak in verband gebracht met processen als suburbanisatie en desurbanisatie. Hierbij komen sociale en economische activiteiten steeds meer los te staan van plaatsen, gebieden en landen (Brenner 1999). Echter, er mag sprake zijn van 'het einde van het verschijnsel afstand' maar niet van het 'einde van de geografie' (Malecki & Gorman 2001). We zien immers ook 'de opkomst van nieuwe plaatsen' (Wilson *et al.* 2001) die nieuwe ontwikkelingen aanjagen (Graham & Marvin 2000). In die zin kan er gesproken worden van een bekend draaiboek maar nu met nieuwe spelers (Mitchell 2000).

Postindustriële theoretici (of futuristen) voorspellen dat het verdwijnen van afstand zal leiden tot stedelijke velden met lage dichtheden, gedomineerd door elektronische bungalows (Toffler 1980; Shen 2000; Ellen & Hempsted 2002). Webber (2004) stelt echter dat *ruimtelijke nabijheid* een noodzakelijke voorwaarde blijft, maar dat *bereikbaarheid* belangrijker wordt dan *fysieke afstand*. In de virtuele ruimte wordt bereikbaarheid verder losgekoppeld van het nabij zijn of samenzijn op een locatie of dat nu een buurt, een wijk, een stad, een regio of een land is. Ook worden geografische sociale gemeenschappen minder belangrijk. Daarom wordt een nieuwe golf van verstedelijking verwacht, die gepaard zal gaan met nieuwe ruimtelijke patronen. In het bijzonder geldt dit voor woongebieden en verzorgingsgebieden.

Nederland is geografisch gezien een klein land, maar ten opzichte van de Europese Unie en de Verenigde Staten heeft het een groot aandeel telewerkers (Todd 2006). Het is daarom een goed laboratorium om een verkenning uit te voeren naar de ruimtelijke gevolgen van telewerken. Kenmerkend in dat verband is dat de werkgeversorganisatie VNO-NCW wil dat de overheid telewerken sterker stimuleert met het oogmerk verkeersopstoppingen te beperken en economische groei te stimuleren (Expatica 2007). Daarom is er een goede voedingsbodem voor het gebruik van ICT voor telewerken, telewinkelen, de elektronische overheid, e-recreatie, afstandsonderwijs en dergelijke. Deze nieuwe manieren om activiteiten uit te voeren hebben belangrijke effecten op de betekenis van afstand. Van alle tele-activiteiten heeft telewerken waarschijnlijk potentieel de meeste invloed op de bereikbaarheid van arbeidsplaatsen en uiteindelijk op toekomstig grondgebruik. Voor Nederland is al empirisch vastgesteld van dat de bereikbaarheid van werk een belangrijke determinant is bij de allocatie van de verschillende categorieën van grondgebruik (Verburg *et al.* 2004).

Gebaseerd op deze theoretische en empirische kennis is de doelstelling van deze studie geformuleerd als 'inzicht verkrijgen in de mogelijke effecten op verstedelijkingspatronen van de veranderde betekenis van afstand (bereikbaarheid) en plaatskwaliteit (geschiktheid voor grondgebruik) die gepaard gaat met het gebruik van ICT voor telewerken'. Om deze effecten onderzoekbaar te maken zijn de volgende onderzoeksvragen gesteld:

a. Welke is de nieuwe betekenis van afstand in de informatiemaatschappij?
b. Hoe kunnen kaarten over de bereikbaarheid van arbeidsplaatsplaatsen gemaakt worden die de nieuwe betekenis van afstand reflecteren?
c. Wat kunnen de effecten van het gebruik van ICT in de werksituatie zijn op residentiële lokatievoorkeuren van telewerkers?
d. Hoe kunnen geschiktheidskaarten voor toekomstige woongebieden berekend worden die de nieuwe betekenis van plaatskwaliteit in de informatiesamenleving weerspiegelen?
e. Welke mogelijke veranderingen kunnen verwacht worden in toekomstige verstedelijkingspatronen onder invloed van toenemend ICT-gebruik?
f. Wat betekenen die nieuwe verstedelijkingspatronen voor het ruimtelijke beleid in de toekomst?

In deze studie zijn de volgende antwoorden op bovengenoemde vragen gevonden:

De nieuwe betekenis van afstand

Een literatuuroverzicht van de stand van zaken met betrekking tot de discussie over afstand laat zien dat steden nieuwe ICT-infrastructuur krijgen (glasvezelnetwerken, netinhoud) die bestaande fysieke netwerken aanvullen. Deze fysieke en virtuele netwerken maken het mogelijk dat personen zowel de fysieke als de virtuele ruimte kunnen gebruiken. Mensen die de capaciteiten en middelen hebben om gebruik te maken van de virtuele ruimte zijn in een positie om die ruimte onafhankelijk van afstand te benutten. Dat bevrijdt hen van fysieke bindingen zoals de noodzaak om een woning te kiezen op pendelafstand van het werk. Het gevolg is dat telewerkers de mogelijkheid krijgen om verder van hun kantoor of werkplaats te gaan wonen en te zoeken naar beter betaalbare opties binnen hun bundel van voorkeuren. Echter, de noodzaak van fysieke aanwezigheid op de locatie van de werkgever blijft veelal bestaan. Gedeeltelijk omdat sommige banen vereisen dat personen op dezelfde plek samenwerken, maar ook vanwege het feit dat mensen sociale wezens zijn die regelmatige persoonlijke ontmoetingen op prijs stellen.

Bovendien leidt virtuele interactie niet zelden tot persoonlijke ontmoetingen. Daarom zal telecommunicatie aanleiding geven tot een toenemende interactie over de hele linie in de hybride ruimte. Dit kan verschillende vormen aannemen: substituering, modificering, versterking. In elk geval betekent het gebruik van ICT een algemene toename van de bereikbaarheid van personen in de hybride ruimte. Daarom ook zal het gebruik van moderne ICT niet resulteren in het verdwijnen van afstand, maar zullen nieuwe locaties opkomen in de virtuele ruimte die gebaseerd zijn op het verbinden van interacties en faciliteiten in de virtuele en de fysieke ruimte. Daarbij komen mensen die ICT-competenties hebben en daar gebruik van maken in een bevoorrechte positie.

De consequentie hiervan is dat bereikbaarheid niet langer alleen gemeten kan worden in termen van fysieke separatie omdat ook de virtuele component meegenomen moet worden. Voor het meten van die virtuele component is een aantal indicatoren van belang: de persoonlijke karakteristieken van personen (opleiding, vaardigheden, ervaring) en de kenmerken van de werkzaamheden. De genoemde variabelen moeten dan ook opgenomen in de wijze van berekening van de 'nieuwe' bereikbaarheidsmaten.

Bereikbaarheid in de hybride ruimte

In dit onderzoek wordt gebruik gemaakt van twee scenario's: het Fysieke Ruimte Scenario (FRS) en het Hybride Ruimte Scenario (HRS). In het FRS kunnen werkplekken alleen bereikt worden in de fysieke ruimte. In het HRS kan zowel van de fysieke als de virtuele ruimte gebruik gemaakt worden.

Twee modellen zijn toegepast: het traditionele Hansen-model, een bestemmingsbeperkt model voor de berekening van potentiële bereikbaarheid en het Shen-model, dat is gebaseerd op de berekening van potentiële bereikbaarheid met competitiefactoren. Het model van Hansen leverde betere (meer plausibele en beter interpreteerbare) uitkomsten. Shen (1998) gaat er van uit dat de verwachte waarde van een locatie de verhouding is tussen het totaal aantal bereikbare werkplekken en het totale aantal werkzoekenden per gebied. Daarom is het bij het gebruik van een Shen-model noodzakelijk om min of meer gesloten arbeidsmarktgebieden af te bakenen met, bij voorkeur ongeveer gelijke bevolkingsomvang. Immers, een metropolitaan stadsgwest en een rurale region zullen dezelfde werkbereikbaarheid hebben als de aantallen bereikbare arbeidsplaatsen en het aantal werkzoekenden voor wie die arbeidsplaatsen binnen bereik zijn proportioneel zijn. Dit kan tot misleidende uitkomsten leiden. Het problem verergert als de berekende bereikbaarheidswaarden gebruikt worden voor het toewijzen van grondgebruik in projectiemodellen.

Daarnaast beïnvloedt bij het modelleren van de bereikbaarheid van arbeidsplaatsen de afstandsverval-parameter de bereikbaarheidswaarden substantieel. De parameter wordt beschouwd als een proxy voor afstandsgedrag omdat deze de bereidheid van mensen om afstand te overwinnen aangeeft. Teleforensen hebben een langere pendelafstand dan traditionele forensen. Om dit goed in de afstandsverval-parameter te kunnen representeren moet de waarde ervan overeenkomstig aangepast worden. Maar, als de waarden worden versoepeld, blijkt, mede gelet op de gemiddelde pendelafstand, de uitgestrektheid van het gebied een belangrijke factor te worden. Om nu de gemodelleerde gemiddelde ritlengte op hetzelfde niveau te houden moet, hoe groter het arbeidsmarktgebied wordt, de parameterwaarde meer aangepast worden.

De uitkomsten van beide modeltoepassingen laten zien dat de bereikbaarheid van arbeidsplaatsen in geheel Nederland verbetert als telewerken belangrijker wordt. Het westen van het land (de Randstad) is altijd het meest attractief geweest voor werkzoekenden en deze positie verandert niet in de toekomstige hybride ruimte. Maar in de hybride ruimte kunnen de arbeidsmogelijkheden van Randstad beter bereikt worden vanuit steden en plattelandsgebieden rond de grote stadsgewesten. Dat niet alleen door te gaan telewerken, maar ook door de combinatie met woon-werkritten met een beperkte frequentie. Op langere termijn zal dit patroon van geografische bereikbaarheid van werk leiden tot een verruiming van de locatiemarges van telewerkers. Voor de noordelijke en zuidwestelijke delen van Nederland, die de laagste bereikbaarheidsniveaus in de fysieke ruimte hebben, zal de bereikbaarheid van werk verbeteren, maar relatief gezien zullen ze een nog wat meer perifere positie gaan innemen. Al deze uikomsten bevestigen de veronderstelling dat de toepassing van een bereiksbaarheidsmodel voor werk dat rekening houdt met telewerken nuttige informatie kan opleveren voor ruimtelijke planning en beleid.

Woonvoorkeuren van telewerkers

De gemodelleerde veranderingen in arbeidsbereikbaarheid gemeten in pendelafstand zullen naar verwachting van invloed zijn op woonvoorkeuren. Er wordt van uitgegaan dat telewerken decentralisatie kan faciliteren en dat huishoudens daardoor voorkeur gaan geven aan gebieden met een lage tot middelmatige woningdichtheid en een aantrekkelijk landschap. Hierdoor kan een aantal negatieve aspecten van hoge stedelijke dichtheden, zoals hoge grond- en woningprijzen, kleine percelen en woningen en congestie, vermeden worden.

Om de effecten van telewerken, in relatie tot traditionele factoren, op de huidige woonlocaties, verhuisgeneigdheid in de komende twee jaar en gewenste toekomstige woonomgeving te verkennen zijn gegevens uit het Woningbehoefte Onderzoek (WBO) van 2002 geanalyseerd. Daarbij is gebruik gemaakt van meervoudige regressie. Het blijkt dat groepen met midden- en hogere opleidingen en inkomens oververtegenwoordigd zijn onder de telewerkers. De huidige telewerkers wonen meer dan gemiddeld in een landelijke omgeving of in een 'groene' stedelijke omgeving met lage dichtheden. Echter, de meerderheid van de jongere telewerkers, die (nog) niet over ruime inkomens kunnen beschikken, in kleine huishoudens wonen en een meer stedelijke oriëntatie hebben, woont in stedelijke woonmilieus.

Wat betreft de gewenste toekomstige woonsituatie geven zowel de meeste reguliere forensen als teleforensen aan te opteren voor het blijven wonen in het type woonomgeving waar men thans woont. Binnen dit algemene beeld hebben telewerkers een grotere voorkeur voor groenstedelijke en kleinstedelijke omgevingen. Een accentverschil met hun huidige woonomgeving, dat overwegend ruraal van karakter is. Van de traditionele factoren zijn leeftijd, aantal kinderen en huidige woonomgeving de belangrijkste kenmerken die correleren met de gewenste toekomstige woonsituatie.

Deze resultaten geven aan dat, hoewel telewerken langere woon-werkafstanden faciliteert, dit niet leidt tot de dramatische verandering in woonvoorkeuren die sommige onderzoekers veronderstellen. In de huidige, prehybride ruimtelijke situatie in Nederland speelt telewerken nog een bescheiden rol bij residentiële locatiebeslissingen. Bovendien dienen twee groepen telewerkers nadrukkelijk te worden onderscheiden. De jonge en hoogopgeleide groep heeft een stedelijke oriëntatie, de oudere, hoge inkomens groep heeft een voorkeur voor landelijke woongebieden. De laatste groep is het meest omvangrijk, maar dat kan in de toekomst veranderen

Toekomstige geschiktheid voor residentieel grondgebruik

De afgelopen jaren is een flink aantal projectiemodellen voor grondgebruik ontwikkeld. De Leefomgevingsverkenner (LOV), een omvattend dynamisch model gebaseerd op een benadering met drie schaalniveaus (nationaal, regionaal, locaal) is geselecteerd om de toekomstige locatie van woongebieden voor de Fysieke Ruimte en Hybride Ruimte scenario's (FRS, HRS) te berekenen. Maar het LOV-model, zoals dat geïmplementeerd is bij het Natuur en Milieu Planbureau, heeft een aantal belangrijke beperkingen wat betreft het toewijzen van ruimteclaims (berekend voor

COROP-gebieden, Nederland in 40 functionele regio's) en het vervolgens gedetailleerd alloceren van toekomstig woongebied voor het HRS (de allocatie vindt apart plaats binnen elk COROP). Bovendien wordt de arbeidsbereikbaarheid voor zowel het FRS als het HRS bepaald voor LMS-subzones (1308 zones voor Nederland), terwijl de vervoersmodule van de LOV gebaseerd is op LMS-hoofdzones (345 gebieden). In het HRS wordt aangenomen dat regionale arbeidsmarkten zich zullen verruimen en dat de allocatie zich zal gaan afspelen op interregionale schaal. Ook is het wenselijk de toewijzing van woongebied met een hoge mate van geografisch detail te doen om relevant te kunnen zijn voor het ondersteunen van ruimtelijke planning.

Om onder deze beperkingen uit te komen is een residentieel projectiemodel voor grondgebruik ontwikkeld dat uitgaat van de bereikbaarheid van arbeidsplaatsen op het niveau van LMS-subzones en het berekenen van ruimteclaims voor de vier macroregio's van Nederland (Noord, Oost, West, Zuid). De belangrijkste drijvende krachten zijn: arbeidsbereikbaarheid, transitiepotentieel voor grondgebruik, fysieke geschiktheid en ruimtelijke beleidsplannen. Ze zijn verschillend gewogen in de twee scenario's. De toepassing van dit nieuwe model heeft geschiktheidskaarten en patronen van nieuwe woongebieden voor de FR en HR scenario's opgeleverd voor 2030. Ook zijn de scenario-uitkomsten vergeleken en afgezet tegen de situatie in 2000.

Toekomstige verstedelijkingspatronen

Nederland vertoont thans een grote spreiding van stedelijk grondgebruik met duidelijke concentraties in de Randstad en een relatief groot aantal middelgrote stadsgewesten in de andere delen van het land. De processen van meerkernige stedelijke ontwikkeling en gebundelde suburbanisering zijn kenmerkend voor Nederland en zijn langdurig ondersteund door nationaal ruimtelijk beleid. In het algemeen lijkt telewerken deze processen te versterken. Maar in het HR-scenario vertoont is het patroon van nieuwe woongebieden in 2030 duidelijk meer gespreid dan het huidige residentiele grondgebruik (2000) en het patroon dat geprojecteerd wordt voor het FR-scenario. In het HR-scenario zullen meer mensen in de gelegenheid zijn in gebieden met een lagere dichtheid en meer groen te gaan wonen, maar dit zal geen structurele verandering in het Nederlandse verstedelijkingspatroon teweeg brengen.

Het globale beeld is dat telewerken beperkt een decentralisatie van woongebieden mogelijk zal maken in combinatie met meer kans op gespreide suburbanisering. Residentiële groei zal zich op veel plekken in het land voordoen, maar de 'hot spots' zijn: de overloopregio's binnen en buiten de Randstad-ring, het westelijke Groene Hart en de uitstralingsgebieden in zuidoostelijke en zuidelijke richting (Gelderland en Noord-Brabant). Deze algemene ruimtelijke tendensen worden gevoed door verbeterde en ruimtelijke uitdijende arbeidsbereikbaarheid en de daaruit voortvloeiende veranderende patronen van residentiële geschiktheid. Of de groei van woongebieden een meer geclusterd of een meer gespreid karakter heeft is afhankelijk van regionale en lokale omstandigheden met betrekking tot bestaand stedelijk patroon, landschappelijke aantrekkelijkheid en ruimtelijk beleid.

Consequenties van telewerken voor het ruimtelijk beleid

In Nederland ontwikkelen zich een netwerkeconomie en een netwerksamenleving. Daarbinnen lijkt sprak te zijn van enerzijds een voortgaande individualisering en anderzijds een toenemende sociale inter-connectie in vele fysieke en virtuele netwerken. Telewerken verbetert de bereikbaarheid van arbeidsplaatsen zowel in de stedelijke gebieden als in afgelegen rurale gebieden. Het betekent dat bepaald nog dun bevolkte gebieden een niveau van arbeidsbereikbaarheid in de hybride ruimte zullen krijgen dat ze aantrekkelijker maakt voor nieuwe bewoners. Dit kan leiden tot (meer) nieuwe clusters van residentieel grondgebruik dan tot dusver is verondersteld.

Hoewel Nederland één van de dichtstbevolkte landen in de wereld is, is nog steeds tweederde van alle grond in gebuik voor de landbouw. In de huidige golf van globalisering van economische relaties en de waarschijnlijke vermindering van Europese landbouwsubsidies (Koomen & Groen 2004), komt naar verwachting meer ruimte beschikbaar om telewerkers in staat te stellen hun woonvoorkeuren te volgen. Deze nieuwe ruimtelijke trends vormen een uitdaging voor diverse paradigma's in de Nederlandse ruimtelijke ordening.

Volgens Van Oort *et al*. (2003a) zijn de ruimtelijke gevolgen van het gebruik van moderne ICT in Nederland weinig structureel. Dat komt deels overeen met wat in deze studie is gevonden. Uit de uitgevoerde ruimtelijke sectorstudies blijkt dat agglomeratie-effecten, zoals het incubatoreffect voor bedrijven in de ICT-sector en voor ICT-gebruik in het hele bedrijfsleven, de neiging hebben zich uit te spreiden over grote verstedelijkte gebieden. Traditioneel hebben steden deze broedplaatsfuncties, maar nu worden ze aangetroffen in het hele stadsgewest. Er is sprake van een opkomend multi-nodaal patroon van economische clusters met die functies. Bestaande stadscentra, goed bereikbare suburbane centra, maar ook rurale gebieden tussen de grotere stedelijke agglomeraties blijken een rol te spelen in de ruimtelijke lappendeken van nieuwe economische ontwikkeling. De onderhavige studie vult hierop aan door het ITC-effect van woon-werkrelaties voor ruimtelijk-stedelijke ontwikkeling toe te voegen aan de locatiestudies over de werkgelegenheid van Van Oort c.s.

Om tegemoet te kunnen komen aan de eisen van stijl en inhoud van ruimtelijke planning die voortvloeit uit de hiervoor genoemde onderzoeksresultaten kunnen drie strategieën aangevoerd worden: *intensiverering van grondgebruik, combineren van typen grondgebruik* en *tranformering van stedelijke en rurale ruimte in een regionale context*. Hierbij dient rekening gehouden te worden met de ruimtelijke voorkeuren van bewoners, werkers en bezoekers. De processen van geconcentreerde suburbanisering en polycentrische ontwikkeling hebben een lange traditie in Nederland. Diverse onderzoeken bevestigen dat de ruimtelijke effecten van de moderne ICT die processen niet fundamenteel zullen ondermijnen (Van Oort *et al.* 2003a; Van Oort *et al.* 2003b; Weterings 2006). Maar ook dat zij de processen zullen kunnen versnellen omdat ICT als een katalysator werkt (Van Oort *et al.* 2003a). Uiteindelijk zal dat kunnen resulteren in een vergrote druk van stedelijke spreiding, deconcentratie en uitwaaiering.

Appendix A

Measuring Job Accessibility in Hybrid Space

A.1 Shen's model for measuring job accessibility

In this appendix, the background to Shen's model, described in chapter 3 in brief, is explained in more detail. There are several types of activity based accessibility measures. Five are widely used: the contour measure, the potential accessibility measure, the accessibility measure with competition, the inverse balancing factor and the accessibility measure based on time-space geography (Geurs & Ritsema van Eck 2001). The potential accessibility measure, based on the gravitational model of Hansen (1959) is probably most widely used. The measure has been modified over time, like incorporating a competition factor. Hansen's measure accounts only for the supply side. The demand side, the spatial distribution of demand for available opportunities is limited in capacity and if demand is not uniformly distributed across space, a competition factor needs to be incorporated.

According to Hansen's gravity formula, the potential accessibility measure is:

$$A_i = \sum_j O_j f(t_{ij}) \qquad \text{(Eq. A.1)}$$

Where:
A_i is accessibility for zone i
O_j is the number of relevant opportunities in zone j
$f(t_{ij})$ is the impedance function measuring the spatial separation between i and j
For an urban or regional system with N zones, $i = 1,2\ldots N$, and $j = 1,2\ldots N$.

According to Shen (Shen 1998a), advancements in transportation will generally reduce spatial separation between locations, which is measured by $f(t_{ij})$. Consequently, according to Equation A.1, if land use patterns remain unchanged, accessibility will increase for all zones. Although the rate of increase may vary from one zone to another, every zone will benefit from technological progress. It is obvious that this aggregate measure of accessibility coincides with the view that the use of ICTs compresses the interaction dimension of urban space.

Over the decades, urban researchers have modified this accessibility measure by incorporating other factors that affect the accessibility (like disaggregating by mode of transport and including competition for opportunities) to help in understanding the complex relationship between transportation technologies and the changing geography of opportunities. Their efforts have resulted a large volume of literature. Most researchers agree that the level of accessibility for an opportunity seeker is a function of the total number of relevant opportunities, the spatial distribution of these opportunities, the spatial location of the individual and the individual's ability to overcome the spatial separation. When opportunities are relatively scarce, the competition with other opportunity seekers must also be taken into account (Ritsema van Eck & De Jong 1999; Shen 2000; Van Wee *et al.* 2001).

Many mathematical formulas have been proposed for the measurement of accessibility (Shen 2000; Geurs & Ritsema van Eck 2001). In the following formula, first suggested by Weibull (1976) and recently generalized by Shen (1998a) and shown in the Equation A.2, each available opportunity is weighted by a demand factor, expressed as denominator, which represents the competing demand generated by other opportunity seekers.

$$A_i^v = \sum_j \frac{O_j f(t_{ij}^v)}{\sum_m \sum_k P_k^m f(t_{kj}^m)} \qquad \text{(Eq. A.2)}$$

Where:
A_i^v is the accessibility opportunity seekers who live in zone i and travel by mode v
O_j is the number of relevant opportunities in zone j
$f(t_{ij}^v)$ is the impedance for travel from i to j by mode v
P_k^m is the number of opportunity seekers who live in zone k and travel by mode m
$f(t_{kj}^m)$ is the impedance for travel from k to j by mode m
For a metropolitan area with N zones, i, j, k = 1,2,3…N
For a metropolitan area with M modes, v, m = 1,2,3…M

As an accessibility measure, Equation A.2 has several attractive properties. One important property is that it provides a consistent framework for incorporating geographic locations and transportation modes into the measurement and therefore allows direct comparison of accessibility across modes as well as across locations. Because the modal choices are related to the individual's socio-economic conditions – for example, low-income people are much more likely to travel by public transport – this measure can reveal accessibility differences among social groups. It can help in understanding how geographic locations and transportation technologies, which are highly correlated with the socio-economic variables, jointly determine the individual's relative positions in the geography of opportunity. Another important point, mathematically worked out by Shen (1998b), is that the expected value of a location always equals the ratio of the total number of opportunities to the total number of opportunity seekers. Therefore for each mode of transportation, accessibility poor zones can be distinguished easily from accessibility rich zones. However, this was not found in our case study, where the accessibility for different regions in the Netherlands was compared. The validity might be restricted to accessibility studies dealing with different zones in a metropolitan area, as was the case with Shen's application for the Boston area.

For a community, represented by a geographic zone, the overall position in the geography of opportunity is determined by the levels of accessibility for its residents. Shen (2000) proposes the following general accessibility measures to specify this relationship.

$$A_i^G = \sum_v (P_i^v / P_i) A_i^v \qquad \text{(Eq. A.3)}$$

Where:
A_i^G is the general accessibility for all opportunity seekers who live in zone i
P_i^v is the number of opportunity seekers who live in zone i and travel by mode v
P_i is the total number of opportunity seekers in zone i

Equation A.3 calculates a weighted score of accessibility for each zone. The number of people travelling by different modes are used as the weights. The higher the percentage of a zone's residents that use advanced transportation, the higher a zone's general accessibility will be. The expected value of general accessibility also equals the ratio of the total number of opportunities to the total number of opportunity seekers (Shen 1998a). Therefore, this measure depicts an overall picture of the geography of opportunity for a metropolitan area by defining the relative position of each zone in terms of accessibility.

In this age of information technology, the opportunities can be accessed either in physical space or in virtual space. Hence for both mediums the measure of the accessibility will be different. As shown in Figure A.1 to Figure A.6, both people and opportunities, need to be categorized according to ICT skills and the way of accessing opportunities.

According to Shen (2000), if there are O total opportunities and P is the total number of opportunity seekers, then $\phi\ O$ opportunities will be accessible to the δP people (δ proportion of the total opportunity seekers P), who have ICTs' skills and c is the necessary means of accessing these opportunities. The λO opportunities are accessible either by physical or virtual means of communication by δP opportunity seekers, who use ICTs to access them and $(1\text{-}\delta)P$ who use the physical means. While $(1\text{-}\phi\text{-}\lambda)O$ are the opportunities that can be accessed only by using physical means and are available to all opportunity seekers P. The means of accessing these opportunities are the transportation modes, m. The accessibility for different groups of opportunity seekers can be measured using the following equations A.4 and A.5, which are the extended versions of Equation A.2.

- For opportunity seekers who do not have ICT skills:

$$A_i^v = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m) + \delta_k P_k^m f(t_{kj}^{cm})]} \quad \text{(Eq. A.4)}$$

- For opportunity seekers who have ICTs' skills:

$$A_i^{cv} = \Sigma_j \frac{(1-\phi_j-\lambda_j)O_j f(t_{ij}^v)}{\Sigma_m \Sigma_k P_k^m f(t_{kj}^m)} + \Sigma_j \frac{\lambda_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k [(1-\delta_k)P_k^m f(t_{kj}^m) + \delta_k P_k^m f(t_{kj}^{cm})]} + \Sigma_j \frac{\phi_j O_j f(t_{ij}^{cv})}{\Sigma_m \Sigma_k \delta_k P_k^m f(t_{kj}^{cm})} \quad \text{(Eq. A.5)}$$

These equations were applied for measuring job accessibility in chapter 3.

A.2 Preparation of travel time matrix for the public transport (as multi-mode trip, including, train, bus/tram and/or bike)

In order to construct a multi-mode travel time distance matrix, the following steps were followed:

1. From AVV travel time data for different modes of transport for LMS sub-zones having a railway station, both as the origin and the destination, the train was considered as the mode of transport used. For the other sub-zones the fastest mode was selected (bus/tram or bicycle). For train trips only the travel time from station to station was used, while for bus/tram and bike, the travel time including access and egress time was taken. The access and egress time for train was excluded at this stage because they were not included in the AVV data.
2. The above table having the fastest travel time between all the LMS sub-zones by using public/multi-mode transport was exported as a text file, with a condition that the maximum travel time is not more than 60 minutes. This was done because, there is a limitation in the DBMS to handle data files having more than 1 million entries. In the sub-zone file there were 1.17 million (1308*1308) combinations.
3. This table was converted into a *.bna and a *.dat files, in order to use this data in FLOWMAP software. After importing the *.bna file to the FLOWMAP format, this file is displayed spatially, to assess whether important links are missing. It was found that 15 more links were needed to get the most appropriate connections. These 15 links were added in *.txt file and again this file is converted into a *.bna and a *.dat file. The *.bna file is imported in FLOWMAP. The *.dat file has two fields, one is a label, having a combination of origin and destination sub-zones and the other is the travel time between them. By using the label field as the primary key, the travel time is copied to the FLOWMAP file. This file was used to compute the travel time matrix between various LMS sub-zones by using multi-mode public transport. The spatial centres of the LMS sub-zones were used as nodes of the transportation network.
4. This computed travel time matrix was exported as a *.dbf file in order to add the time for access and egress for the train as a mode of transport and intra zonal travel time. There are certain entries in AVV data, where there are railway stations in both origin and destination zones, but the time to egress and access is not given. In order to compute this, a script in visual basic was implemented, by taking three consecutive LMS sub-zones having railway stations and solving that quadratic equation, to estimate the time to access and egress. These computed times for access and egress for train travel were added in the table for the entries having a train station in both origin and destination LMS sub-zones.
5. This final table was imported in FLOWMAP as the distance matrix for public transport.

A.3 Distribution of jobs and job seekers (commuters and telecommuters)

By using the criteria mentioned in chapter 3, jobs and job seekers (commuters and telecommuters) were distributed in physical, hybrid and virtual space for each LMS sub-zone for the years 1986, 1995, 2000 and 2020. These distributions are shown for 2000 and 2020 (Figure A.1 to Figure A.12).

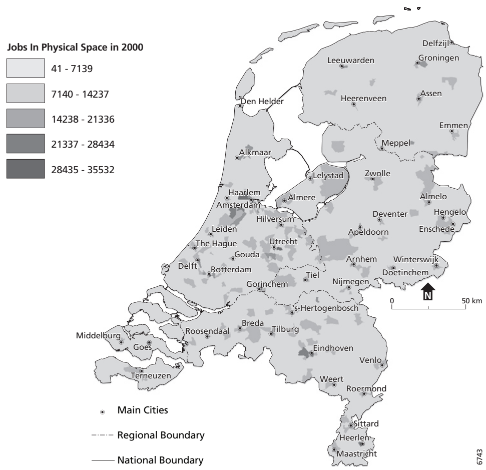

Figure A.1 Distribution of jobs available in physical space of 2000

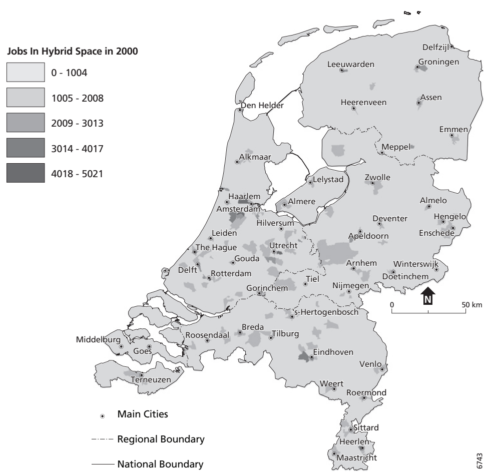

Figure A.2 Distribution of jobs available in hybrid space of 2000

Figure A.3 Distribution of jobs available in virtual space of 2000

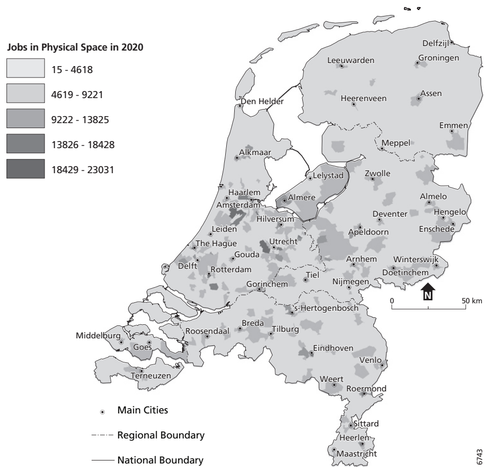

Figure A.4 Distribution of jobs available in physical space of 2020

Figure A.5 Distribution of jobs available in hybrid space of 2020

Figure A.6 Distribution of jobs available in virtual space of 2020

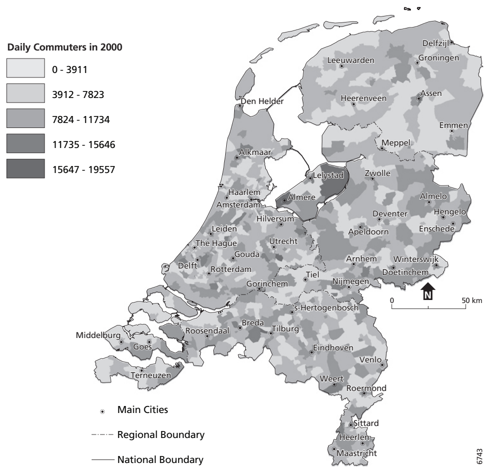

Figure A.7 Distribution of daily commuters in 2000

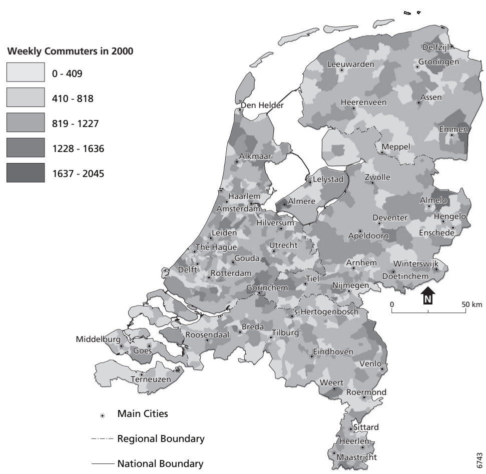

Figure A.8 Distribution of weekly commuters in 2000

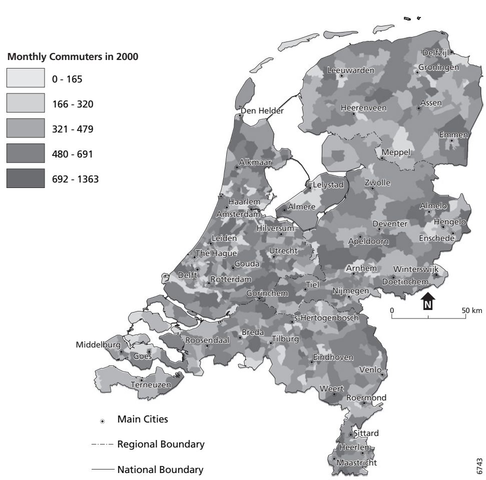

Figure A.9 Distribution of monthly commuters in 2000

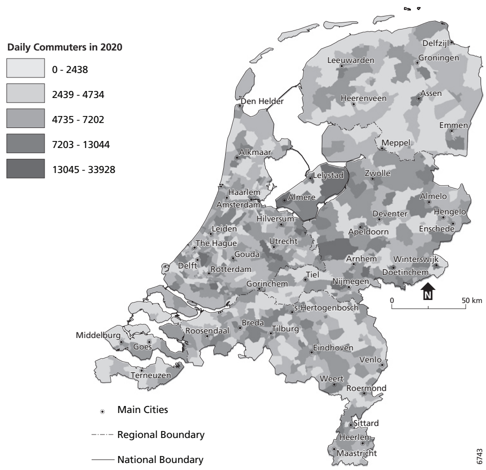

Figure A.10 Distribution of daily commuters in 2020

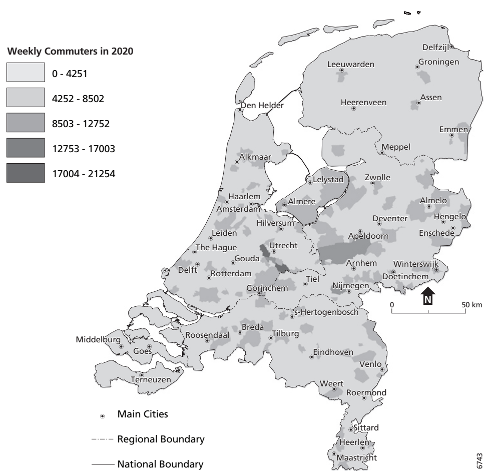

Figure A.11 Distribution of weekly commuters in 2020

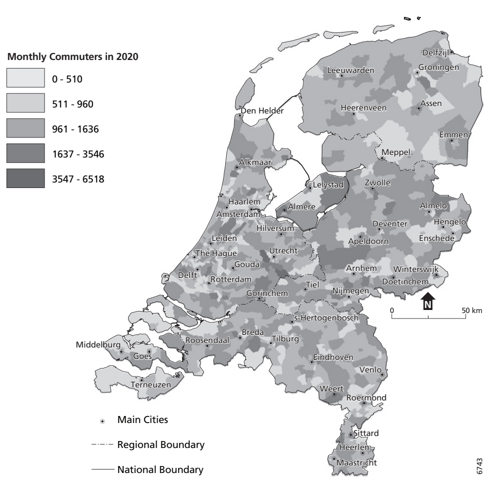

Figure A.12 Distribution of monthly commuters in 2020

The majority of jobs are and will be available in physical space, and the Randstad area is and will be dominating region in the Netherlands for employment. But in future the regions around Arnhem, Apeldoorn and Veenendaal and areas between Gorinchem and Tiel will in particular benefit from increased job accessibility in hybrid and virtual space.

In future, both weekly and monthly telecommuters will be overrepresented in the regions around the city of Utrecht. Monthly commuters are and will remain scattered all over the Netherlands. But also in the foreseeable future the majority of the working population will consist of daily commuters and they are scattered all over the Netherlands with concentrations in the large and medium sized urban areas.

A.4 Job accessibility for PSS and HSS of 1986 and 1995

By applying Hansen's destination constrained potential accessibility model and Shen's potential accessibility model with competition factors, the job accessibility for the Physical Space Scenario (PSS) and the Hybrid Space Scenario (HSS) for 1986, 1995, 2000 and 2020, for the Netherlands has been computed. Job accessibility computed for PSS and HSS in 2000 and 2020 are presented and discussed in chapter 3. Here, job accessibility for PSS and HSS for 1986 and 1995 are presented and discussed.

For 1986 by using the destination constrained potential accessibility model, by incorporating the virtual component (although it was only 2 percent of all jobs), job accessibility was improved for the HSS as compared to the PSS (Figure A.13 and Figure A.14). This improvement is prominent in the Western region of the Netherlands (Randstad area comprising of the four major cities, Amsterdam, Rotterdam, The Hague, Utrecht and the lower density areas in between, the Green Heart. One reason is that most major firms have their head offices there. Moreover, many innovative and creative industries have a preference for a location in the heartland. Besides this, a lot of well-educated people are living in the Randstad area. But quite some eastern and southern regions (Arnhem, Eindhoven, Tilburg and Roosendaal) show the same trends.

By using Shen's model for the PSS and the HSS for 1986, for HSS, the job accessibility has improved for the most areas of the Netherlands as compared to the one for the PSS (Figure A.15 and Figure A.16). In the Randstad, and the regions around Apeldoorn, Arnhem, Enschede and Deventer have improved job accessibility in hybrid space. In the North, the areas around Groningen, Assen and Heerenveen also show quite some improvement in job accessibility when the virtual component is incorporated. In the South, the regions Eindhoven, Tilburg and 's-Hergtogenbosch depict a moderate positive effect.

For the year 1995, when seven percent of all jobs were telecommuted by using ICTs, there is more improvement in job accessibility for the areas mentioned for the year 1986 (Figure A.17 and Figure A.18). By applying the Hansen model, the improvement in job accessibility for the HSS for Randstad area is substantial. In the eastern region, the areas in the Apeldoorn-Arnhem-Nijmegen triangle also have increased job accessibility for the HSS compared to the PSS. The regions around Zwolle, Hengelo, and Enschede and the areas between Tiel and Gorinchem show the same trend. There was not any particular difference in job accessibility for the Northern region of the country between the PSS and the HSS for the year 1995. In the South, the areas around and between 's-Hertogenbosch, Eindhoven and Roosendaal and the Maastricht and Sittard regions show an improvement in job accessibility for the HSS.

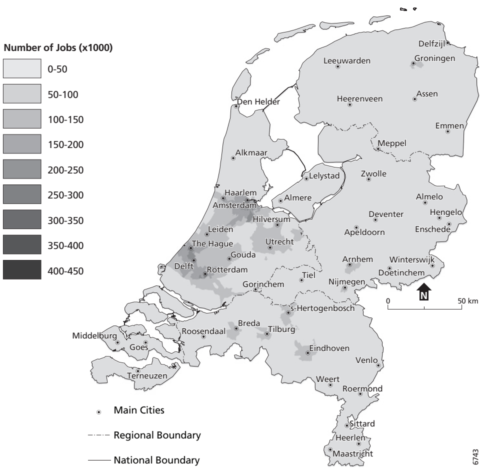

Figure A.13 Job accessibility in PSS of 1986 by destination constrained potential model (Hansen)

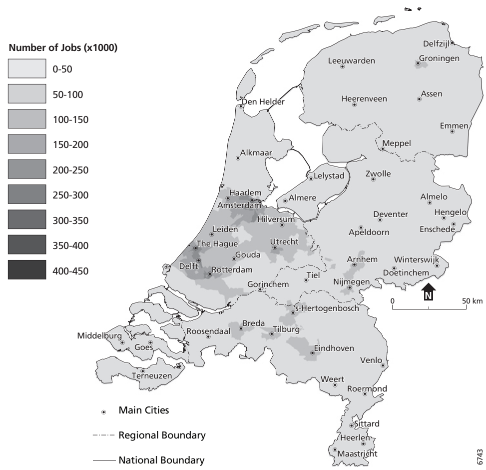

Figure A.14 Job accessibility in HSS of 1986 by destination constrained potential model (Hansen)

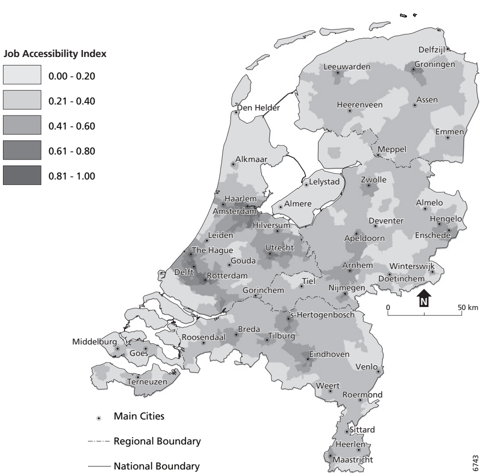

Figure A.15 Job accessibility in PSS of 1986 by potential model with competition factor (Shen)

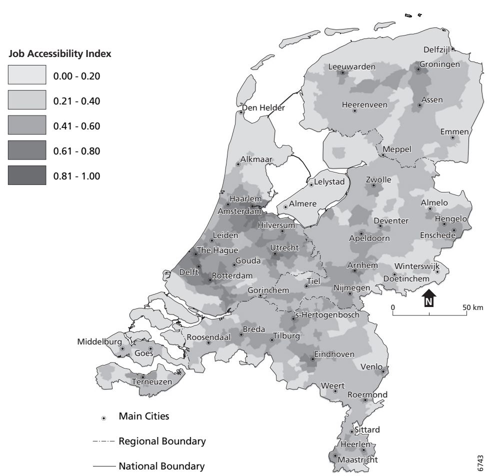

Figure A.16 Job accessibility in HSS of 1986 by potential model with competition factor (Shen)

The results for 1995 using Shen's model are given in Figure A.19 and Figure A.20. As explained in chapter 3, this model yielded outcomes that are not very plausible. Nevertheless, it is useful to show them here as they show the same problems mentioned for the 2000 and 2020 model runs.

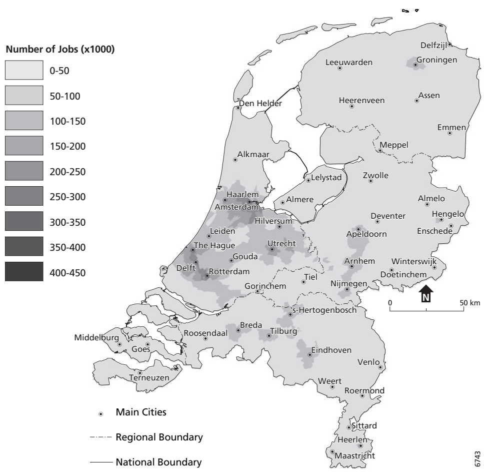

Figure A.17 Job accessibility in PSS of 1995 by destination constrained potential model (Hansen)

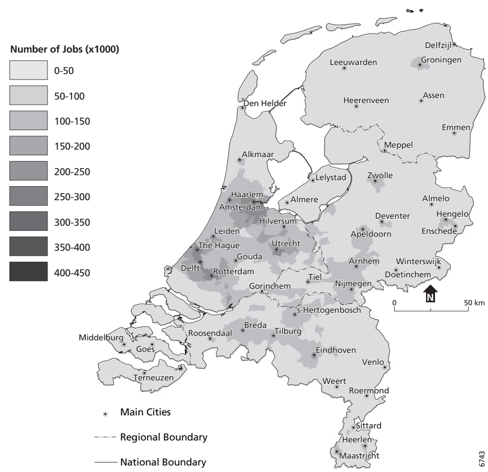

Figure A.18 Job accessibility in HSS of 1995 by destination constrained potential model (Hansen)

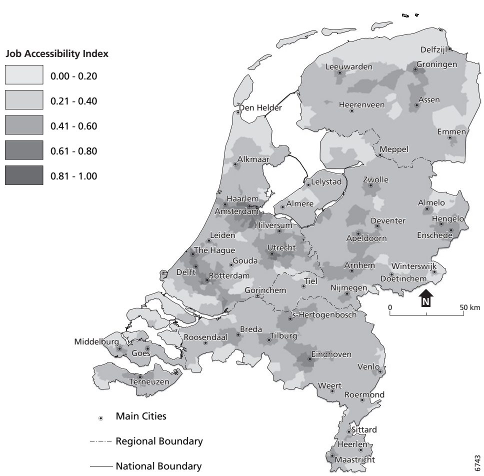

Figure A.19 Job accessibility in PSS of 1995 by potential model with competition factor (Shen)

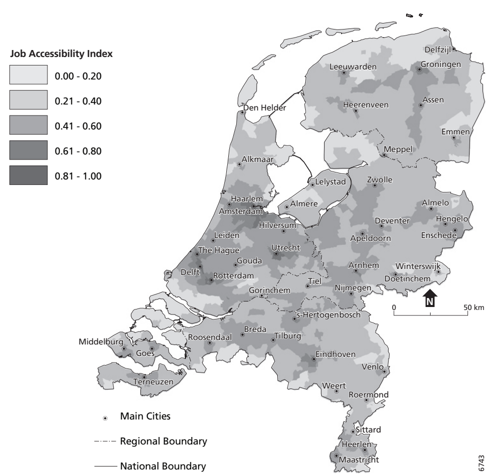

Figure A.20 Job accessibility in HSS of 1995 by potential model with competition factor (Shen)

A.5 Analysis of job accessibility at LMS sub-zone level between PSS and HSS of 1986, 1995 and 2000 by Hansen and Shen Model

Job accessibility computed by the Hansen and Shen models for the PSS and the HSS for the years 1986, 1995, 2000 and 2020 per LMS sub-zone. The values are sorted in descending order of job accessibility and are presented in Figure A.21 to Figure A.26.

From these figures it can be concluded there was and will be improvement in job accessibility when ICTs are also used for accessing work opportunities in the HSS. Job accessibility computed

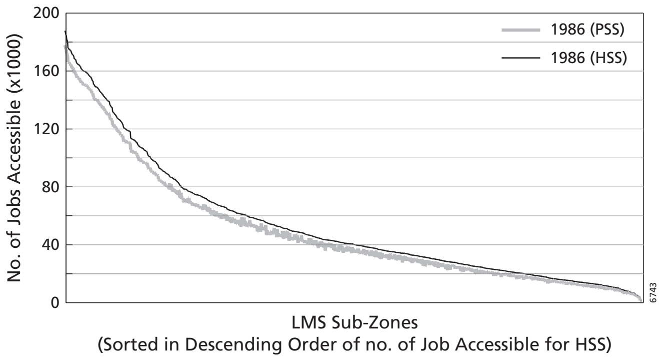

Figure A.21 No. of jobs accessible per LMS sub-zone in 1986 (Hansen Model)

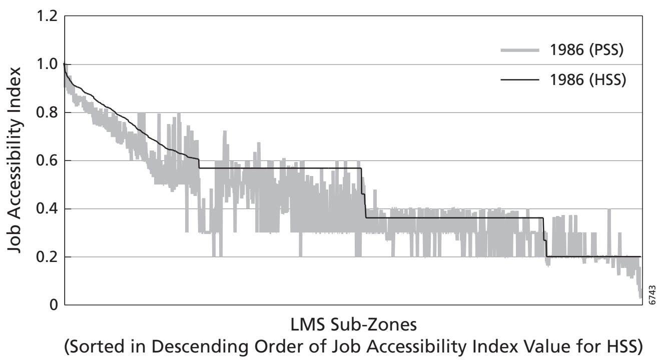

Figure A.22 Job accessibility index per LMS sub-zone in 1986 (Shen Model)

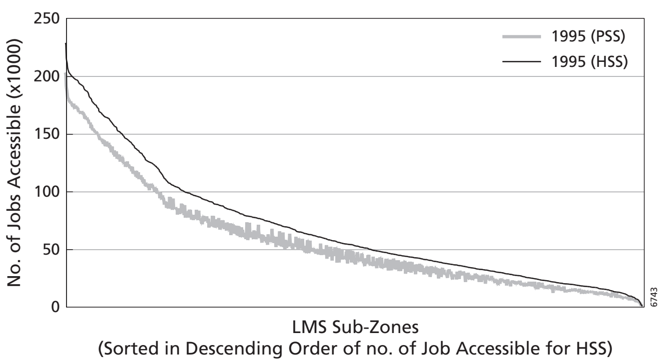

Figure A.23 No. of jobs accessible per LMS sub-zone in 1995 (Hansen Model) by Hansen's model, are more consistent, plausible and better interpretable as compared to the accessibility values produced by Shen's model.

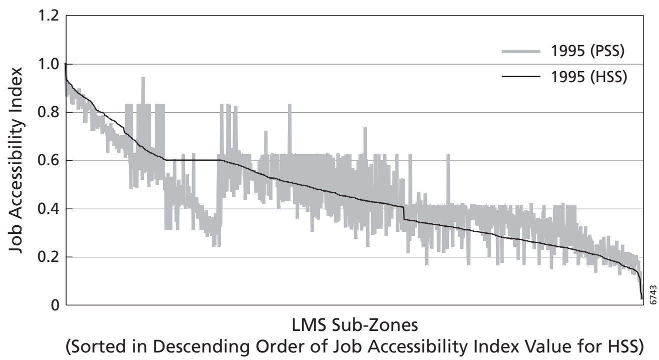

Figure A.24 Job accessibility index per LMS sub-zone in 1995 (Shen Model)

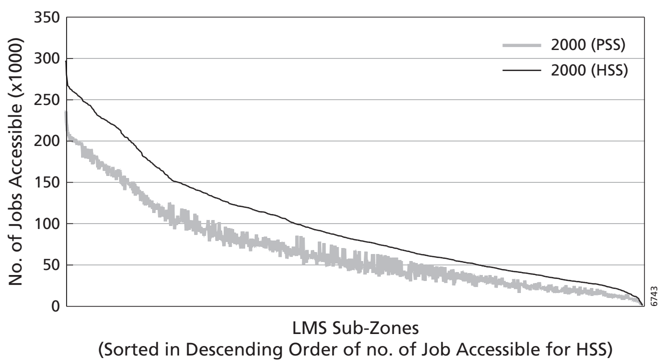

Figure A.25 No. of jobs accessible per LMS sub-zone in 2000 (Hansen Model)

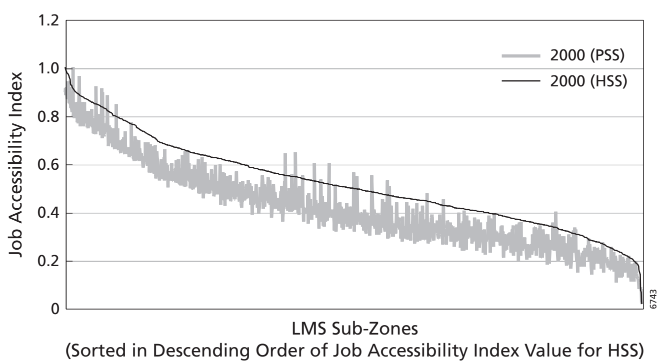

Figure A.26 Job accessibility index per LMS sub-zone in 2000 (Shen Model)

A.6 Analysis of job accessibility at regional level between PSS and HSS of 1986, 1995, 2000 and 2020 by Hansen and Shen models

Average job accessibility for both the PSS and HSS for 1986, 1995, 2000 and 2020 by Hansen and Shen's model were computed at regional level for the Netherlands (Figure A.27 and Figure A.28).

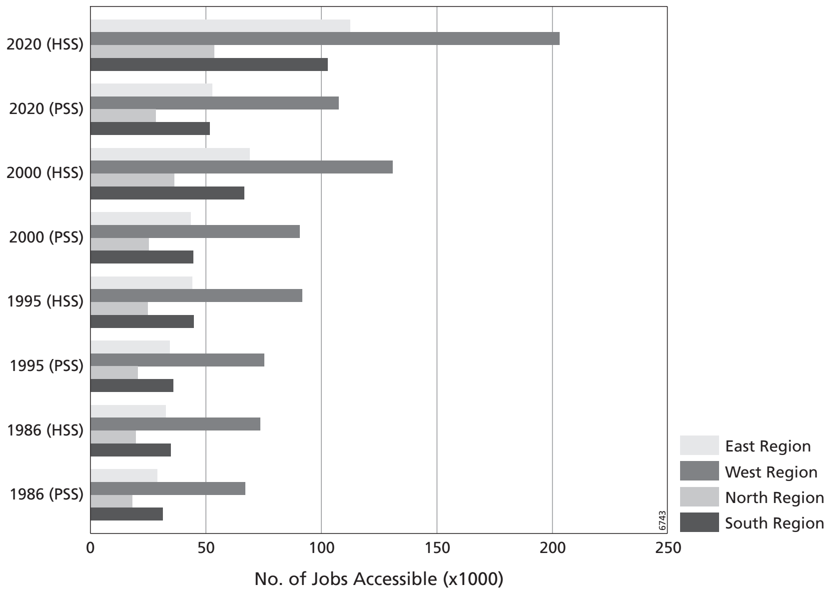

Figure A.27 Average number of job accessible in four regions of the Netherlands (Hansen Model)

The Randstad region shows the highest job accessibility for both the PSS and HSS for the whole study period. Applying the Hansen model, improvement in job accessibility in all four regions for all the years is more apparent as compared to accessibility values computed by Shen's model.

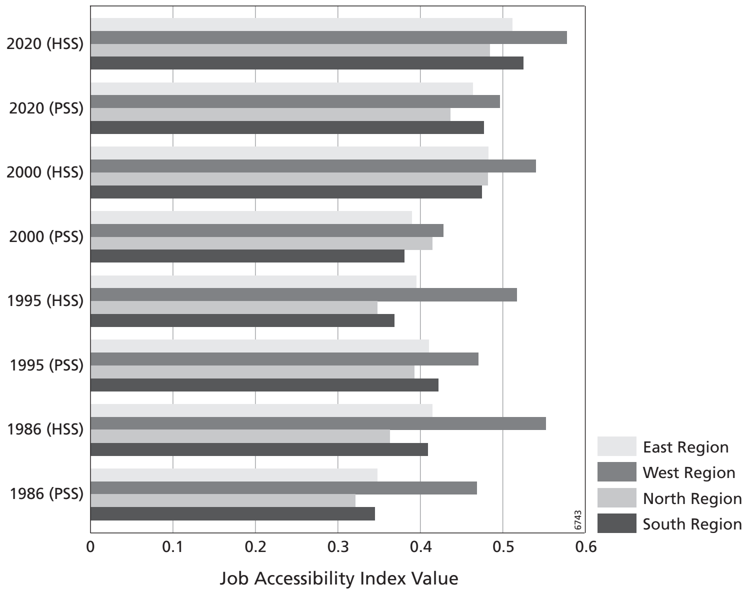

Figure A.28 Average job accessibility index value for four regions of the Netherlands (Shen Model)

Appendix B

Existing land-use Projection Models

B.1 Urban land-use projection models

There are a number of urban land-use projection models and a number of ways to classify these models of urban growth. For example, in terms of system completeness, models can be system-level or specific-level. The former takes all components of urban systems into account. The latter focuses only on a specific phenomenon or problem by using a limited number of components in the system under study, such as residential dynamics.

In terms of dimension, they can be divided into spatial models, temporal models and spatio-temporal models. Different dimensions distinguish focus or emphasis and requirements of data. In terms of analysis objectives, they can be pattern models, process models and behaviour models. With the general purpose of understanding the complexity of urban growth, the models can be classified on the basis of the mathematical/statistical techniques being used, such as cellular automata modelling, multi-agent modelling, neural network modelling, fractal modelling etc. (Cheng 2003).

For this research, models that have the capability to handle spatial dynamics of land use transportation interaction in the temporal domain, and that include socio-economic and demographic characteristics of actors, are of interest. Over the last forty years, a variety of large-scale land use models have been developed for future urban land-use projection. In these models the main aim is to is to predict the development of population in different places, the location of working places like industry and services and the resulting mobility of people and goods. Most of these models (as described in brief next) are used to predict the effects on land use by changes in human activities and location preferences.

B.1.1 CLUE Model

In the Conversion of Land Use Change and its Effects (CLUE) model, the complexity of land use changes is captured by a combination of dynamic modelling and empirical quantification of the relations between land use and its driving factors. Economic models and/or existing projections are used in the non-spatial demand module, which calculates the area of change demanded for by the different sectors of the economy. The allocation module is used to allocate these demands to different locations within the study area (Verburg *et al.* 1999).

B.1.2 Environment Explorer

The Environment Explorer is a multi-scale (national, regional and local level) cellular automaton based land use-transportation interaction model. By taking into consideration regional competition for socio-economic growth, the land use demands are calculated at regional level according to socio-economic trends at national level. At local level these demands are allocated to cells. The land use allocation module is based on constrained cellular automata. Cellular automata use neighbourhood land use transition rules that reflect land use transition trends in the past, and compute 'historic' land use transition potential values. These values, together with physical suitability, accessibility, zoning and random factors are used to compute the total land use transition potential. The land use demand and allocation iterates for a time step of one year. The model is calibrated with historical land use and socio-economic data. This model allows for experimenting with future scenarios and studying their potential impact (Engelen *et al.* 2002).

B.1.3 Land use Scanner

The land use scanner is a logit model that simulates future land use in a GIS environment. The model uses claims from sectoral models as input, next to physical suitability, distance decay and policy maps. At present, the land use scanner is predominantly used for the elaboration of scenarios, since it is not yet really suited for spatial optimization problems. This means more or less qualitative scenarios, which indicate future socio-economic developments, serve as input to sectoral models to predict the future demand for land per distinguished land use type. Moreover, expert judgment is also often used to generate land use claims (Hilferink & Rietveld 1999).

B.1.4 PROPOLIS Model

PROPOLIS is a strategic urban planning system developed for the EU project 'Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability'. PROPOLIS is not a model but a model system which links three existing land use transport interaction models (MEPLAN, TRANUS, IRPUD) to urban sustainability indicators. A GIS-based raster module, a database and presentation module and a decision-support tool to evaluate the results of policy options are also implemented. The model system is applied for several European regions (PROPOLIS 2003).

B.1.5 RAMBLAS Model

The RAMBLAS model is developed to estimate the intended and unintended consequences of planning decisions related to land use, building programmes and road construction for households and firms. The main purpose of RAMBLAS is to predict the spatial distribution of individuals' activities and related traffic flows for a chosen time period given the forecasted spatial distribution of dwellings, the forecasted distribution of households over dwellings and the transport network. RAMBLAS is based on micro simulation and consists of the following modules:

Allocate: The calculation of households for all zones (in the Dutch application municipalities) at the beginning of the period

Planning: Forecasts for changes in roads, dwelling stock and the location of working places for the chosen plan period

Relocate: Relocation of households for all the municipalities

Personal: Calculate individuals for all the Dutch municipalities at the end of the planning period

Interact: Estimation of the interactions relevant for a chosen region

Present: Calculation of the person vehicle trips through the day as well as the aggregation to road traffic volumes in the chosen region

Wegennet: An independent program for connecting the zones/postal areas to the nodes of the Dutch road system (Veldhuisen *et al.* 2003).

B.1.6 SLEUTH Urban Growth Model

The SLEUTH model (Slope, Land use, Exclusion, Urban Extent, Transportation and Hill-shade), is formerly known as the Clarke Cellular Automaton Urban Growth Model. It is a cellular automata based urban growth model which is intended to simulate urban growth ranging in spatial extent from individual metropolitan areas to national coverage in order to support understanding of how expanding urban areas consume their surrounding land, and the environmental impact this has on the local environment. This model simulates the transition from non-urban to urban land-use using a grid of cells. The land-use state of cells is dependent upon local factors (e.g. roads, existing urban areas and topography), temporal factors, and random factors. The growth is based on four "growth rules" or types of growth which include: spontaneous growth, road influence, new spread centre, and edge growth (Silva & Clarke 2002).

B.1.7 Space Use Model

The Space Use Model is a descriptive multi-agent layer model for monitoring urban growth for a polycentric region and used as an explorative approach in planning and policy reconnaissance. The concept of the model is based on the perception that spatial, or rather environmental, qualities are often mainly the product of space exploitation. Hence, the influence of government intervention is indirect and secondary, although this differs per legislative system (De Waard 2003). This model is focussed on physical factors, as, according to the adopted definition of landscape, it comprises of an upper, building space layer over the digital cadastral map and a nature space layer below it. The Space Use Model is therefore parcel based and actor and object orientated to accommodate future research and explorative interactive planning at local and regional scale.

B.1.8 TIGRIS Model

TIGRIS is a long-term incremental, time based interaction and allocation model for the following aspects: land use, mobility, congestion and accessibility. In TIGRIS accessibility is described as a location factor for land use that generates mobility. This increased mobility leads to congestion and changes in accessibility and, subsequently, to new changes in land use. The model is used for regional and national forecasting that adheres to the learning by doing concept (Van der Hoorn & Schoemakers 2003).

B.1.9 UrbanSim Model

This model is based on the view that urban development over time and space is the composite outcome of the interactions of individual choices and actions taken by households, businesses, developers and governments. The structure of this model includes components that model the behaviour of these decision-making units interfaced through the land market. The model works on a series of one-year steps. The UrbanSim is designed for micro level application. Since individual jobs and households are basic units of computation, the model requires detailed bookkeeping and large databases (Waddel 2000).

B.1.10 Urban Land Allocation Model (ULAM)

The ULAM is designed to provide an automated process to allocate and control future population and employment at the Traffic Analysis Zone (TAZ) level. An additional objective of the ULAM model is to provide a basic land use inventory and monitoring system of past, current and future land use trends. A number of default values and control variables are available with the ULAM model. Most of these variables can be modified. This model is designed for regional level planning (Kramer 2000).

Among these models, the Environment Explorer (EE) is the one which suits the aims of this research best, because:

- All spatial development policies for the Netherlands have been incorporated in the EE through earlier applications of the model
- The EE has already been calibrated by using past land uses changes
- The EE is a multi-level model, that can handle a spatial detail of up to 500*500 meter
- The EE has the capability to handle the spatial dynamics of land use by cellular automata for scenario studies at both the regional and the local level
- The EE is user friendly and is designed for different users, like land use planners and policy makers in order to support them to evaluate scenarios of future spatial development.

The EE model will be described in more detail in the next section.

B.2 Land use projection by the Environment Explorer model

The EE model represents processes at three spatial levels, national (the Netherlands), regional (40 functional regions named COROP) and local level (3,51,000 cells of 25 hectares) as shown in Figure B.1 (Engelen *et al.* 2002):

National level: National economic, demographic and environmental growth figures are taken from different growth scenarios considering the development in the Netherlands, in the context of Europe and global competition, prepared by the official Dutch policy analysis agencies. These scenarios are the input for the models at the regional level. For both Physical Space and the Hybrid Space Scenario used in this study the same data input is used.

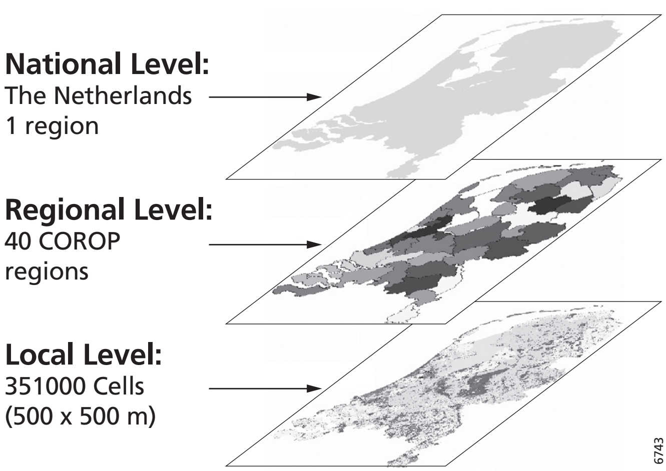

Figure B.1 Three levels of Environment Explorer model
(Source: (Engelen et al. 2002))

Regional level: Each of the 40 COROP regions competes with all other regions for new residents and new activities on the basis of its geographical position relative to other regions. This means, its employment level and structure, size and structure of population, and the quality of the activities already present and location relative to the public and the private transportation systems. In addition to these, and novel in the context of interaction based models, summarized cellular measures obtained from the model at the local level, characterizing the space within the regions are factors determining the relative regional attractiveness. There are four sub modules at regional level (shown in Figure B.2):

Regional economic module: calculates the amount of production and employment for each economic activity, its allocation and reallocation among regions.

Regional demographic module: deals with the growth of the regional population; its allocation and re-allocation among the regions and the demand for housing.

Regional transportation module: deals with the changes in the characteristics of the transportation infrastructure (railways and railway stations, navigable waterways, and road networks). It uses the LMS (Landelijk Model Systeem) level road network developed for the Ministry of Transport, Public Works and Water Management and consists of the motorways and main national and regional roads.

Regional land-claim module: Translates the regional growth volumes into spatial claims. The latter are passed on to the model at local (cellular) level for a detailed allocation. These future land use requirements per COROP are used for both the PSS and the HSS.

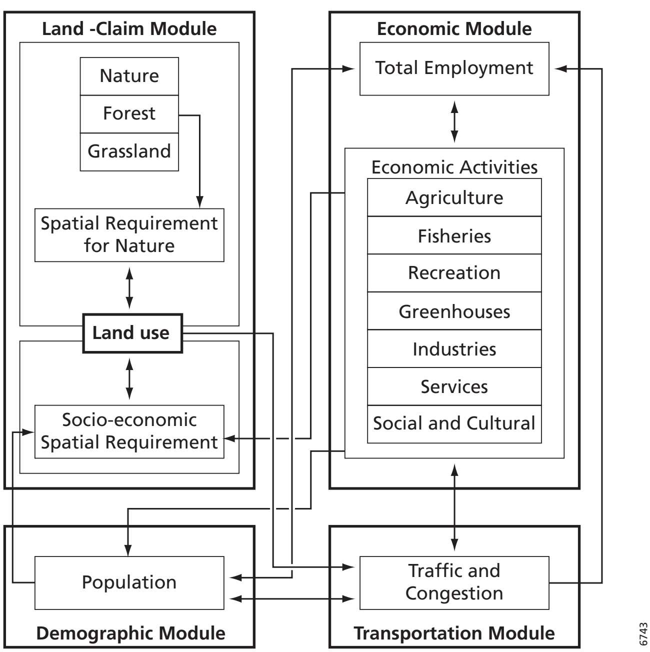

Figure B.2 Regional level model of Environment Explorer
(Source: (Engelen et al. 2002))

Local level: at local level the detailed allocation of economic activities and people is modelled by means of a cellular automata based land use model (shown in Figure B.3). Hence, 40 cellular automata calculations are running at same time for each COROP region.

The following characteristics are used for computing land use suitability surfaces:

Physical suitability

Suitability is represented in the model by one map for each land use function modelled. It is a composite measure, prepared in a Geographical Information System (GIS), on the basis of some 15 factor maps determining the physical, ecological and environmental appropriateness of cells to support a land use function and the associated economic or residential activity. Factors among others are: elevation, soil quality, agricultural capacity, air quality, noise pollution, etc. ICTs (telecommuting) can be expected to have positive direct environmental effects due to the reduction in the total travelled distance, but those effects have not yet been quantified. Hence in this research the physical suitability is the same for both the PSS and the HSS.

Zoning or institutional suitability

Zoning too is specified by one map per land use function. It is a composite measure based on master plans and planning documents available from the national and regional planning authorities and containing ecologically valuable and protected areas, protected city- and villagescapes, buffer areas, etc. For three planning periods, to be determined by the user (example: 2000-2005, 2005-2015, and 2015-2030), they specify which cells will and cannot be changed to a (particular) land use category. These policies were formulated without taking into consideration the spatial effects of the use of ICTs, hence will in this study only be used for the PSS.

Accessibility

The accessibility for each land use function is calculated in the model relative to the transportation system. It is an expression of the ease with which an activity can fulfil its needs for transportation and mobility in a particular cell. It accounts for: the distance of the cell to the nearest link or node, the quality of that link, and the needs for transportation of the particular activity or land use function. Accessibility for jobs is the characteristic which is impacted the most by the use of ICTs. Hence in this research a dedicated model to calculate job accessibility for both the PSS and the HSS is developed and applied.

Dynamics at the local level

The three elements mentioned above are introduced into the model to determine the non-homogeneous nature of the physical space within which the land use dynamics unfold. However, a fourth and important aspect also needs attention: the dynamic impact of land uses in the immediate surrounding of a location. This is no longer the domain of abstract planning, but that of the reality on the ground representing the fact that the presence of complementary or competing activities and attracting or repelling land uses is of great significance for the quality of that location and thus for its appeal for particular activities. For each location, the model assesses the quality of its neighbourhood: a circular area with a radius of 4 km containing 196 nearest cells. For each land use function, a set of rules determines the degree to which it is attracted to, or repelled by the other functions present in its neighbourhood.

The strength of the interactions as a function of the distance separating the different land uses within the neighbourhood is articulated in rules. If the attractiveness is high enough, the function will try to occupy the location, if not, it will look for more attractive places elswhere Thus new activities and land uses invading a neighbourhood over time will change its attractiveness for

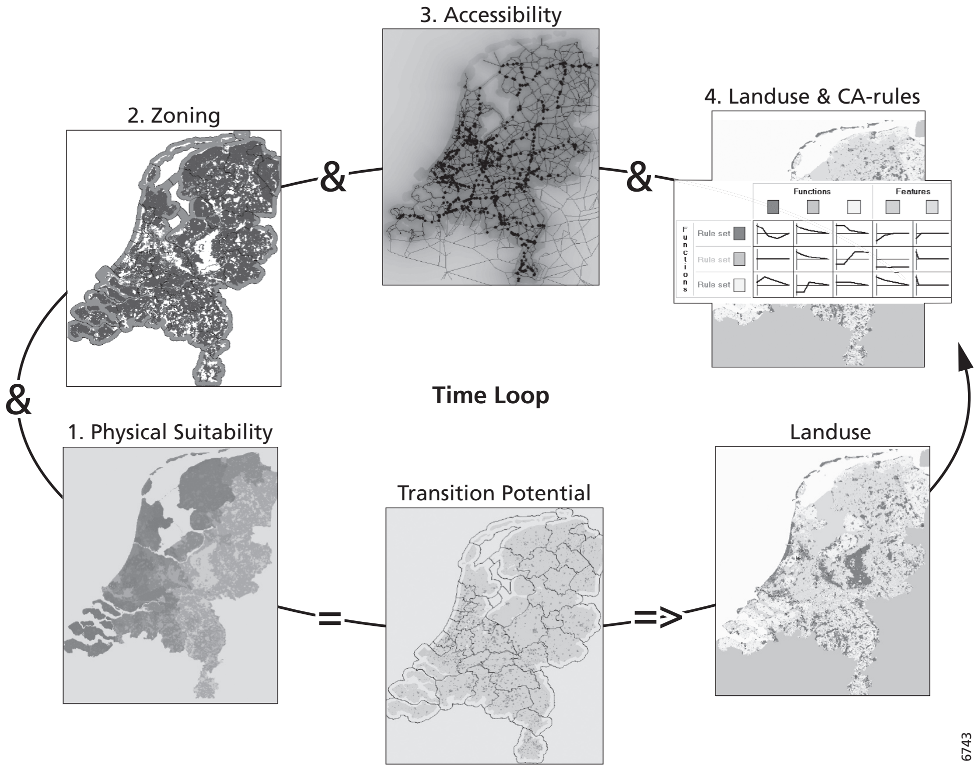

Figure B.3 Local level model of the Environment Explorer
(Source: (Engelen et al. 2002))

activities already present and others searching for such a space. This process explains the decay of a residential neighbourhood due to invasion by industrial or commercial activities, as well as the revival of run-down neighbourhoods initiated by the arrival of (sometimes only a few) high quality functions like parks, exclusive office buildings, high-end condominiums, etc. The rules determining the interactions between the different functions: the inertia, the push and pull forces, and economies of scale, are defined as part of the calibration of the model based on the historic land-use change data.

On the basis of these four elements, the model calculates for every simulation step (for each year) the transition potential for each cell and function (Land use). In the course of time and until regional demands are satisfied, cells will change to the land use function for which they have the highest potential. Consequently, the transition potentials reflect the pressures exerted on the land and thus constitute important information to those responsible for the design of sound spatial planning policies.

The Environment Explorer model is calibrated for data of year 1989 and 1993 and validated for year 2000. In this research, the calibrated and validated parameters were modified by using the land use change matrix produced by Statistic Netherlands, (show in Table B.1). On the basis of this matrix, the findings from the literature review and the WBO 2002 survey analysis for effects of telecommuting on residential preferences, neighbourhood rules of land use transition for low

Table B.1 Change in the land use between 1996 and 2000 (Source: Statistics Netherlands)

Land use in 2000 (ha)

Land use in 1996	1 Transport	10 Railway	11 Highway	12 Airport	2 Built up Area	20 Residential	21 Retail and Gross Market	22 Public Use	23 Social and Cuture	24 Industrial	3 Semi Built up Area	30 Dumping Site	31 Wrek Storage	32 Graveyard	33 Mineral Extraction	34 Construction Site	35 Other Areas
1 Transport	**106**	**57**	**47**	**2**	**759**	**490**	**14**	**22**	**29**	**204**	**285**	**5**	**2**	**8**	**5**	**214**	**50**
10 Railway	**41**		41	-	**116**	58	2	2	4	49	**33**	1	0	0	0	25	6
11 Highway	**59**	57		2	**625**	421	11	20	24	150	**226**	5	2	8	5	163	44
12 Airport	**6**	-	6		**18**	12	1	0	-	5	**25**	-	-	-	-	25	-
2 Built up Area	**589**	**29**	**558**	**2**	**815**	**334**	**74**	**69**	**140**	**198**	**889**	**7**	**6**	**37**	**2**	**816**	**20**
20 Residential	**391**	7	384	-	**337**		53	29	102	152	**289**	0	-	32	0	252	4
21 Retail and Gross Market	**17**	-	17	-	**74**	59		2	11	2	**22**	-	-	-	-	22	-
22 Public Use	**18**	0	16	1	**87**	44	9		15	17	**116**	5	-	0	-	103	7
23 Social and Cuture	**27**	0	26	-	**175**	118	11	20		26	**62**	0	-	4	-	58	0
24 Industrial	**137**	22	115	0	**143**	112	1	18	12		**400**	1	6	1	2	380	9
3 Semi Built up Area	**524**	**8**	**463**	**53**	**7053**	**3896**	**67**	**90**	**82**	**2918**	**408**	**18**	**7**	**25**	**117**	**233**	**9**
30 Dumping Site	**8**	0	8	-	**2**	2	-	-	-	0	**59**		0	-	-	59	0
31 Wrek Storage	**0**	-	0	-	**9**	1	2	-	-	5	**9**	0		-	-	9	-
32 Graveyard	**4**	-	4	-	**11**	10	0	0	1	1	**3**	-	-		-	3	-
33 Mineral Extraction	**13**	-	13	-	**6**	1	-	-	-	5	**23**	-	-	-		20	3
34 Construction Site	**448**	6	389	53	**6915**	3860	64	78	80	2832	**171**	17	6	25	117		6
35 Other Areas	**51**	2	49	-	**110**	22	-	12	1	74	**144**	0	1	-	0	143	
4 Recreation	**132**	**3**	**129**	**-**	**628**	**468**	**20**	**13**	**44**	**83**	**629**	**0**	**0**	**9**	**-**	**611**	**9**
40 Parks	**46**	1	45	-	**219**	169	2	3	22	23	**124**	-	-	5	-	118	1
41 Spots Area	**44**	2	42	-	**294**	219	9	8	16	41	**306**	0	0	1	-	304	1
42 Garden	**8**	1	8	-	**49**	40	2	1	0	7	**103**	-	-	3	-	100	0
43 Day Time Recreation Area	**21**	0	21	-	**42**	24	5	1	2	9	**75**	-	-	0	-	70	5
44 Recreational Housing	**12**	-	12	-	**24**	15	2	-	3	3	**21**	-	-	0	-	18	2
5 Agriculture	**1913**	**32**	**1842**	**39**	**7687**	**4089**	**106**	**110**	**125**	**3256**	**17734**	**49**	**20**	**43**	**258**	**17181**	**182**
50 Green House	**16**	-	16	-	**117**	88	7	1	-	21	**264**	-	-	0	-	264	-
51 Other Agriculture Use	**1897**	32	1825	39	**7570**	4001	100	109	125	3235	**17469**	49	20	43	258	16917	182
6 Forest and Nature	**268**	**5**	**248**	**15**	**414**	**182**	**11**	**36**	**31**	**154**	**819**	**12**	**1**	**14**	**75**	**688**	**30**
60 Forest	**223**	4	210	9	**390**	171	11	36	31	141	**665**	12	1	14	70	563	6
61 Dry Natural Area	**25**	0	18	7	**4**	1	0	0	0	3	**26**	-	-	-	5	9	12
62 Wet Natural Area	**20**	0	20	-	**20**	10	-	0	-	10	**128**	-	-	0	0	117	11
7 Inner Water	**66**	**6**	**59**	**-**	**134**	**66**	**1**	**5**	**5**	**58**	**438**	**2**	**-**	**0**	**2**	**325**	**108**
70 IJsselmeer/Markermeer	**4**	-	4	-	**1**	-	-	0	-	0	**198**	2	-	-	-	188	8
71 Afgesloten zeearm	**-**	-	-	-	**0**	-	-	0	-	-	**0**	-	-	-	-	-	0
72 Rijn & Maas	**-**	-	-	-	**-**	-	-	-	-	-	**3**	-	-	-	-	-	3
73 Randmeer	**-**	-	-	-	**-**	-	-	-	-	-	**38**	-	-	-	-	5	32
74 Spaarbekken	**-**	-	-	-	**1**	-	-	1	-	-	**7**	-	-	-	-	-	7
75 Water with Recreational Function	**1**	-	1	-	**1**	1	-	0	-	0	**7**	-	-	-	1	6	0
76 Water with Mineral Extraction	**-**	-	-	-	**0**	-	-	-	0	-	**0**	-	-	-	0	0	-
77 Silt	**-**	-	-	-	**0**	-	-	-	-	0	**1**	-	-	-	-	-	1
78 Other Inner Water	**61**	6	55	-	**131**	65	1	3	4	57	**183**	0	-	0	2	125	55
8 Outer Water	**0**	**-**	**0**	**-**	**2**	**-**	**-**	**0**	**0**	**1**	**66**	**-**	**-**	**-**	**-**	**31**	**36**
80 Wadden Sea, Eems en Dollard	**0**	-	0	-	**2**	-	-	0	-	1	**48**	-	-	-	-	30	18
81 Eastern Schelde	**-**	-	-	-	**0**	-	-	-	0	0	**11**	-	-	-	-	0	10
82 Western Schelde	**-**	-	-	-	**-**	-	-	-	-	-	**6**	-	-	-	-	-	6
83 North Sea	**-**	-	-	-	**-**	-	-	-	-	-	**2**	-	-	-	-	-	2
Totaal	**3598**	**140**	**3346**	**111**	**17492**	**9525**	**293**	**347**	**455**	**6872**	**21267**	**94**	**36**	**136**	**459**	**20098**	**443**

Land use in 1996	4 Recreation	40 Parks	41 Spots Area	42 Garden	43 Day Time Recreation Area	44 Recreational Housing	5 Agriculture	50 Green House	51 Other Agriculture Use	6 Forest and Nature	60 Forest	61 Dry Natural Area	62 Wet Natural Area
1 Transport	**149**	**73**	**35**	**9**	**21**	**10**	**1192**	**8**	**1184**	**502**	**464**	**23**	**15**
10 Railway	**15**	8	3	3	1	0	**143**	1	143	**65**	63	1	1
11 Highway	**132**	63	33	6	20	10	**1036**	8	1028	**429**	395	18	15
12 Airport	**2**	2	-	-	-	-	**13**	-	13	**9**	6	4	-
2 Built up Area	**398**	**277**	**78**	**16**	**13**	**14**	**810**	**14**	**797**	**295**	**276**	**14**	**6**
20 Residential	**300**	216	52	10	9	12	**641**	12	629	**59**	52	6	2
21 Retail and Gross Market	**6**	4	1	-	-	-	**10**	-	10	**9**	7	2	-
22 Public Use	**13**	11	2	0	0	-	**46**	-	46	**55**	52	3	0
23 Social and Cuture	**41**	28	7	3	0	2	**30**	1	29	**102**	100	2	-
24 Industrial	**39**	19	15	2	3	0	**84**	1	83	**70**	66	1	4
3 Semi Built up Area	**872**	**298**	**115**	**12**	**248**	**200**	**500**	**5**	**495**	**533**	**257**	**173**	**102**
30 Dumping Site	**49**	9	35	-	5	-	**58**	-	58	**63**	53	9	1
31 Wrek Storage	**0**	0	0	-	-	-	**5**	0	4	**1**	1	-	-
32 Graveyard	**2**	1	0	0	1	-	**6**	-	6	**7**	7	-	1
33 Mineral Extraction	**66**	0	-	0	66	-	**38**	0	38	**72**	48	21	4
34 Construction Site	**699**	262	77	10	156	193	**191**	4	186	**256**	110	94	52
35 Other Areas	**56**	26	2	1	20	6	**203**	-	203	**133**	40	49	45
4 Recreation	**357**	**85**	**122**	**13**	**57**	**79**	**217**	**1**	**216**	**441**	**417**	**15**	**9**
40 Parks	**95**		48	6	41	0	**39**	0	39	**16**	15	-	1
41 Spots Area	**74**	47		7	7	13	**73**	0	73	**125**	123	1	1
42 Garden	**31**	13	11		2	5	**32**	-	32	**13**	12	0	0
43 Day Time Recreation Area	**146**	25	60	0		60	**28**	1	28	**187**	168	12	7
44 Recreational Housing	**11**	1	3	-	7		**45**	0	45	**101**	99	2	0
5 Agriculture	**2445**	**815**	**803**	**115**	**274**	**438**	**2027**	**1749**	**278**	**6955**	**6145**	**211**	**600**
50 Green House	**5**	1	4	1	0	-	**278**		278	**1**	0	0	-
51 Other Agriculture Use	**2439**	815	799	114	274	438	**1749**	1749		**6955**	6144	210	600
6 Forest and Nature	**859**	**344**	**163**	**7**	**155**	**190**	**1337**	**2**	**1335**	**3430**	**2364**	**881**	**186**
60 Forest	**767**	331	138	6	125	167	**1045**	2	1043	**771**		685	86
61 Dry Natural Area	**28**	2	7	0	0	20	**55**	-	55	**1893**	1794		99
62 Wet Natural Area	**64**	12	18	1	30	4	**237**	-	237	**766**	570	196	
7 Inner Water	**106**	**19**	**11**	**2**	**54**	**18**	**352**	**2**	**350**	**589**	**123**	**264**	**202**
70 IJsselmeer/Markermeer	**13**	-	-	-	8	5	**0**	-	0	**12**	-	10	2
71 Afgesloten zeearm	**-**	-	-	-	-	-	**-**	-	-	**24**	-	24	-
72 Rijn & Maas	**-**	-	-	-	-	-	**-**	-	-	**0**	-	-	-
73 Randmeer		-	-	-	-	-	**-**	-	-	**187**	-	129	58
74 Spaarbekken	**-**	-	-	-	-	-	**1**	-	1	**6**	6	0	0
75 Water with Recreational Function	**35**	1	3	-	24	8	**8**	-	8	**6**	3	3	0
76 Water with Mineral Extraction	**0**	-	-	-	0	-	**0**	-	0	**1**	0	1	-
77 Silt	**-**	-	-	-	-	-	**0**	-	0	**0**	0	-	-
78 Other Inner Water	**57**	19	9	2	22	5	**343**	2	341	**353**	114	98	141
8 Outer Water	**0**	**-**	**-**	**-**	**0**	**-**	**1**	**-**	**1**	**1681**	**-**	**1597**	**84**
80 Wadden Sea, Eems en Dollard	**-**	-	-	-	-	-	**0**	-	0	**671**	-	631	40
81 Eastern Schelde	**-**	-	-	-	-	-	**0**	-	0	**3**	-	3	0
82 Western Schelde	**-**	-	-	-	-	-	**-**	-	-	**44**	-	-	44
83 North Sea	**0**	-	-	-	0	-	**-**	-	-	**964**	-	964	-
Totaal	**5185**	**1912**	**1328**	**174**	**822**	**950**	**6436**	**1781**	**4655**	**14427**	**10046**	**3178**	**1203**

Land use in 1996	7 Inner Water	70 IJsselmeer/Markermeer	71 Afgesloten zeearm	72 Rijn & Maas	73 Randmeer	74 Spaarbekken	75 Water with Recreational Function	76 Water with Mineral Extraction	77 Silt	78 Other Inner Water	8 Outer Water	80 Wadden Sea, Eems en Dollard	81 Eastern Schelde	82 Western Schelde	83 North Sea	Totaal
1 Transport	**69**	**0**	**-**	**-**	**-**	**-**	**2**	**0**	**0**	**66**	**0**	**-**	**-**	**-**	**0**	**3061**
10 Railway	**7**	-	-	-	-	-	0	-	-	7	**-**	-	-	-	-	**419**
11 Highway	**59**	0	-	-	-	-	1	0	0	57	**0**	-	-	-	0	**2566**
12 Airport	**3**	-	-	-	-	-	1	-	-	2	**-**	-	-	-	-	**76**
2 Built up Area	**189**	**-**	**-**	**0**	**-**	**-**	**0**	**1**	**25**	**162**	**0**	**0**	**-**	**-**	**0**	**3986**
20 Residential	**138**	-	-	-	-	-	0	1	-	136	**0**	0	-	-	-	**2154**
21 Retail and Gross Market	**1**	-	-	-	-	-	-	-	-	1	**-**	-	-	-	-	**139**
22 Public Use	**10**	-	-	-	-	-	-	-	1	9	**-**	-	-	-	-	**344**
23 Social and Cuture	**5**	-	-	-	-	-	-	0	-	5	**-**	-	-	-	-	**441**
24 Industrial	**35**	-	-	0	-	-	0	-	24	11	**0**	-	-	-	0	**908**
3 Semi Built up Area	**583**	**1**	**-**	**2**	**0**	**-**	**31**	**162**	**3**	**384**	**0**	**0**	**-**	**-**	**0**	**10473**
30 Dumping Site	**5**	0	-	-	-	-	-	-	2	3	**-**	-	-	-	-	**244**
31 Wrek Storage	**-**	-	-	-	-	-	-	-	-	-	**-**	-	-	-	-	**23**
32 Graveyard	**2**	-	-	-	-	-	2	-	-	1	**-**	-	-	-	-	**36**
33 Mineral Extraction	**122**	-	-	-	-	-	8	96	-	18	**-**	-	-	-	-	**340**
34 Construction Site	**442**	1	-	2	-	-	20	66	1	352	**-**	-	-	-	-	**9121**
35 Other Areas	**11**	-	-	0	0	-	1	-	-	11	**0**	0	-	-	0	**708**
4 Recreation	**72**	**0**	**-**	**-**	**0**	**-**	**14**	**-**	**-**	**57**	**-**	**-**	**-**	**-**	**-**	**2476**
40 Parks	**34**	-	-	-	-	-	3	-	-	31	**-**	-	-	-	-	**574**
41 Spots Area	**10**	-	-	-	-	-	2	-	-	8	**-**	-	-	-	-	**925**
42 Garden	**2**	-	-	-	-	-	-	-	-	2	**-**	-	-	-	-	**239**
43 Day Time Recreation Area	**20**	0	-	-	0	-	9	-	-	11	**-**	-	-	-	-	**518**
44 Recreational Housing	**6**	0	-	-	-	-	1	-	-	5	**-**	-	-	-	-	**220**
5 Agriculture	**1978**	**-**	**-**	**2**	**-**	**4**	**28**	**167**	**30**	**1747**	**-**	**-**	**-**	**-**	**-**	**40738**
50 Green House	**6**	-	-	-	-	-	0	-	-	5	**-**	-	-	-	-	**687**
51 Other Agriculture Use	**1972**	-	-	2	-	4	28	167	30	1742	**-**	-	-	-	-	**40051**
6 Forest and Nature	**981**	**1**	**-**	**-**	**-**	**3**	**6**	**8**	**-**	**962**	**1252**	**930**	**-**	**54**	**268**	**9360**
60 Forest	**137**	-	-	-	-	3	3	7	-	124	**0**	0	-	-	-	**3998**
61 Dry Natural Area	**283**	0	-	-	-	-	-	0	-	283	**1178**	915	-	-	263	**3492**
62 Wet Natural Area	**560**	1	-	-	-	-	4	0	-	555	**75**	15	-	54	5	**1871**
7 Inner Water	**336**	**3**	**1**	**6**	**8**	**1**	**190**	**1**	**65**	**62**	**20**	**11**	**0**	**0**	**9**	**2040**
70 IJsselmeer/Markermeer	**19**		-	-	-	-	19	-	-	0	**-**	-	-	-	-	**247**
71 Afgesloten zeearm	**-**	-		-	-	-	-	-	-	-	**-**	-	-	-	-	**24**
72 Rijn & Maas	**-**	-	-		-	-	-	-	-	-	**-**	-	-	-	-	**3**
73 Randmeer	**59**	-	-	-		-	0	-	59	-	**-**	-	-	-	-	**283**
74 Spaarbekken	**-**	-	-	-	-		-	-	-	-	**-**	-	-	-	-	**16**
75 Water with Recreational Function	**24**	0	-	-	-	-		-	-	24	**2**	2	-	-	-	**84**
76 Water with Mineral Extraction	**81**	-	-	-	-	-	47		-	35	**-**	-	-	-	-	**84**
77 Silt	**4**	-	-	-	-	-	-	-		4	**-**	-	-	-	-	**5**
78 Other Inner Water	**150**	3	1	6	8	1	124	1	6		**18**	9	0	-	9	**1294**
8 Outer Water	**5**	**-**	**-**	**-**	**-**	**-**	**5**	**-**	**-**	**0**	**0**	**0**	**-**	**-**	**0**	**1756**
80 Wadden Sea, Eems en Dollard	**5**	-	-	-	-	-	5	-	-	0	**0**		-	-	0	**726**
81 Eastern Schelde	**-**	-	-	-	-	-	-	-	-	-	**-**	-		-	-	**14**
82 Western Schelde	**-**	-	-	-	-	-	-	-	-	-	**-**	-	-		-	**50**
83 North Sea	**-**	-	-	-	-	-	-	-	-	-	**0**	0	-	-		**966**
Totaal	**4213**	**5**	**1**	**10**	**8**	**8**	**276**	**339**	**123**	**3441**	**1273**	**941**	**0**	**54**	**277**	**73890**

Bovenstaande tabel is berekend op basis van de gemeentegrenzen 2000

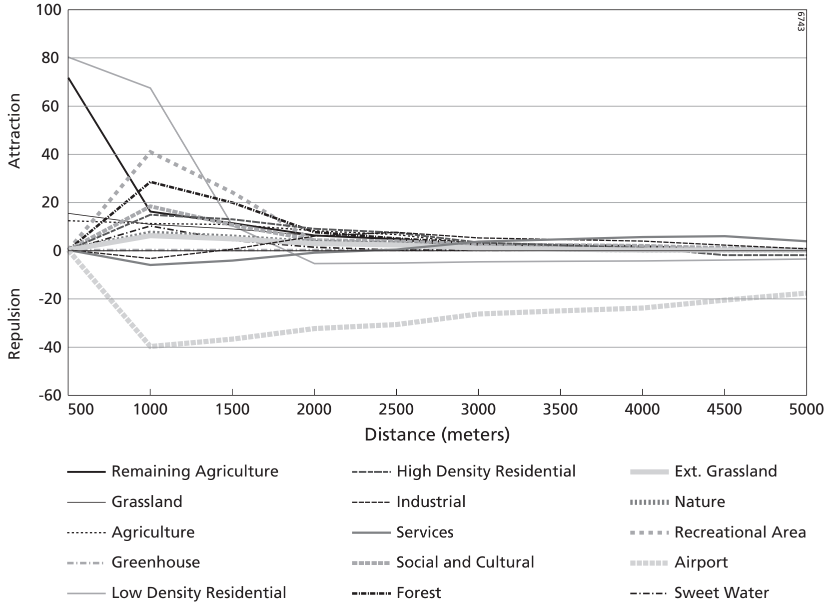

Figure B.4 Neighbourhood rules for land use transition potential for future low density residential areas *(Adapted from (De Nijs et al. 2001))*

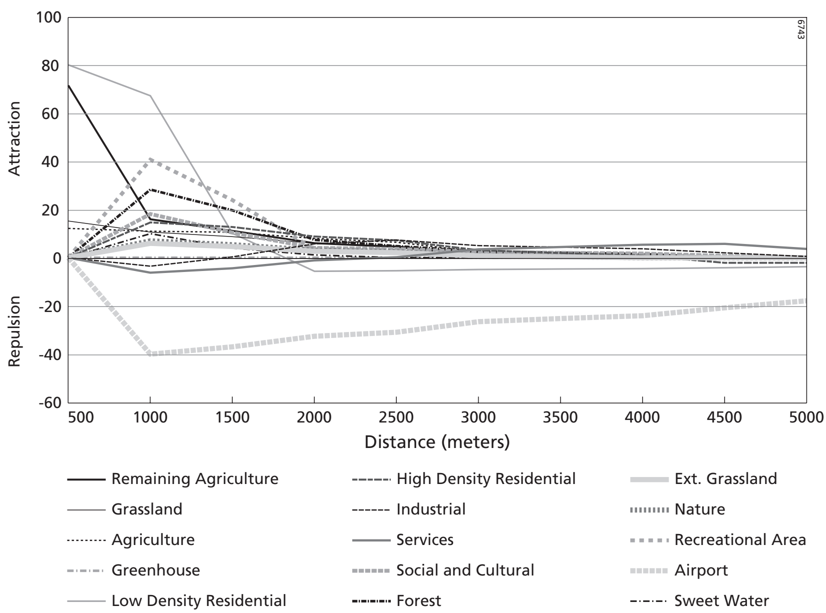

Figure B.5 Neighbourhood rules for land use transition potential for future high density residential areas *(Adapted from (De Nijs et al. 2001))* and high density residential areas are specified as shown in Figure B.4 and Figure B.5. These rules were used for computation of the land-use transition potentials for future low and high density residential land use for the HSS, while for the PSS the calibrated neighbourhood land use transition rules calculated by De Nijs *et al.* (2001) were used.

In the Environment Explorer, the transport module works at regional level, has the spatial resolution of LMS main zones (345 units). Therefore, job accessibility should be available at the same resolution. Job accessibility is computed at LMS sub-zone level (1308 units) level for the Netherlands and has been aggregated to the LMS main zone level. Along with job accessibility, which will be termed in EE's transport module as home to work accessibility, three other accessibilities, namely home to social (family and friends etc.), home to recreation areas and work to work areas are also considered for the allocation of different land uses (Bongers *et al.* 2002). The weights adopted for these four types of accessibility for the allocation of different land uses are shown in Table B.2. These factors were used for future land-use allocation for both the PSS and the HSS.

B.2.1 Computation of transition potential in Environment Explorer

In the Environment Explorer (EE), the Cellular Automata (CA) transition potential is a dynamic measure calculated on the basis of a complete set of distance functions (eight cell on each side, 4km) defined in the local model. It determines the likeliness that a cell will change state. It can have a positive or a negative value. In the EE, the CA-transition potential for each land use function is visualized in a map, the so-called potential map. The transition potential for land use K is calculated as:

$$\begin{aligned} & If\, {}^{t}R_{k,x,y} \geq 0 \\ then: \quad & {}^{t}P_{k,x,y} = {}^{t}v.({}^{t}S_{k,x,y})^{\sigma 1_k}.({}^{t}Z_{k,x,y})^{\sigma 2_k}.({}^{t}A_{k,x,y})^{\sigma 3_k}.({}^{t}R_{k,x,y})^{\sigma 4_k} \end{aligned} \qquad \text{(Eq. B.1)}$$

Table B.2 Weight factors for accessibility for the allocation of land uses

Land use	Home to Work Accessibility	Social Accessibility	Recreational Accessibility	Work to Work Accessibility
Greenhouses	0	0	0	1
Low Density Residential Areas	0.5	0.2	0.1	0.2
High Density Residential Areas	0.5	0.2	0.1	0.2
Industry	0.5	0	0	0.5
Trade and Services	0.5	0	0	0.5
Social and Cultural Buildings	0	1	0	0
Forest	0	0	1	0
Green Area	0	0	1	0
Nature	0	0	1	0
Recreation Area	0	0	1	0

$$If\ {}^{t}R_{k,x,y} < 0$$

$$then: \quad {}^{t}P_{k,x,y} = {}^{t}v.({}^{t}R_{k,x,y})^{\sigma 4_k}.\left[2-({}^{t}S_{k,x,y})^{\sigma 1_k}.({}^{t}Z_{k,x,y})^{\sigma 2_k}.({}^{t}A_{k,x,y})^{\sigma 3_k}\right]$$

(Eq. B.2)

$${}^{t}R_{k,x,y} = \sum_{c}\sum_{l} w_{k,l,c}.{}^{t}I_{c,l}$$

(Eq. B.3)

$${}^{t}v = 1 + (-\ln[rand])^{\alpha}$$

(Eq. B.4)

With:

$0 < rand < 1$ is a uniform random function;

${}^{t}I_{c,l}$, The Kronecker delta function: ${}^{t}I_{c,l} = 1$ if cell l at a distance (the concentric ring) c is in the state L, other wise ${}^{t}I_{c,l} = 0$;

${}^{t}R_{K,x,y}$, Neighbourhood effect for cell *(x,y)* for land use K at time t;

$w_{k,l,c}$, Weighting parameter expressing the strength of the interaction between a cell with land use K and a cell with land use L at a distance c in the CA-neighbourhood;

${}^{t}p_{k,x,y}$, Cellular Automata transition potential of cell *(x,y)* for land use K;

${}^{t}v$, Scalable stochastic perturbation term in the transition potential;

$S_{k,x,y}$, Suitability of cell *(x,y)* for land use K;

${}^{t}Z_{k,x,y}$, Zoning status of cell *(x,y)* for land use K at time t;

${}^{t}A_{k,x,y}$, Accessibility of cell *(x,y)* for land use K at time t;

α, Stochastic noise factor;

Exponents $\sigma 1K$, $\sigma 2K$, $\sigma 3K$ *and* $\sigma 4K$ determine whether the effects of Suitability, Zoning, Accessibility and the Neighbourhood are (equals to 1) or not (equals to 0) taken into consideration in the calculation of the CA-transition potential.

For land use K for which $\sigma 4K = 0$ the micro model is simplified to a quasi-dynamic version of the typical overlay model which is extensively used. In this case, in order to avoid the randomization, the rand value is set to null, hence ${}^{t}v$ as shown in Equation B.4, will be equal to one.

Further, for the HSS, as the existing policies are not taking into consideration the effects of ICTs, and in order to have the full effect of accessibility, the weights to zoning is set to null. Thus in the HSS, only $S_{k,x,y}$, ${}^{t}R_{K,x,y}$ and ${}^{t}A_{k,x,y}$ are the variables shown in Equation B.1 and B.2, which will effect the computation of transition potential of cells.

Transition potential for future low and high density residential land-use for the whole Netherlands for years 2030 were computed by using job accessibilities for the years 1986, 1995, 2000, 2010, 2020 and 2030 for both the PSS and the HSS. By using that transition potential, future low and high density residential land-use for whole the Netherlands were projected at COROP level on year based iteration for year 2030. The differences between future low density residential area by the PSS and the HSS for the year 2030 are shown in Figure B.6 (see page 181).

For both the PSS and the HSS, the future allocated low density residential areas are mostly around the existing residential concentrations. For the HSS there are also allocations lying more peripheral to the existing pattern of residential clusters. This pattern is clear all over the Netherlands, especially in the northern region. There were no big differences between future high density residential areas by the PS and HS scenarios for the year 2030. That's why they are not presented here.

B.2.2 Limitations of Environment Explorer model

The EE is a good land use projection model for future scenarios studies. However, there are limitations for this research as already mentioned in Chapter 6. Additional remarks in this respect are:

- The calibration period should be sufficiently long that underlying processes in the system have time to manifest themselves in a representative way. But since it is necessary to have data for both the initial and final year of the interval, data availability often constrains the choice of the calibration period. In the case of the EE, the data was available for the mentioned years. This is a much shorter period than is desirable, since many trends in the dynamics may not be sufficiently clear over such an interval. In particular during this period, there was recession, so that industrial activity declined in the last two years. The calibration must reflect this, even though over the whole economic cycle there was net growth. In short, parameters values calibrated over such short periods are likely to be somewhat arbitrary and unstable (De Nijs *et al.* 2001).
- In case of Flevoland, its growth is largely result of planned development rather than inter COROP competition. Hence, this development is not represented well in this modelling framework (De Nijs *et al.* 2001).

Figure B.6 see page 181

Appendix C

Spatial Pattern Analyses of Future Residential Areas

C.1 Measuring spatial patterns

The measurement of spatial arrangement can be based on the distance between adjacent point features. The nearest neighbour indices measure the degree of spatial dispersion in a distribution based on inter-feature distances. The rationale is that, in general, the average distance between points in a clustered pattern is shorter than in a scattered pattern. In addition, a random pattern is associated with an average inter-space distance larger than a clustered pattern and smaller than a scattered pattern (Smith 1977; Bailey & Gatrell 1995; Chou 1996; Kaluzny *et al.* 1997).

Along with visual analysis, there are many spatial statistical tools for measuring spatial patterns. In chapter 6 the Spatial Clumpiness Index is applied for analyzing the spatial patterns of existing residential areas in 2000 and future residential areas in the Physical Space Scenario (PSS) and the Hybrid Space Scenario (HSS) for year 2030. This choice is based on explorative application of different measures (described briefly next) and an assessment of fitness for use for the purpose of this research.

C.1.1 Nearest Neighbour Ratio

There are many distance to neighbour based indices used for spatial pattern analysis. The Nearest Neighbour Ratio (NNR) is applied for existing and future residential areas for both the PSS and the HSS.

The NNR measures the distance between each feature's centroid and its nearest neighbour's centroid location. It then averages all these nearest neighbour distances. If the average distance is less than the average for a hypothetical random distribution, the distribution of the features being analyzed is considered clustered. If the average distance is greater than a hypothetical random distribution, the features are considered to be scattered. Thus if the calculated index value is less than 1, the pattern exhibits clustering. If the index value is greater than 1, the trend is towards scattering.

The NNR of the future total residential areas is calculated for four regions of the Netherlands and for the Netherlands as a whole for both the PSS and the HSS. All of them have a tendency of clustering, but of different intensity (Table C.1).

For whole the Netherlands, the projected future residential areas for both the PSS and the HSS, the computed NNR is less than one. This indicates that overall in the Netherlands residential areas are, relatively, clustered. This NNR value for the HSS is higher than for the PSS, which indicates that there is more clustering in the PSS than in the HSS.

In the eastern region, the NNR values for the HSS are somewhat higher than the ones for the PSS. Indicating more clustered future residential areas for the PSS.

Table C.1 Nearest neighbour ratio values for future residential areas

Region	Nearest Neighbour Ratio	Observed Mean Distance	Expected Mean Distance	Z Score (Standard Deviations)
The Netherlands (PSS)	0.3783	741.01	1958.49	-84.3693
The Netherlands (HSS)	0.3990	707.23	1772.47	-90.2894
Eastern Region (PSS)	0.4276	825.86	1931.24	-37.0677
Eastern Region (HSS)	0.4413	773.05	1751.48	-40.0440
Western Region (PSS)	0.3691	653.26	1769.65	-57.6772
Western Region (HSS)	0.3628	610.98	1683.92	-64.4887
Northern Region (PSS)	0.4106	903.71	2200.63	-25.5112
Northern Region (HSS)	0.4615	954.42	2067.72	-25.8125
Southern Region (PSS)	0.3993	766.80	1920.03	-37.8835
Southern Region (HSS)	0.4290	739.86	1724.23	-39.7409

In the western region, the NNR for the PSS is slightly higher than for the HSS, which indicates that future residential areas will be a little bit more clustered in the PSS. This is also obvious from visual inspection of the map.

In northern region, the NNR for the HSS is higher than the PSS. In the southern region, the NNR for the HSS is higher than PSS. This means relatively more clustering in PSS as compared to ones in HSS.

The NNR was also calculated for the existing residential areas and future total residential areas for both the PSS and the HSS for the year 2030. As the existing residential areas occupy much more area than the new areas, they strongly dominate the future patterns of clustering, showing the power of geographical inertia.

Besides the NNR, there are other spatial metrics based on nearest-neighbour distance at the patch, class, and landscape levels. These metrics are based on the distance from a patch to a neighbouring patch of the same or different class, calculated from cell centre to cell centre.

The following indices were computed in Fragstats, a spatial statistical package developed by McGarigal *et al.* (2002):

C.1.2 Clumpiness Index:

$$Given \quad G_i = \left[\frac{g_{ii}}{\left(\sum_{ii=1}^{m} g_{ik} - \min e_i \right)} \right] \qquad \text{(Eq. C.1)}$$

$$Clumpy = \begin{bmatrix} \dfrac{G_i - P_i}{P_i} \;\; for \;\; G_i < P_i \;\; \& \;\; P_i < 0.5; \;\; else \\ \dfrac{G_i - P_i}{1 - P_i} \end{bmatrix} \qquad \text{(Eq. C.2)}$$

Where:

g_{ii} is the number of like adjacencies (joins) between pixels of patch type (class) i based on the *double-count* method.
g_{ik} is the number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method.
Min-e_i is the minimum perimeter (in number of cell surfaces) of patch type (class) i for a maximally clumped class.
P_i is the proportion of the landscape occupied by patch type (class) i.

The Clumpiness Index (CI) equals the proportional deviation of the proportion of like adjacencies involving the corresponding class from that expected under a spatially random distribution. If the proportion of like adjacencies (G_i) is less than the proportion of the landscape comprised of the focal class (P_i) and $P_i < 0.5$, then CI equals G_i minus P_i, divided by P_i. Else, CI equals G_i minus P_i, divided by 1 minus P_i. Note, it can be shown that G_i equals 1 when the patch type is maximally clumped, but this requires adjustment for the perimeter of the class. If a_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than a_i, and $m = a_i - n^2$, then the minimum perimeter of class i (i.e., when it is maximally clumped), min-e_i, will take one of the three forms:
min-$e_i = 4n$, when $m = 0$, or
min-$e_i = 4n + 2$, when $n^2 < a_i \leq n(1 + n)$, or
min-$e_i = 4n + 4$, when $a_i > n(1 + n)$.

Note, g_{ii} in the numerator includes only internal like adjacencies. So, adjacencies involving cells in the border are not included. The sum of g_{ik} in the denominator includes all adjacencies involving the focal class, including adjacencies involving background and all adjacencies involving the landscape boundary, regardless of whether a border is present or not. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved. Note, P_i is based on the total landscape area (A) including any internal background present.

Given any P_i, CI equals -1 when the focal patch type is maximally disaggregated. CI equals 0 when the focal patch type is distributed randomly, and approaches 1 when the patch type is maximally aggregated.

C.1.3 Proximity Mean Index

The Proximity Mean Index (PMI) equals to the sum of patch area divided by the squared nearest edge-to-edge distance between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance of the focal patch. Note, when the search buffer extends beyond the landscape boundary, only patches contained within the landscape are considered in the computations. In addition, note that the edge-to-edge distances are from cell centre to cell centre.

The PMI is null, if a patch has no neighbours of the same patch type within the specified search radius. The PMI increases as the neighbourhood (defined by the specified search radius) is increasingly occupied by patches of the same type and as those patches become closer and more contiguous (or less fragmented) in distribution. The upper limit of the PMI is affected by the search radius and the minimum distance between patches.

C.1.4 Euclidean Nearest Neighbour Index

This measure is equal to the distance to the nearest neighbouring patch of the same type, based on the shortest edge-to-edge distance. Note that the edge-to-edge distances are from cell centre to cell centre.

Euclidean Nearest Neighbour Index (ENNI) approaches 0 as the distance to the nearest neighbour decreases. The minimum ENNI is constrained by the cell size, and is equal to twice the cell size when the 8-neighbor patch rule is used or the distance between diagonal neighbours when the 4-neighbor rule is used. The upper limit is constrained by the extent of the landscape. The ENNI is undefined if the patch has no neighbours (i.e., no other patches of the same class).

C.1.5 Proportion Like Adjacencies Index

This index equals to the number of like adjacencies involving the focal class, divided by the total number of cell adjacencies involving the focal class; multiplied by 100 (to convert to a percentage). In other words, the percentage of cell adjacencies involving the corresponding patch type that like adjacencies. All background edge segments are included in the sum of all adjacencies involving the focal class, including landscape boundary segments if a border is not provided. Cell adjacencies are tallied using the *double-count* method in which pixel order is preserved, at least for all internal adjacencies (i.e., involving cells on the inside of the landscape). If a landscape border is present, adjacencies on the landscape boundary are counted only once, as are all adjacencies with background.

The Potential Like Adjacencies Index (PLAI) equals the value zero when the corresponding patch type is maximally disaggregated (i.e., every cell is a different patch) and there are no like adjacencies. This occurs when the class is subdivided into one cell patches. Note, this condition can only be achieved when the proportion of the landscape comprised of the focal class (P_i) is more or equal to 0.5. When P_i is equal 0.5, this occurs only when the class is distributed as a perfect checkerboard. When P_i is more than 0.5, the checkerboard begins to fill in and there will exist like adjacencies. The PLAI increases as the corresponding patch type becomes increasingly aggregated such that the proportion of like adjacencies increases. The PLAI is equal to 100 when the landscape consists of single patch and all adjacencies are between the same class, and the landscape contains a border comprised entirely of the same class. If the landscape consists of single patch but does not contain a border, the PLAI will be less than 100 due to the background edge segments in the tally of adjacencies involving the focal class. Finally, the PLAI is undefined if the class consists of a single cell.

C.1.6 Aggregation Index

The Aggregation Index (AI) equals the number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving the corresponding class, which is achieved when the class is maximally clumped into a single, compact patch; multiplied by 100 (to convert to a percentage). If a_i is the area of class i (in terms of number of cells) and n is the side of a largest integer square smaller than a_i, and $m = a_i - n^2$, then the largest number of shared edges for class i, max-g_{ii} will take one of the three forms:

max-g_{ii} = $2n(n-1)$, when $m = 0$, or
max-g_{ii} = $2n(n-1) + 2m - 1$, when $m \leq n$, or
max-g_{ii} = $2n(n-1) + 2m - 2$, when $m > n$.

Note, because of the design of the metric, like adjacencies are tallied using the *single-count* method and all landscape boundary edge segments are ignored, even if a border is provided.

Given any P_i, the AI equals 0 when the focal patch type is maximally disaggregated (i.e., when there are no like adjacencies); the AI increases as the focal patch type is increasingly aggregated and equals 100 when the patch type is maximally aggregated into a single, compact patch. AI is undefined and reported as "N/A" if the class consists of a single cell. The AI is closely related to the Landscape Shape Index (LSI), only the latter is based on perimeter surfaces as opposed in internal like adjacencies. Both metrics can be normalized to reflect the fact the minimum and maximum values vary depending on P_i; the range of possible values is greatest when P_i is equal to 0.5. The normalized versions of the LSI and AI are completely redundant; thus, only the normalized LSI was computed.

These statistical indices are computed in Fragstats for residential areas in both the PSS and the HSS. The analysis is carried out on a raster dataset with cell size of 500*500 m. The results are shown in Table C.2.

From this table it is clear that for the whole Netherlands, the Clumpiness Index for the PSS is higher than the HSS. This is not exactly according to the expectation. For the eastern region the values are almost the same for both scenarios. For the western region, the residential areas are more clustered for the HSS as compared to the PSS. In the northern and southern regions, the CI index value for the PSS is higher than for the HSS.

The Proximity Mean Index value is always higher for the HSS than the PSS except for the northern region. This index involves the total area allocated as low density residential areas

Table C.2 Spatial indices computed in Fragstats

Region with Scenario	Clumpiness Index	Proximity mean Index	Euclidean Nearest Neighbor Mean Index	Proportion Like Adjacencies Index	Aggregation Index
The Netherlands (HSS)	0.354	2.718	2028.595	39.180	39.688
The Netherlands (PSS)	0.361	1.952	2159.383	39.012	39.573
Eastern Region (HSS)	0.319	1.763	2091.645	34.596	35.549
Eastern Region (PSS)	0.320	0.982	2310.323	33.879	34.927
Western Region (HSS)	0.424	5.581	1878.082	48.773	49.719
Western Region (PSS)	0.410	3.655	1914.586	46.112	47.099
Northern Region (HSS)	0.271	0.491	2762.518	27.653	28.811
Northern Region (PSS)	0.322	0.513	2747.688	32.944	34.490
Southern Region (HSS)	0.242	1.131	1818.000	29.042	29.869
Southern Region (PSS)	0.287	0.939	2103.690	32.017	33.030

(LDRAs) and the nearest squared distance. As the area of LDRAs allocated in the HSS is larger than in the PSS, this measure is not suitable for this analysis.

The Euclidean Nearest Neighbour Index has the same limitations, as it is just taking into account only the nearest neighbour.

Overall, proportions like adjacencies index values are almost same for whole the Netherlands for both scenarios. For the eastern and western regions, the HSS has more proportion like adjacencies. For the northern and southern regions the opposite is true.

The Aggregation Index values for whole the Netherlands are more or less the same for both scenarios. But there are differences between the eastern and western and the northern and southern regions.

The outcomes of these analysis show that they add relatively little to a thorough and informed visual analysis of the land use maps with the land use patterns generated for the two scenarios.

C.1.7 Second Order Spatial Pattern Analysis

The Nearest Neighbour Index and other spatial indices computed in Fragstats are essentially concerned with exploring the first order statistical properties of spatial point patterns. In other words with estimating the way in which, the intensity varies in the study region by computing only the distance to the first closest neighbour. In the second order spatial methods, this limitation is removed by computing the distances between all events in the study area. The following functions are used to analyze the spatial patterns:

The Fhat and Ghat statistics are useful for assessing the first assumption: constant intensity. The Khat and Lhat statistics are useful for assessing the second assumption: second-order intensity which does not depend on absolute location.

Fhat Function

This nearest-neighbour distribution function relates to the distribution of distances from each of a set of sample points (clusters) covering the region of interest to the nearest event of an observed spatial point pattern (Diggle 1983). Fhat provides an estimate of $F^{\wedge}(y)$, the proportion of a set of sample points on a grid within distance y of the nearest point. For a completely spatially random process without edge effects, the theoretical distribution of $F^{\wedge}(y)$ is:

$F^{\wedge}(y) = 1 - \exp(-pi * intensity * y^2)$

Where the intensity is the number of points per unit area.

Ghat Function

Ghat provides an estimate of $G^{\wedge}(y)$, for each point in a spatial point pattern within a distance y of their nearest neighbour in a given grid. For a completely spatially random process without edge effects the theoretical distribution of $G^{\wedge}(y)$ is:

$G^{\wedge}(y) = 1 - \exp(-pi * intensity * y^2)$

Khat Function

The K function, or reduced second-order moment function, relates to the distribution of the inter-event distances between all ordered pairs of events in a spatial point pattern. The function is formally defined as the expected number of further events within distance *t* of an arbitrary event, divided by the overall intensity of events per unit area. An approximately unbiased estimator of K which incorporates corrections for edge effects can be obtained using the method of Ripley (1976). This estimator, denoted by $K^{\wedge}(t)$, is essentially an empirical distribution function of weighted inter-event distances. The weight associated with an inter-event distance t derived from events at positions (x_1, y_1) and (x_2, y_2) is the reciprocal of the conditional probability that any event separated from the point (x_1, y_1) by the distance t will fall in the study region and so be observed.

The term complete spatial randomness is used to represent the hypothesis that the overall intensity of events in a spatial point pattern is constant throughout the study region, and that the events are distributed independently and uniformly. Under complete spatial randomness, the expected number of further events which lie within a distance t of an arbitrary event in the pattern is simply the area of a circle of radius t, multiplied by the overall intensity of events. Thus, the K function for a completely random pattern is given by:

$K^{\wedge}$ (t) = (1/intensity) * E[number of events < or = distance t of an arbitrary event]

The theoretical K-function for a Poisson completely spatially random process is

$K^{\wedge}$ (t) = pi * t^2

Lhat Function

Lhat computes Ripley (1976)'s estimate of $L^{\wedge}(t)$ for a spatial point pattern, the theoretical L-function for a Poisson completely spatially random process is

$L^{\wedge}$ (t) = sqrt($K^{\wedge}$ (t)/pi)

The default plots $L^{\wedge}(t)$ versus t, which should approximate a straight line for a homogeneous process with no spatial dependence.

All the results from these second order spatial statistics have shown the trends of clustering. However, to interpret the differences in the spread of residential areas between the PSS and the HSS is difficult. This is clear from the Figs. C.1 to C.5. Although the regional differences are according to expectation, they are not helpful to elaborate the differences of residential areas patterns between the PSS and the HSS at regional level.

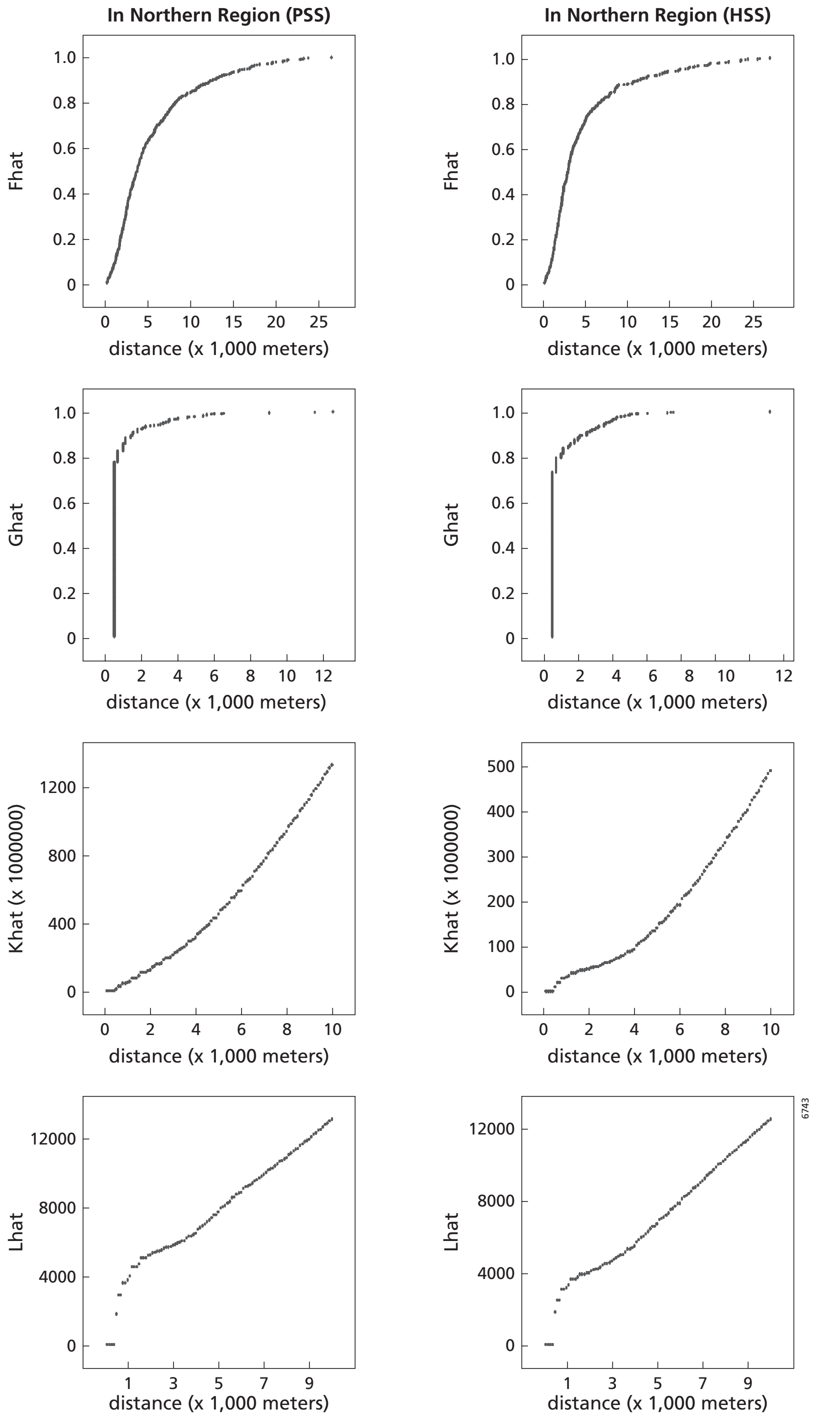

Figure C.1 Second order spatial statistics for the Northern Region

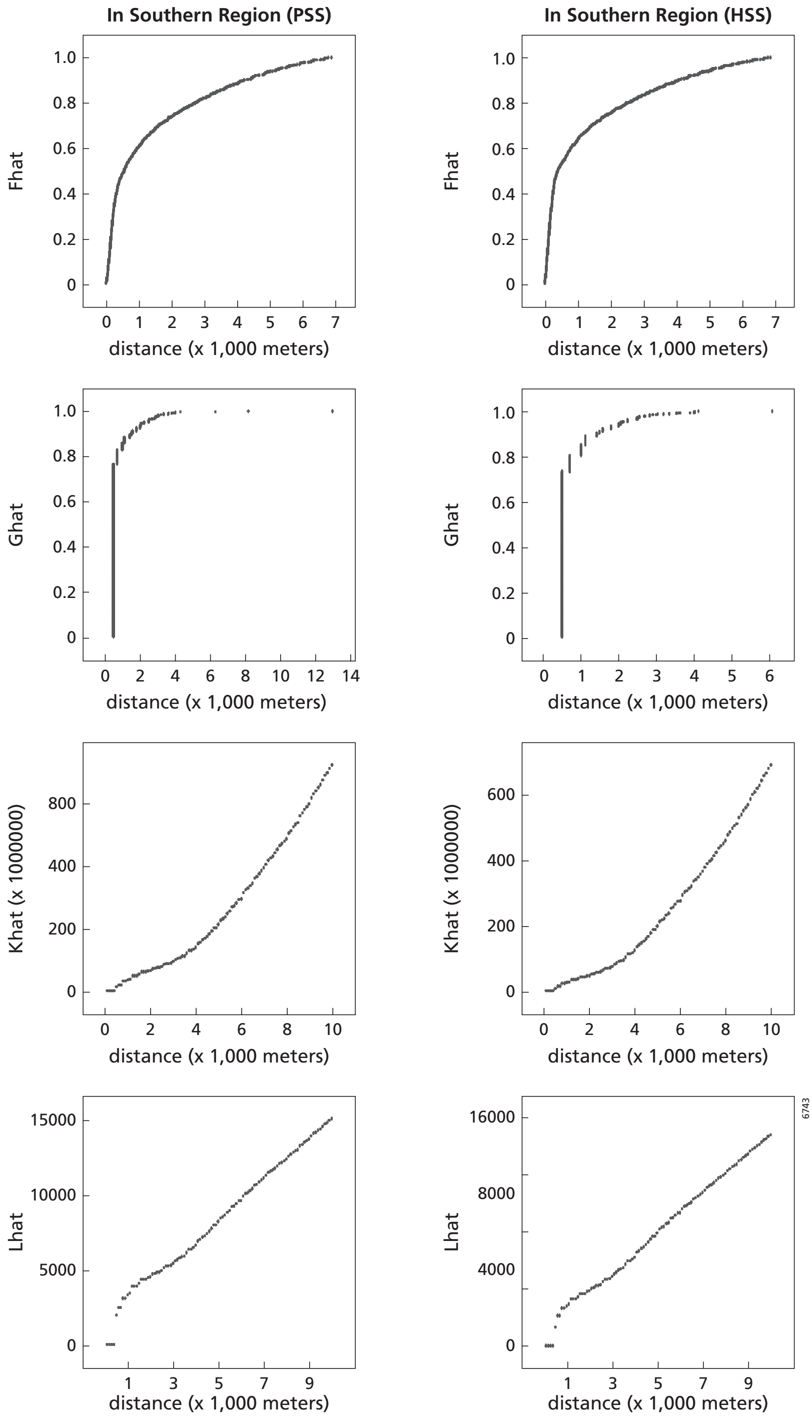

Figure C.2 Second order spatial statistics for Southern Region

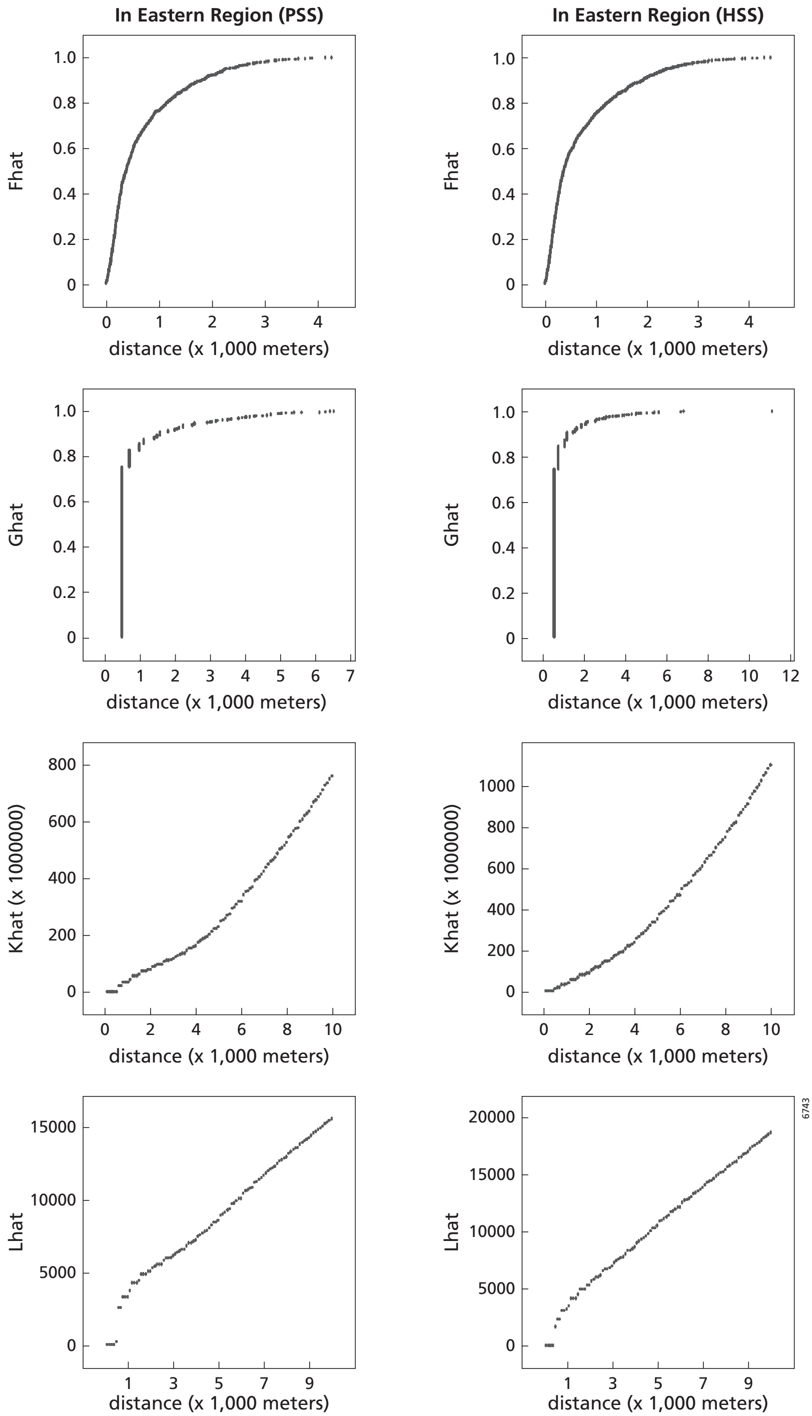

Figure C.3 Second order spatial statistics for Eastern Region

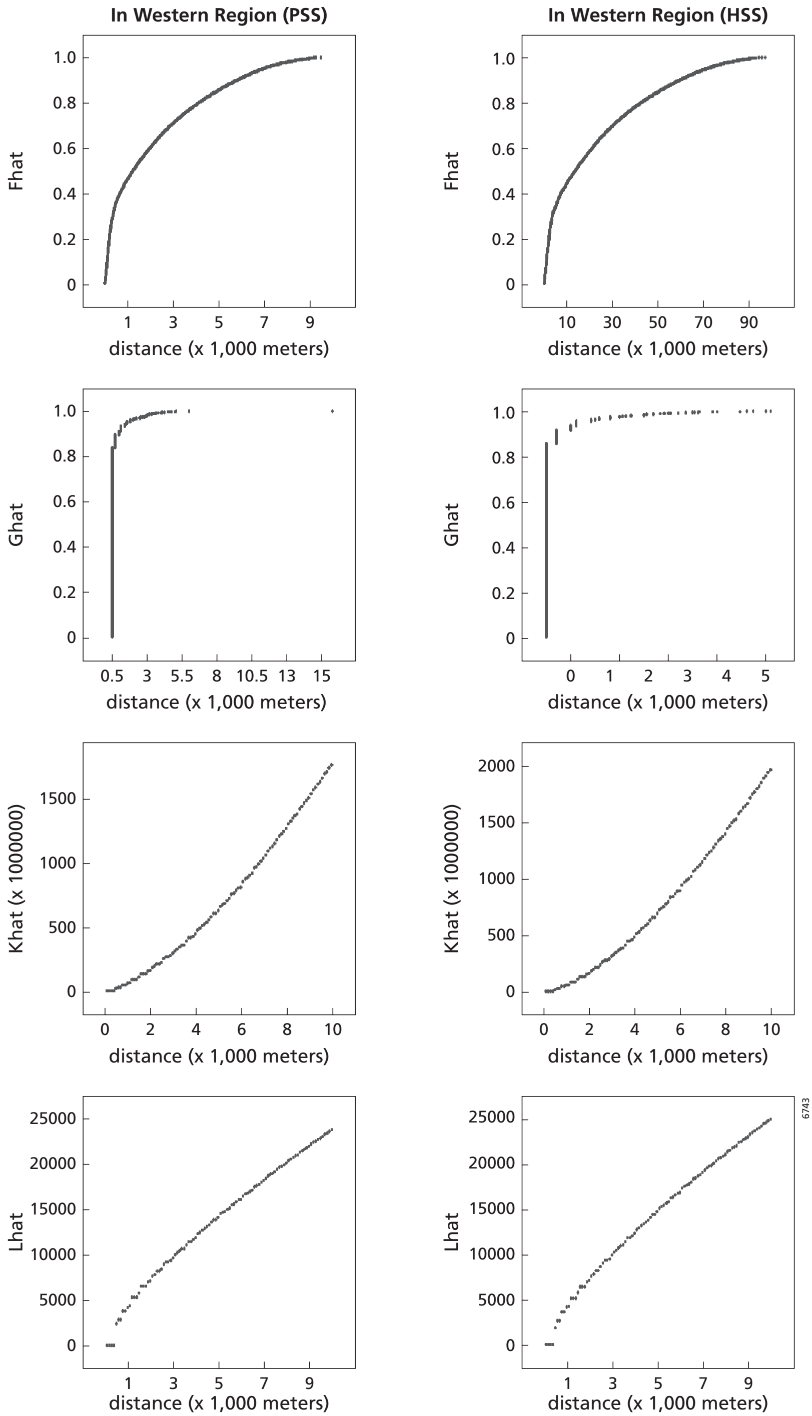

Figure C.4 Second order spatial statistics for Western Region

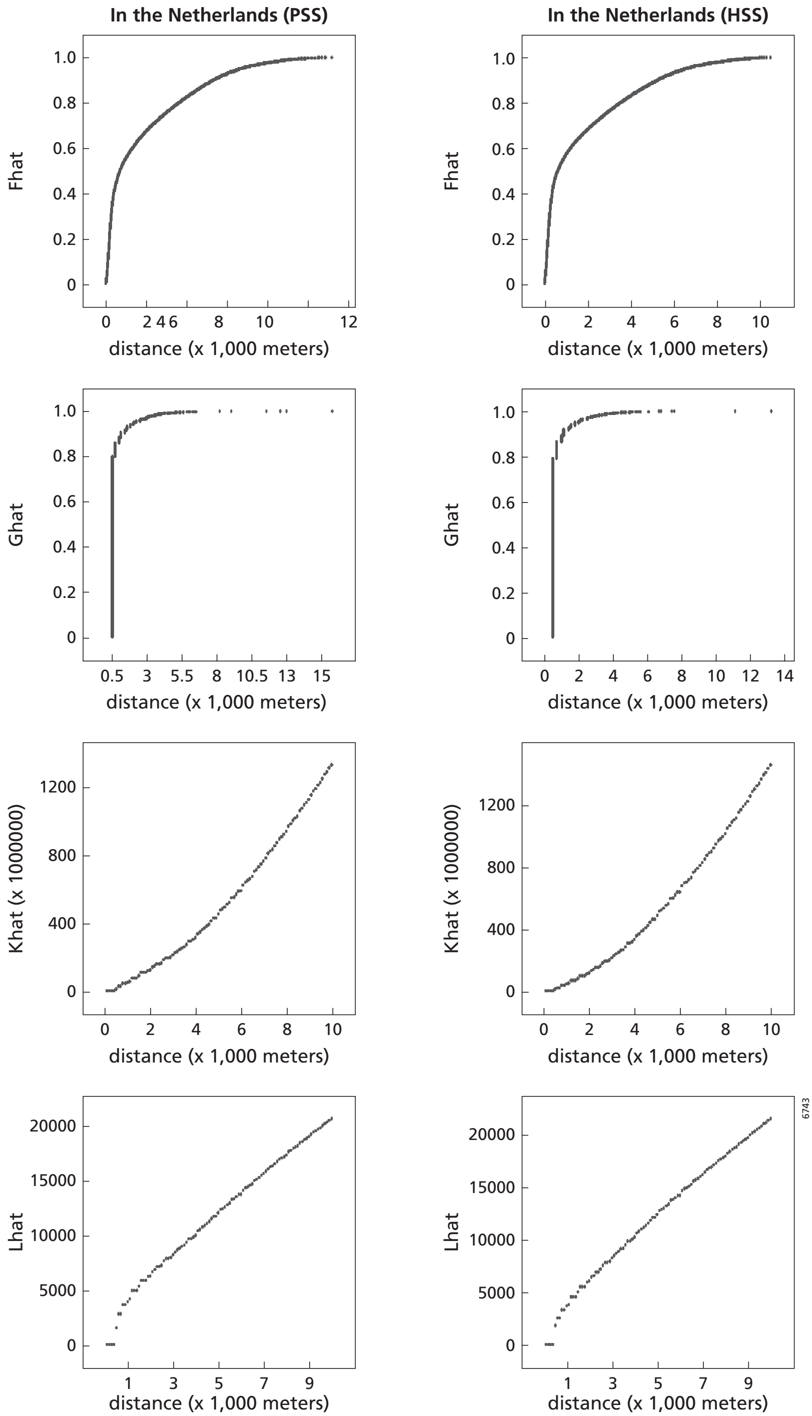

Figure C.5 Second order spatial statistics for the Netherlands

C.1.8 Spatial correlation analysis

Spatial correlation measures the extent to which the occurrence of one feature is influenced by the distribution of similar features in the adjacent areas (Chou 1996).

For computing spatial correlation, Moran's Coefficient is used. The Moran coefficient is:

$$M = \frac{(n/A) * \mathrm{sum}(w[i,j] * z[i] * z[j])}{\mathrm{sum}(z[i] * z[i])} \qquad \text{(Eq. C.3)}$$

Here the numerator sum is over i and j, while the denominator sum is over i.
w[i,j] is the weight for the relationship between observations i and j (zero means no relationship).
A is the sum of the weights w[i,j], and z[i] = x[i]-mean(x) is the cantered variant obtained from x[i].
The Moran measure most resembles a Pearson correlation coefficient, and has as mean 1/(n-1) when there is no association. Here n is the number of rows in x (or, for vectors, n is the length of x).

Permutation distributions are important when computing measures of spatial correlation because the null distribution of the association statistic varies with the spatial lattice size and shape. This variability makes it difficult to provide approximate theoretical distributions, making the distribution of the Monte Carlo estimates all the more valuable. Confidence intervals and tests can be computed from the permutation distribution, as they would be from an exact distribution.

By using Moran's Coefficient, the spatial correlation between existing residential areas and projected low density residential areas are computed as shown in Table C.3. It is clear that not only for whole the Netherlands but also for East, West, North and South Regions, spatial correlation between existing residential areas in 2000 and future allocated residential areas in the PSS in 2030 is higher than the same spatial correlation for the HSS. This means that future residential areas in the HSS are more dispersed than in the PSS. But regional variation in this outcome is established as well.of

Table C.3 Spatial correlation between existing residential area of 2000 and future allocated residential areas in PSS and HSS of 2030

Region with Scenario	Spatial Correlation	Variance	Standard Error
The Netherlands (PSS)	0.7634	4.181e-5	0.006466
The Netherlands (HSS)	0.6896	4.081e-5	0.006388
East Region (PSS)	0.5508	1.537e-4	0.0124
East Region (HSS)	0.5439	1.585e-4	0.01259
West Region (PSS)	0.731	1.296e-4	0.01138
West Region (HSS)	0.727	1.262e-4	0.01123
North Region (PSS)	0.989	2.84e-4	0.01685
North Region (HSS)	0.8225	2.548e-4	0.01596
South Region (PSS)	0.8221	1.669e-4	0.01292
South Region (HSS)	0.5353	1.192e-4	0.01092

C.1.9 Thiessen polygon analysis

Another approach to analyze the s patial spread of future residential areas is to calculate the distance of future allocated residential areas from their nearest municipality's centre. But the distances between the centres of the municipalities were not large enough to get a clear difference of the distances for the PSS and the HSS. In order to overcome this limitation of small inter-municipal distances, Thiessen polygons were computed for the 22 main urban agglomeration centres of the Netherlands. These agglomerations are delimited by Statistics Netherlands and are shown in Figure C.6. Also the polygons computed are mapped.

The distances of new residential areas in both the PSS and the HSS to their respective Thiessen polygons' centres were calculated. This analysis shows that in general the future allocated residential areas have almost equal average distances. But in the HSS there are agglomerations (represented by Thiessen polygons) where average distances are larger than in the PSS.

The average distances of all these future allocated low density residential areas (LDRAs) in both the PSS and the HSS from their respective agglomeration centres are shown in Figure C.7. It is clear that for Nijmegen, Amersfoort, Enschede, Zwolle, Leeuwarden, Groningen, Maastricht, Heerlen, Tilburg, 's-Hertogenbosch, Haarlem and Dordrecht,, the future allocated LDRAs are located further away from their respective agglomeration centres in the HSS as compared to the PSS. For Arnhem, The Hague, Utrecht, Amsterdam and Rotterdam the situation is reverse.

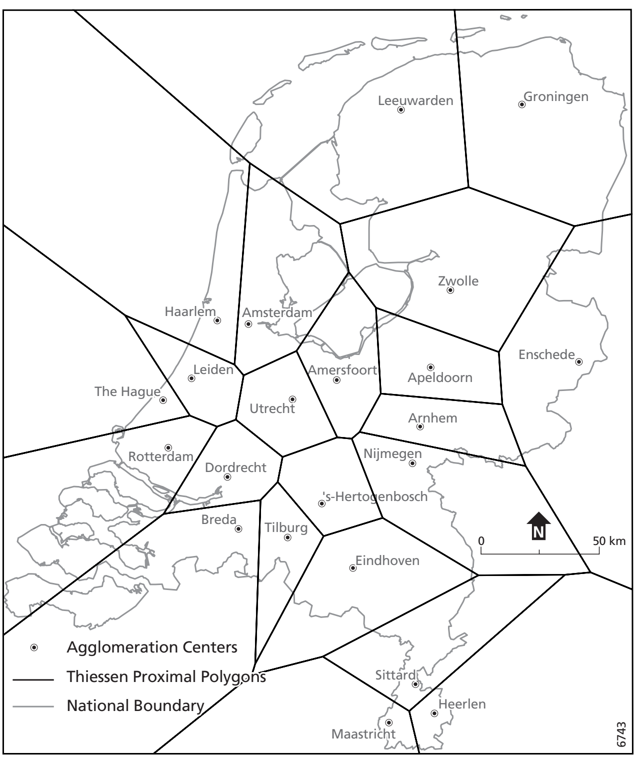

Figure C.6 Thiessen proximal polygons of 22 main agglomeration centres in the Netherlands

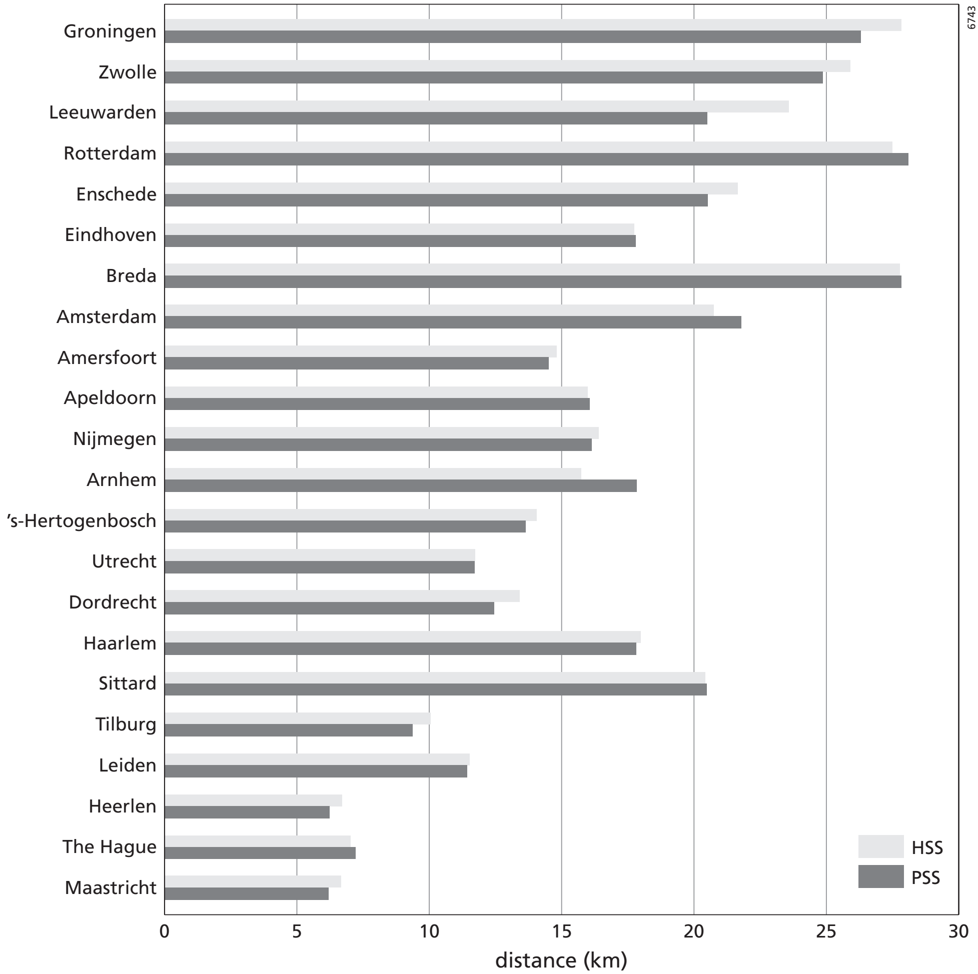

Figure C.7 Average distances of future allocated low density residential areas in PSS and HSS of 2030 from the agglomeration centres

The minimum distances of all new LDRAs in both the PSS and the HSS from their respective agglomeration centres are shown in Figure C.8. It is clear that for the Nijmegen, Groningen,‘s-Hertogenbosch, Breda, Leiden and Haarlem Thiessen polygons, the LDRAs in the HSS are lying at a larger minimum distances from their centres than in the PSS. For Arnhem, Tilburg and Eindhoven the opposite is true.

The results of a comparable analysis of the maximum distances to the centres are shown in Figure C.9. In this case, Enschede, Leeuwarden, Maastricht, Heerlen, and Eindhoven appear to have larger maximum distances in the HSS, while in Arnhem, Zwolle and Amsterdam, the distances in the PSS are longer.

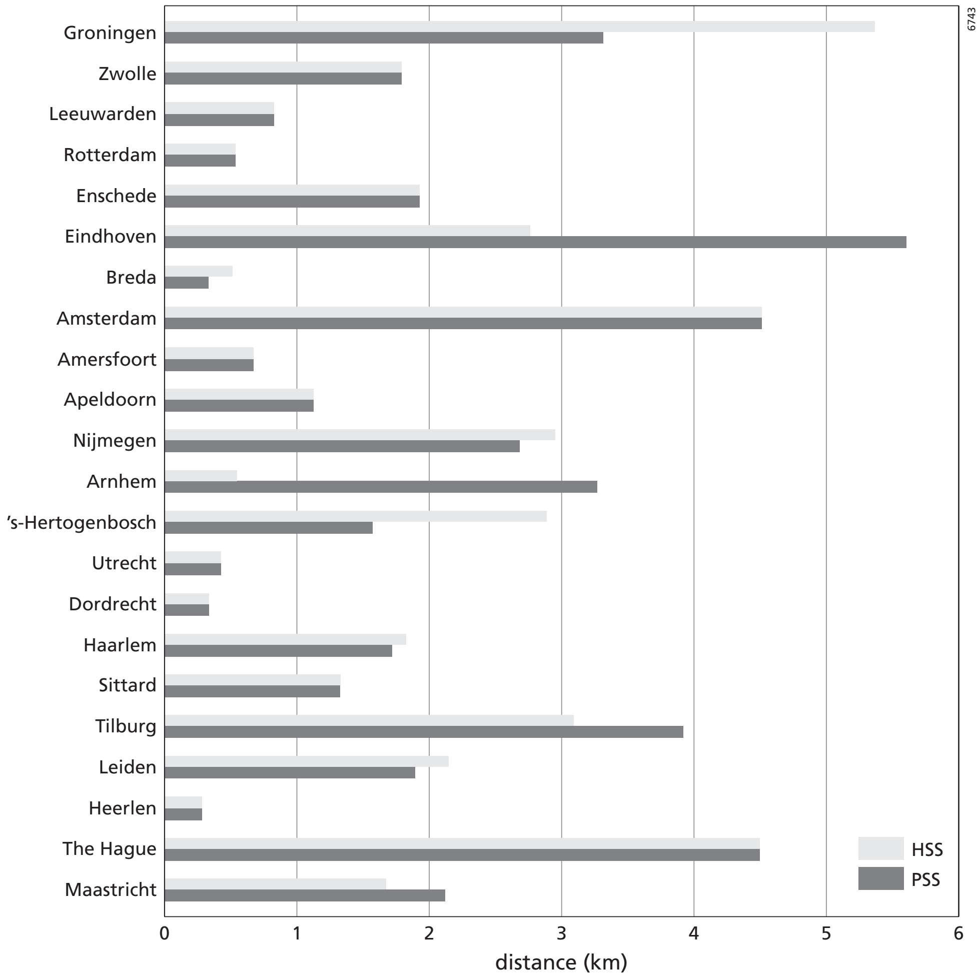

Figure C.8 Minimum distances of future allocated low density residential areas in PSS and HSS of 2030 from the agglomeration centres

When looking at existing and future LDRAs (Figure C.10), their average distances to the centre are larger for the HSS compared to the PSS, but again with same exceptions of Arnhem, Amsterdam and Rotterdam.

C.1.10 Distance of residential areas from main highways

Finally, the spread of residential areas in relation to entry and exit points of highways were computed. The calculated distances are shown in Table C.4.

The results show that new residential areas in the HSS will be more dispersed than in the PSS. This is true for the country as a whole, but also for the four distinguished main regions. Also compared to the situation in 2000, sprawling will increase. The deconcentration is particular strong in the northern and southern regions. However, in interpreting the figures, the

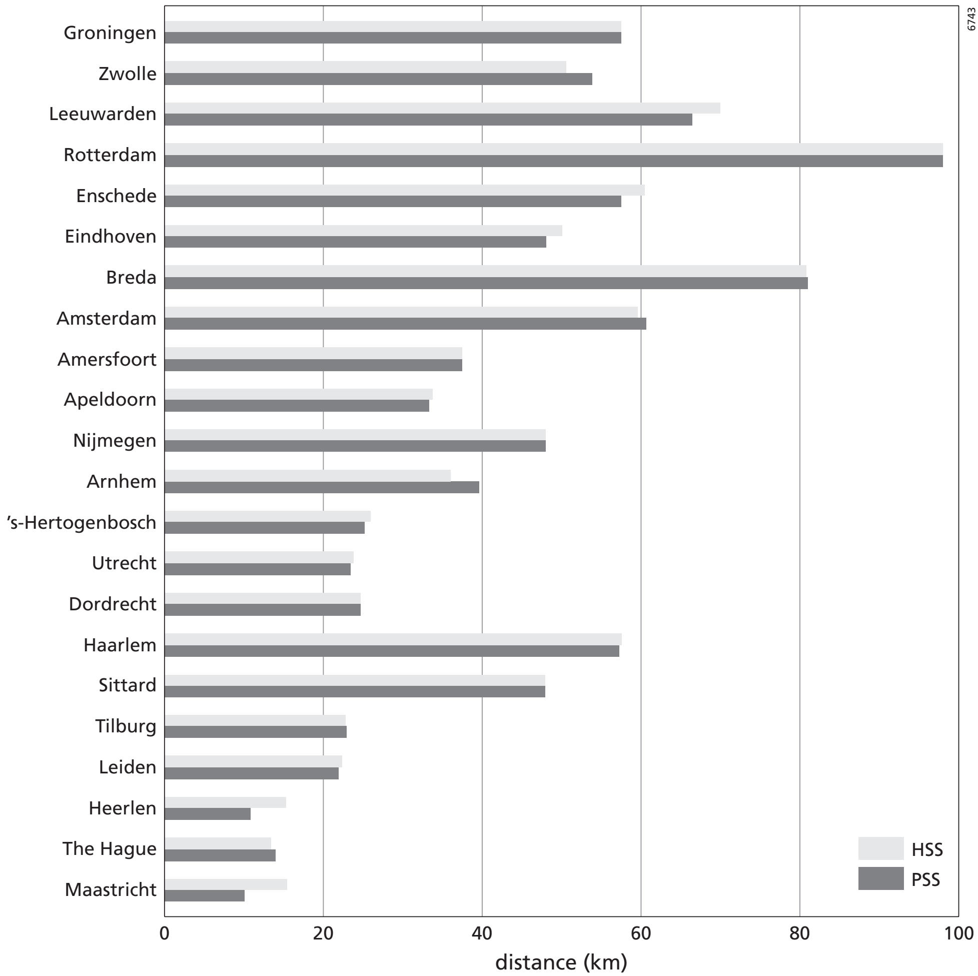

Figure C.9 Maximum distances of future allocated low density residential areas in PSS and HSS of 2030 from the agglomeration centres

road network density should also be taken into consideration. This density is very high in the Randstad area, leading to lower average distances.

Nearly all analyses reported above confirm the hypothesis that an increase in telecommuting, the HSS, will lead to more urban deconcentration. However, regional variations are present. In some areas urban development is a more clustered process, in other areas it takes more clearly the form of urban sprawl. This sprawling is most prominent in the regions with the lowest density, in particular the North Region.

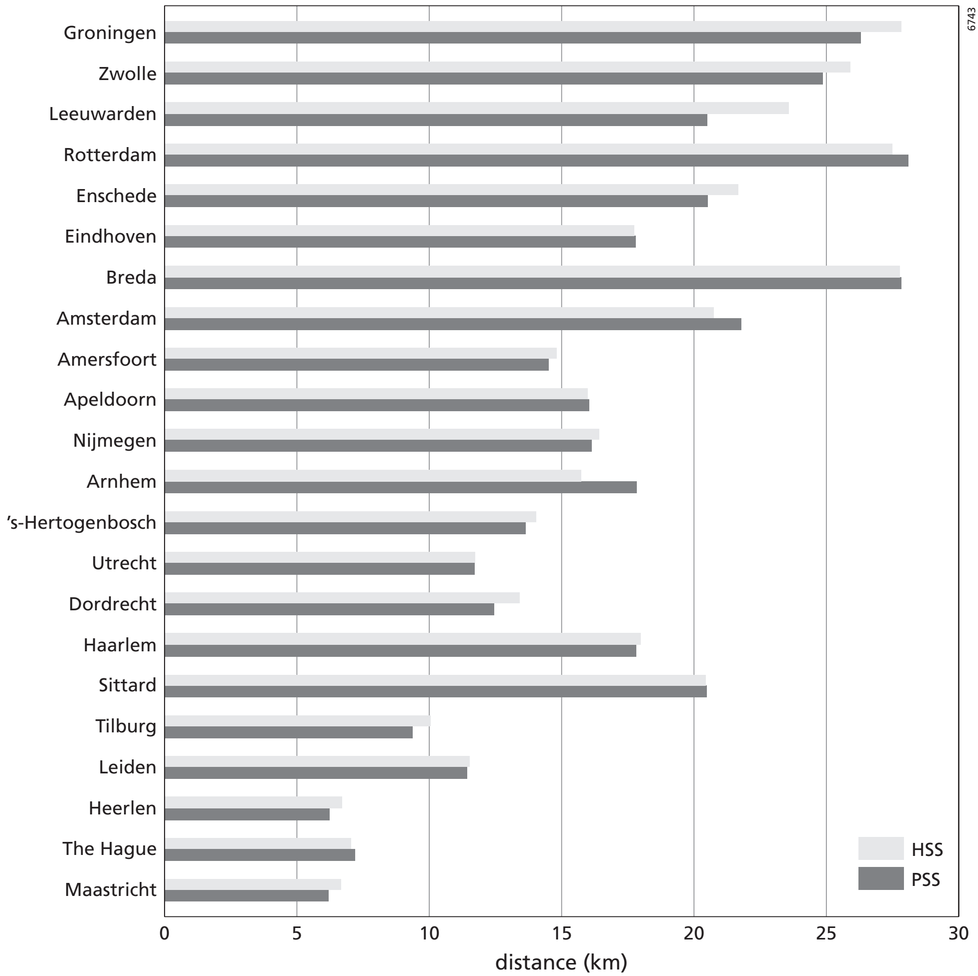

Figure C.10 Average distances of total future (existing plus allocated) low density residential areas in PSS and HSS of 2030 from the agglomeration centres

Table C.4 Average distance of residential areas from main highway (in meters)

Region	Residential Areas in 2000	Future Residential Areas in PSS of 2030	Future Residential Areas in HSS of 2030
The Netherlands	3821	3299	3834
East	3245	3298	3338
West	2953	3118	3155
North	6748	3948	6945
South	3340	3705	4277

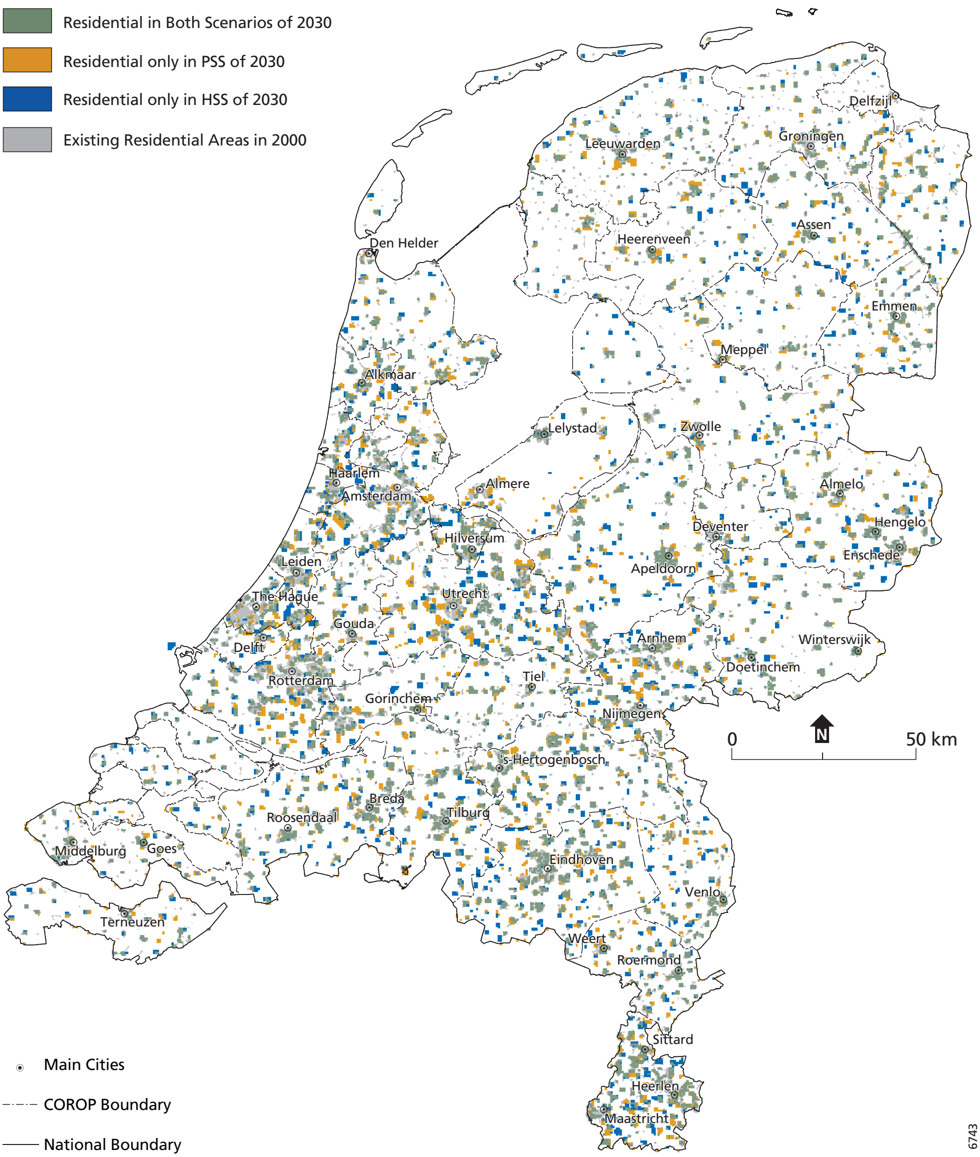

Figure B.6 Differences between future allocated low density residential areas in PSS and HSS of 2030, by Environment Explorer model

Appendix D

Comparison of Residential Areas Projected by Different Land use Models

In order to get more insight into the effects of ICTs, in particular increased telecommuting, on future residential land-use in the Netherlands, the residential areas projected for the Hybrid Space Scenario (HSS) for the year 2030 in this research were compared to the future residential land-use in the Netherlands projected by Borsboom- Van Beurden, *et al.* (2005) using Land use Scanner model and de Nijs, *et al.* (2005) using Environment Explorer model at the Netherlands Environmental Assessment Agency (Milieu en Natuurplanbureau).

Borsboom- Van Beurden, *et al.* (2005) used four scenarios (elaborated in Van Egmond *et al.* (2005): World Competition, World Solidarity, Safe Region and Considerate Region) for the projection of future land use in the Netherlands for 2030. Among these scenarios, the Safe Region closest resembles the European Coordination scenario, the parameters of which were used in this research. Figure D.1 (see page 184) shows the differences between two model applications. Mainly due to different criteria used for determining the future available land for urbanization, there are quite some differences in the allocated residential areas generated by both models. In this study, the forest areas (protected national landscapes) were not considered as potential sites for future allocation of residential areas, while for the Land-use Scanner application, they were available for urban development. As a consequence, for example wooded areas to the north and southwest of the city Apeldoorn become urbanized in this application. This effect can also been seen in the eastern part of the province of Utrecht. The HSS model application allocates more residential areas in the western Randstad region and in the river areas between Gorinchem and Tiel. For the northern region, the HSS scenario model produces a more scattered allocation of residential compared to the Safe Region scenario model application.

De Nijs, *et al.* (2005) projected land use in the Netherlands for a High Spatial Pressure Trend (HSPT) by using the Environment Explorer model. The projected residential areas are also compared with the ones generated using the Hybrid Space Scenario (HSS) and the dedicated model used in this research (Figure D.2, see page 185).

The HSPT model application generates residential land use growth largely around existing residential areas. The new residential areas in the HSS model application have a more scattered pattern. In the Randstad area, in the HSPT application, only the major cities have future residential areas allocated around them. New residential development in the Green Heart area between those sities is very modest. But the HSS-based application projects scattered new residential clusters in the Green Heart. Another hot spot in the HSPT application is the eastern region around the cities of Arnhem and Nijmegen, with concentrated new residential. On the contrary, the HSS model application projects more scattered residential areas in this region and new urban corridor development between Gorinchem and Tiel, south of the Randstad heartland.

The comparisons highlight the way scenario-b ased land-use modelling should be used. By varying assumptions, differences in spatial effects become clearly apparent. This will support discussions and decision making about future spatial planning and policy strategies. The main conclusions of the two comparative analyses presented here is that telecommuting will have an impact on urban development. This impact in general shows more urban deconcentration

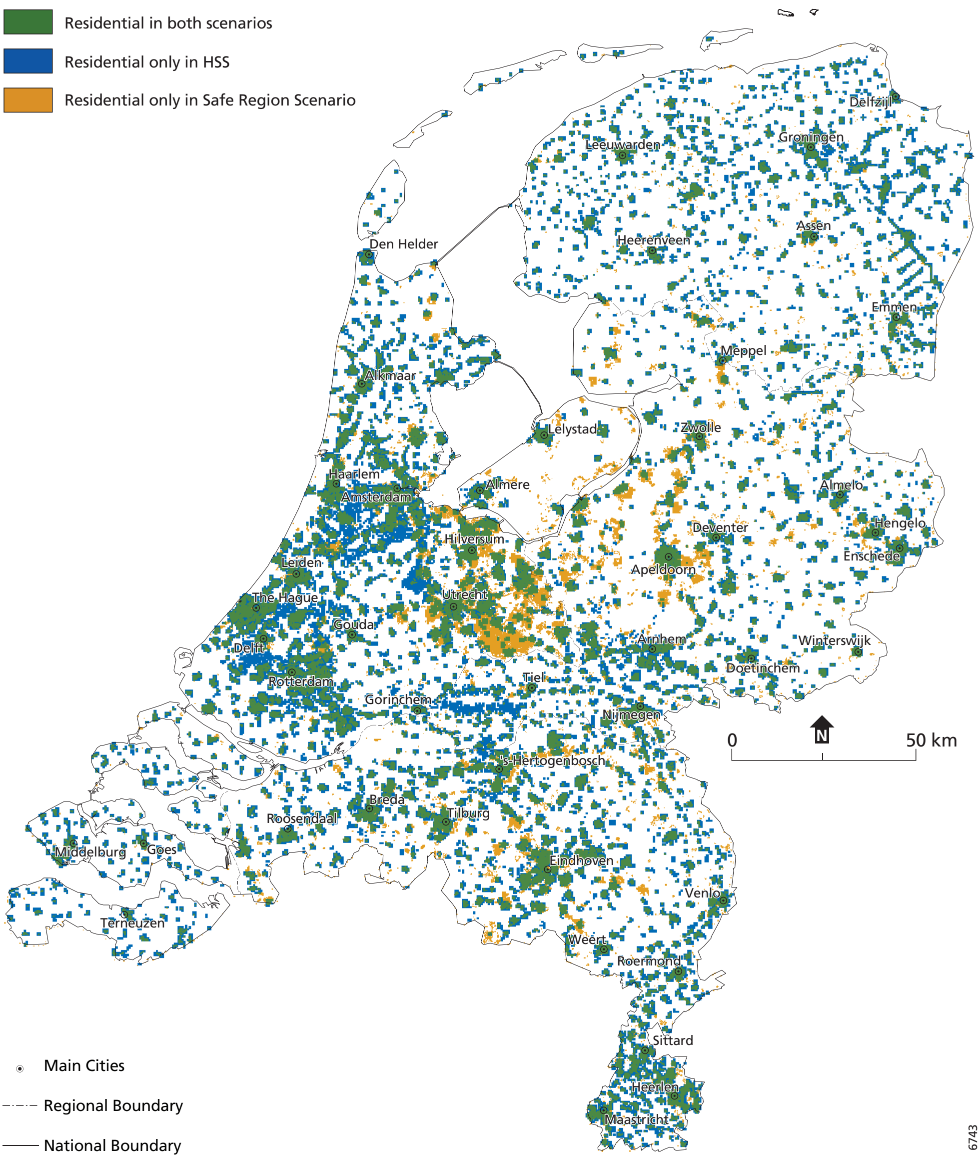

Figure D.1 Differences in residential land-use by Safe Region Scenario and HSS of 2030 and sprawl. On the other hand, well considered spatial policies can control and contain this urban development to balance residential preferences and sustainable development. Further, it is important that regional variations in development and policy impacts should be taken into consideration.

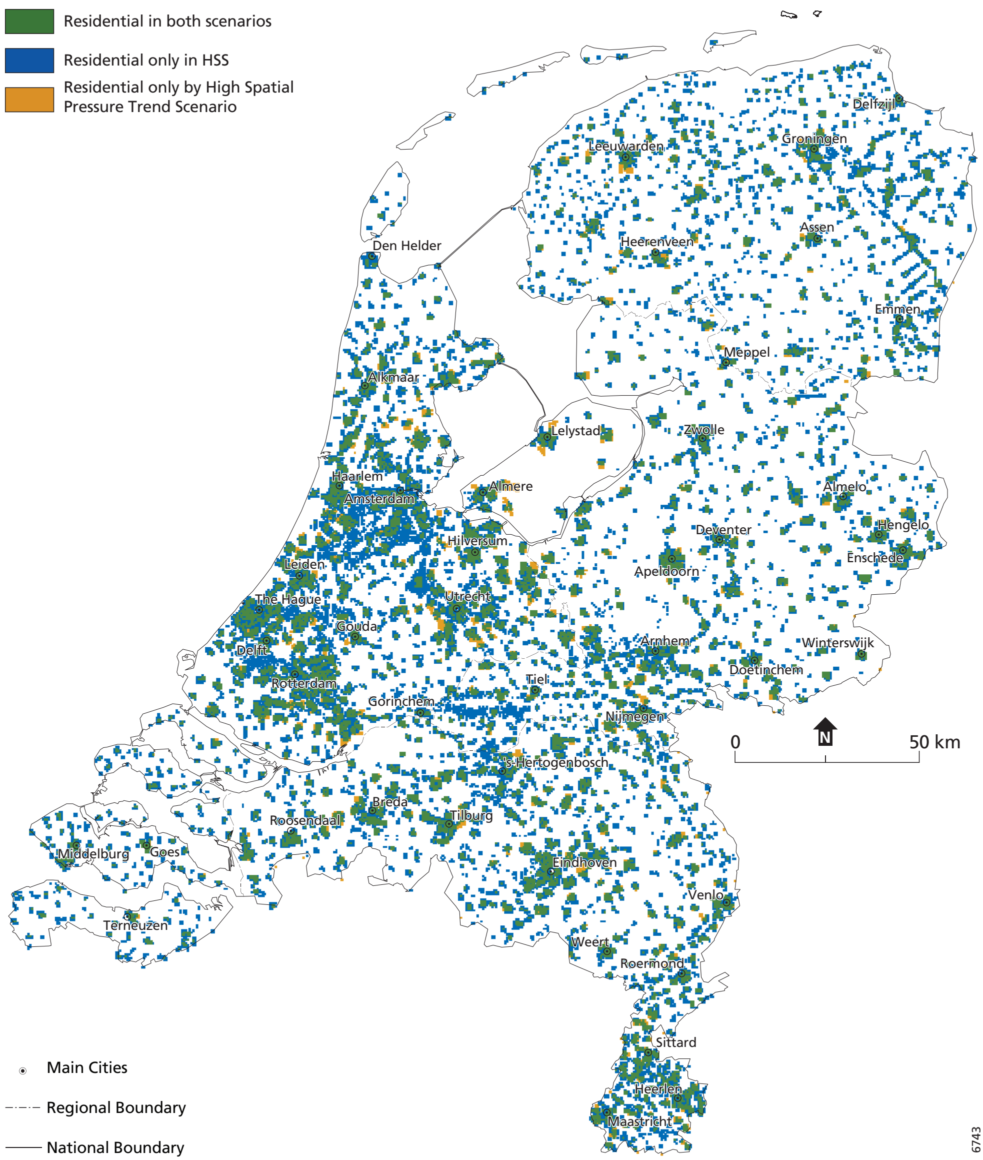

Figure D.2 Differences in residential land-use between the High Spatial Pressure Trend scenario and HSS of 2030

Curriculum Vitae

Saim Muhammad was born on 31 March 1975 in Nankana Sahib, Pakistan. After he was awarded B.Sc. City and Regional Planning in 1998 from University of Engineering and Technology, Lahore, Pakistan, he worked for more than a year as junior GIS and remote sensing scientist at International Water Management Institute (IWMI) Lahore, Pakistan. In August 2000, he came to the Netherlands to follow M.Sc. Geo-information Science course at Wageningen University and Research Centre. After completing that in April 2002, he became a PhD student for four years at Urban and Regional Research Centre Utrecht (URU), the Faculty of Geosciences, Utrecht University. In 2006, after working for a couple of months on an assignment at Netherlands Environmental Assessment Agency, since September 2006 he is working as a scientist at Research Institute for Knowledge Systems (RIKS) in Maastricht. His main interests are development and application of spatially and temporally dynamic decision support systems for urban and regional planning.