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# Towards accessibility planning by means of GIS

## A case study on the access to potential job opportunities by three transport modes

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## Abstract

Over the last decades our global society has been highly influenced by automobility planning. Growing mobility has been seen as an indication of a well-functioning transport system and a society with increasing welfare. Excessive mobility can at the same time lead to urban sprawl, longer travel distances and travel times as well as other problems that can be associated with lower welfare. A planning policy more focused on accessibility, i.e. siting new locations of activities that can be easily reached by other transport means than car, can reduce the size of some of the transport problems. The concept of accessibility should therefore gain more attention since it is believed that it cannot have a negative connotation.

So far it has been difficult to measure accessibility in the right way. Some indicators are so over-simplified that they are misleading, others are so complex that they are difficult to grasp. Geographical Information Systems (GIS) provide a favourable working environment since transport data are spatial in nature. The first aim of the study is to measure accessibility between home and work by comparing the transport modes car, bicycle and public transport in Växjö city, Sweden. GIS is used throughout the analysis. A second aim is to discuss if the results can be used in the municipal planning process. Thirdly, the question of costs involved in this analysis are discussed.

Approximately 150 irregular areas, so called statistical districts, within the city border are investigated. Digital road networks are used for all the three transport modes car, bicycle and public transport. A model based on street types determines the travel speeds by car. The bicycle speed is set to 17 km/h. The bus speeds are determined by travel time, walk time and transfer time. The accessibility is a measure of the number of job opportunities that can be reached from each residential area within a certain amount of time. The definition of a job opportunity is a place of employment, vacant or not, in a company. Most results are maps showing either the general accessibility for the different transport modes or a more focused analysis of one residential or commercial area.

The results indicate that the accessibility to job opportunities by bus in Växjö is relatively low compared to bicycle and car. This is a result of long walking and waiting times as well as long transfer times. The bus frequency is also of great importance. Bicycle, on the other hand, has a very high accessibility compared to the car as long as the commuting distance is below 5 km. However, this requires well-maintained bicycle paths and a dense network.

A quantification of this quality measure, the  $AT_{50}$  (Accessibility Time at 50%), which shows the time it takes to reach 50% of the job opportunities, is proposed. This measure has a potential of being a quantitative environmental indicator. The maps can be used both for visualisation of the present situation and to present planning alternatives and simulations. Environmental Impact Analyses, EIAs, can also gain from simulations of accessibility. In conclusion, these accessibility measures are a step in the right direction. Further studies are needed to verify the results as well as the presentation of maps and measures. Eventually, this will hopefully lead to practical tools that can be used in urban planning.



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# 1 Introduction

The main task for transportation systems is to reduce geographical barriers, which makes the concepts of accessibility and mobility central. An increasing mobility has traditionally been seen as an indication of a well-functioning transport system and a society with increasing welfare. However, excessive mobility has led to urban sprawl, longer travel distances and travel times as well as several other problems that can be associated with lower welfare (SIKA 1999, Ross 2000). Accessibility has therefore gained increased attention as a complement to the more traditional mobility-based measures of performance in transport planning. Transport policy is increasingly focused on promoting sustainable transport schemes and shifting dependence from the private car towards public transport and pedestrian-friendly planning. From a global as well as a Swedish perspective the transport sector is the one with the largest increase in energy use and carbon dioxide emissions. In Sweden, this sector is responsible for more than 40% of the carbon dioxide emissions, the global average is 25% (Steen et al. 1997). Moreover, transports do not only create air, water and noise pollution but also negatively affect our public health and socio-economic society in several ways.

According to several researchers (Owen 1986, Lamm & Görling 1996, Book & Eskilsson 1998 and others) strong evidence indicates that changes in the city structure – the location of built environment and activities – are the fundamental causes to a change in car traffic related problems. With a planning policy more focused on accessibility, i.e. siting new residential areas, businesses and services in locations that can easily be reached by public transport or bicycle, and not only by car, the size of some of the transport problems can be reduced. This kind of policy has to be implemented mainly on a local level, but will hopefully have positive effects with global proportions in the future.

So far, the Netherlands has been leading the way in giving equal emphasis to accessibility and mobility (Tolley & Turton 1995). Dutch planners create mobility profiles for new companies by defining the amount and type of traffic likely to be generated, as well as classify each city into regions of different accessibility levels. For example, high accessibility marks are given to service areas where public transports and biking paths are well developed. Warehouses and large industries with only a few employees, on the other hand, are assigned low marks and should be built in more remote areas that can be conveniently reached by motor vehicles (Ministry of Housing 1997). This Dutch accessibility planning has been adopted by the United Kingdom as the basis for its Planning Policy Guidance 13. According to Newman & Kenworthy (1999) the system is used as guidance rather than as a statutory plan in both the Netherlands and the United Kingdom.

The Swedish government has over the last few years also realised the importance of accessibility; hence the concept is one of five major transport political goals (Swedish Government 1998). However, it has been difficult to measure accessibility in the right way – some of the indicators used are so over-simplified that they can be misleading, others are so complex that they are difficult to understand (Höjer 1998). These problems have made it difficult for politicians to grasp the importance of the concept (Cervero et al. 1998). Geographical Information Systems (GIS) provide a favourable environment for the modelling of accessibility, since transport data are inherently spatial in nature. This study attempts to investigate one measure of accessibility on a local planning level in a different manner, resulting in easy-to-grasp maps.

## 1.1 Objectives and scope of the study

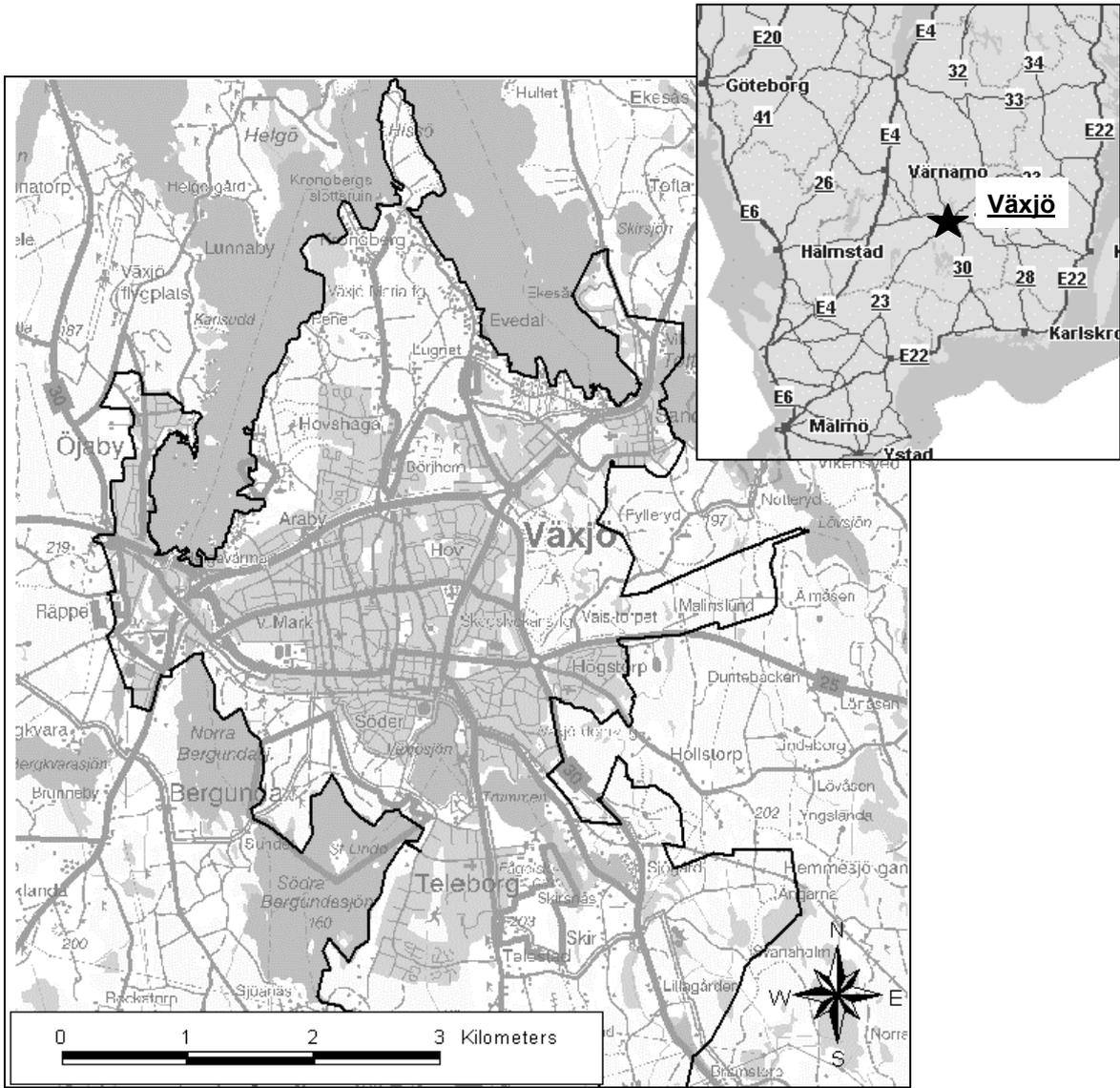
The aim of this study is to measure the accessibility between residential areas and working areas in an average-sized Swedish city using GIS. In one of the cases, the accessibility will be a measure of the total number of job opportunities that can be reached within a certain amount of time from about 150 areas within the city border of Växjö city, Sweden, comparing the transport modes car, public transport (bus) and bike. The definition of a job opportunity is a place of employment, vacant or not, in a company. The output will be maps of various types, which are easily interpreted for decision-makers and laypersons.

As far as the literature review shows, such an extensive comparison of accessibility between different means of transportation has only been partially performed in Sweden before but never implemented in spatial planning. The second aim is therefore to discuss if the results of the case study can be used as a part of the planning process. Is the result only interesting from a traffic planning point of view, or is it also of interest for urban planning? Thirdly, the question of cost is an interesting issue when working with GIS. Is it feasible to perform this type of analysis or is it too time-consuming for the municipality or a consultant company?

## 1.2 Limitations

The focus will be on potential work trips in Växjö. The boundaries of the study area are shown in Figure 1. The type of trips has been chosen since they are so called *forced* trips (Steen et al. 1997). They occur more or less daily and are often thought of as strenuous. They are not as *wanted* as recreational or vacational trips that often are associated with a pleasant and relaxing time. Work trips are also the group of activities that costs most in terms of transport time. According to the same authors, they account for 50% of the short trips, whereas service trips only attribute to 20% and recreational trips 30%. Generally, the forced activities have a larger possibility to be carried out with other transport modes than the car, while activities with greater flexibility in time and space generate higher car dependence. Women use the car in about 50-60% of all trips regardless of the purpose of the trip. The corresponding number for men is 70% (Steen et al. 1997).

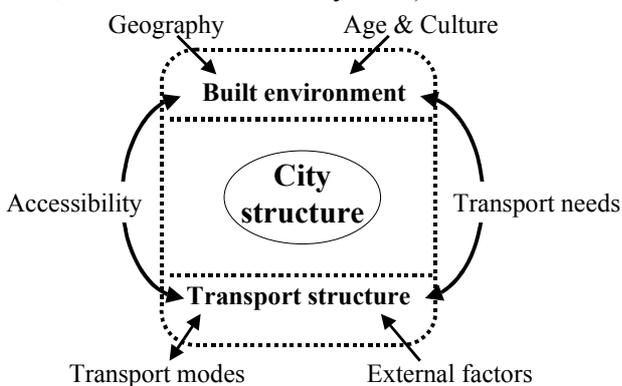
Several generalisations must be taken in this case study. For instance, when dealing with bicycle accessibility the issues of biking at night, in rain, in winter time etc. will not be taken into account. The same applies for bus trips, which many people believe take longer time than they actually do. In other words, this study only assesses the actual time aspect, without individual preferences or beliefs. In the study it is also assumed that all trips are carried out straight from home to work without taking any stops, such as grocery shopping or leaving children at day care centre, into consideration. Furthermore, a railway runs through the city centre. A couple of streets, where there are railway crossings, are therefore blocked for a few minutes at several occasions daily. This barrier has not been taken into account, since it only occurs a few times a day. The largest generalisation made, however, is the actual choice and background each individual has. Two people in the same place may evaluate their accessibility differently, as wants, possibilities and tastes vary (Handy & Niemeier 1997). For instance, a person may live very close to a large company, but if he does not have the skills or education to qualify for those jobs, then they are hardly accessible to employment. These socio-economic differences over the city have not been considered. Nevertheless, adding too many factors can lead to results that are more complex where more uncertainty has been added. These are the main reason to keep the study on this level, by showing the *de facto* situation of potential work trips.



**Figure 1.** The study area Växjö city, Sweden, and the location in the southern part of Sweden.

## 2 Planning, accessibility and mobility

Age, geography and culture are often the initial factors affecting the built environment (Figure 2). Once the city environment is set, it can influence the transport structure in many different ways, and vice versa. The occurrence of nodes (i.e. service areas and job locations), their locations and positions are also very important to the transport structure as they generate movements. When a certain activity cannot be undertaken without movement of people or goods a transport demand arises. The size of the demand depends on the physical city structure as well as the distances that are generated (Reneland 1998a). Owens (1986) quantifies the shape of the city to affect the transport volume with  $\pm 20\%$  while the location of activities affects the volume with  $\pm 130\%$ . In a traditional city there is a main centre where most activities are located, creating a radially shaped transport network. In cities built on rail or car dependence, on the other hand, decentralisation and sprawl create dispersion of locations and movements (Book & Eskilsson 1998, Newman & Kenworthy 1999).



**Figure 2.** Relations between built environment and transport structure (Adapted from Book & Eskilsson 1998).

This reasoning gives rise to two very important concepts in urban and traffic planning: accessibility and mobility. The *accessibility* is here defined as a potential quality to reach different activity choices (i.e. job, stores, school, day care centre, recreation etc.) from a certain origin (usually home) with different means of transportation and at a certain time of day. Accessibility deals in other words with distance and time and is controlled by the urban structure as well as the location of the investigated household or business (Vägverket 1999b). *Mobility* is, on the other hand, a measure of an individual's resources to move, i.e. age, sex, health, economy and access to driver license and car. In a physical sense, mobility is an index on how easily an individual can move (Hagson 1997). Mobility is easy to measure (vehicle kilometres travelled, vehicle occupancy, passenger kilometres, traffic speed, vehicle ownership) and has frequently been used as a welfare indicator. Accessibility is a lot more difficult to define and measure than mobility:

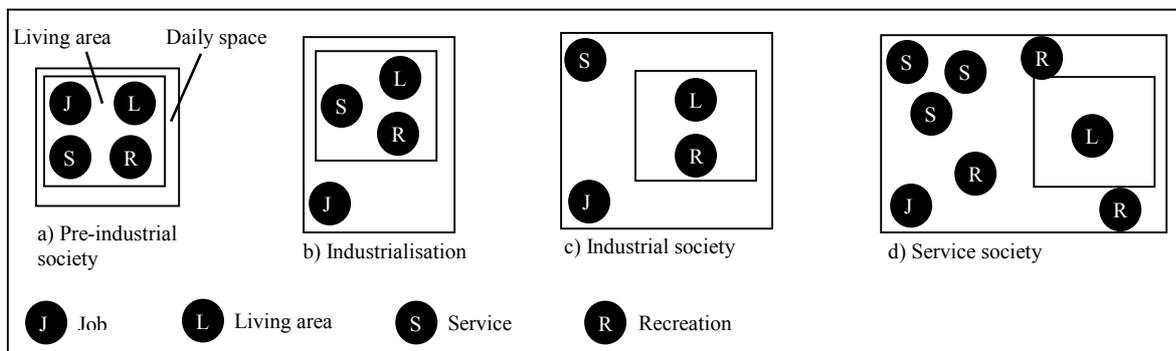
*"percieved costs are subjective; public transport frequency and travel time change during the day; and some variables, such as residential density, public transport level of service, and modal split, are not independent of one another. It becomes apparent that accessibility is not a concept which can be directly measured, but rather one which can only be quantified, or indicated, in terms of other variables."*

*(Ross 2000, p.14)*

Although difficult to measure, accessibility needs to be quantified and used as a tool in spatial planning. As will be shown in the following chapter, too much dependence and focus on mobility measures can have a negative effect on our entire society.

## 2.1 Transport policy affects landuse planning

During the 20<sup>th</sup> Century there has been a massive expansion in mobility in Sweden as well as in other industrial countries. One indicator of this is that the average person travels about 40 km per day compared to only a few kilometres in the beginning of the century (Vilhelmson 1997). Figure 3 shows the transition from the pre-industrial society, where distance was the major friction, to the present service society. At first, population and building density were high and there were few unutilised areas within the urban body. The home was usually also the space for recreation and work. With the industrialisation, rail traffic grew. The daily space expanded and enabled separation of residential and work areas. The service society we live in today is characterised by high mobility, geographical flexibility and growing traffic. Cities have grown larger and wider and suburbs are more common (Steen et al. 1997). According to the Swedish Road Administration (1997) the trend indicates that the geographical expansion of the daily room and the private car traffic will increase with about 30% between 1998 and 2020.

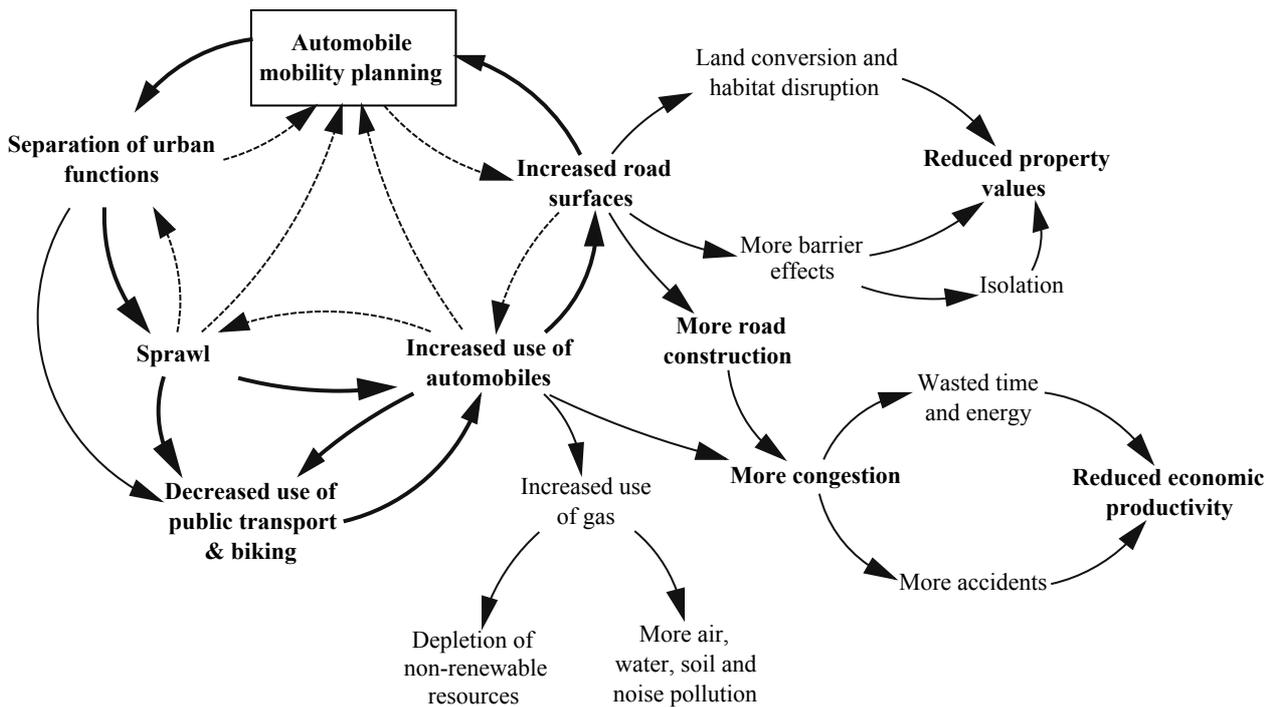


**Figure 3.** Activity location a) in the pre-industrial society, b) during the industrialism, c) in the industrial society and d) in the service society (Adapted from Wårneryd 1990). The smaller box represents the living area and the large the daily space.

Despite much cleaner automobiles over the last decade air quality has only improved little. This is because the technical improvements have largely been saturated by the growth in number of vehicles and miles driven (Bernick & Cervero 1997). Even if the Swedish cities, in an international comparison, are not very dispersed today, one should be aware of the mechanisms and the driving forces that can be in operation. Sprawling and increased car travelling can occur gradually by many small decisions in urban and traffic planning. The positive effects of such planning are a better living environment and also a growing quality of life for many people (Steen et al. 1997).

On the other hand we have larger energy use, more emissions and noise, health issues as well as other problems (Figure 4). The development can be described as a spiral process where increasing mobility in the majority of the population gives new prerequisites for development of residential areas, service and jobs (Berge et al. 1992, Höjer 1998). These new developments are then gradually adapted to further increasing travel possibilities (Hillman & Pool 1997). Reorganisations and closures of various activities, e.g. post offices and hospitals, are partially motivated for the same reasons. The physical distances grow and give rise to demand on further individual mobility and so forth. Public transports and biking loose even more attraction. Stores and services that are moved from city centres to more peripheral locations are an example of this phenomenon that creates more traffic and energy consumption (Vilhelmson 1997, Hagson 1999). Suburbanisation occurs, which only enhances the need for a car (Newman & Kenworthy 1999).

The consensus is that all these effects increase socio-economic costs, ultimately affecting everyone. The goal of any transport system is therefore not mobility, but access to facilities (O’Sullivan et al. 2000). Automobility planning works on the *supply side*, aiming to increase speed and ease for the individual and his or her movement (and thus producing more energy consumption and emissions). Accessibility planning, on the other hand, emphasises *demand management* on a community level by creating places that reduce the need for travelling, which helps conserving resources, protecting the environment and promoting social justice (Cervero 1997). This is verified by Ross (2000) who shows that there is actually a strong negative correlation between mobility and accessibility. The latter is always seen as making a positive contribution to a community, and should therefore be used in the planning process as a welfare indicator.



**Figure 4.** Some of the negative effects that often arise in short-term automobile-dependent mobility planning.

Another troubling effect of an increasingly auto-dependent society is that those who prefer or are in need of other transport modes than the car will find it more and more difficult to reach jobs, service and recreation. Entire residential areas can also become isolated (Figure 4) due to the barrier effects (Bernick & Cervero 1997, Reneland 1998a). In Sweden, the National Road Administration and the National Board of Housing, Building and Planning state that the accessibility for children, handicapped and elderly is poor. For example, 75% of disabled people have problems moving themselves to and from public transits and children are often driven by car to school (Vägverket 1999a, 1999b). Moreover, of all Swedish families with two or more children, around 98% have access to a car in the household (approximately 95% of the men and nearly 90% of the women in these households have a driver license). The number for single mothers is about half as high (Krantz 1997). In 1997 about 83% of the Swedish population had access to car (SCB 1998). In addition, there are an unknown number of people who do have access to a car within the household, but who rarely use it because they do not have a driver license, someone else uses the car or because they do not find car driving attractive.

Regarding trips to work, nearly half of all women go by car (41% as drivers, 9% as passengers), 18% bike, 16% use public transport and 13% walk. The corresponding numbers for men are that 69% go by car (of which 4% are as passengers), 14% bike, 8% walk and 7% go by public transport (Krantz 1999). Considering that 40% of the working force in Sweden has less than 3 km to work and 65% of the population has not more than 850 m to the nearest grocery store (SCB 1993, Sandqvist 1997) it should be quite easy to bike or walk instead of using the car. Moreover, 75-85% of the Swedish population has access to a bike, so there is potentially a large number of people who can switch transport mode and become bikers (Bergman 1994). In national as well as local action programmes, such as Agenda 21 plans, it is clearly expressed that a continued dispersion of built areas, external location of living, work, service and recreation together with a growing number of traffic routes do not coincide with long-term goals or visions for a transport light environment (Hagson 1997).

## 2.2 Is there a solution?

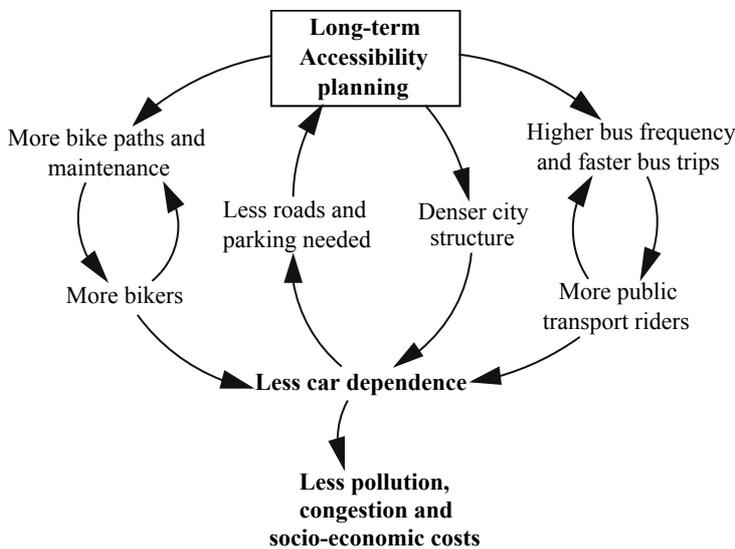
The core of traffic planning is located on the local level, where the main issue is to create a well functioning traffic system that is quick, efficient and environmentally friendly. This should apply for all transport modes, for both public and individual traffic, for both personal and goods transports, for both low- and high-income earners, as well as for both women and men. Some researchers (Hagson 1997 and 1999, Snickars 1997) believe that a paradigm shift is needed to solve this massive problem that an auto-dependent society creates.

In spatial planning, a mixture of solutions is needed. If planning is performed with long-term goals and with a focus on a more compact urban structure, public transports and biking (Figure 5) we are well on our way to a shift in paradigm. Instead of creating new roads, suburbs and parking areas, which only allow further car dependence, the existing urban space should be used more efficiently. According to Hagson (1999), some important strategies of accessibility planning are:

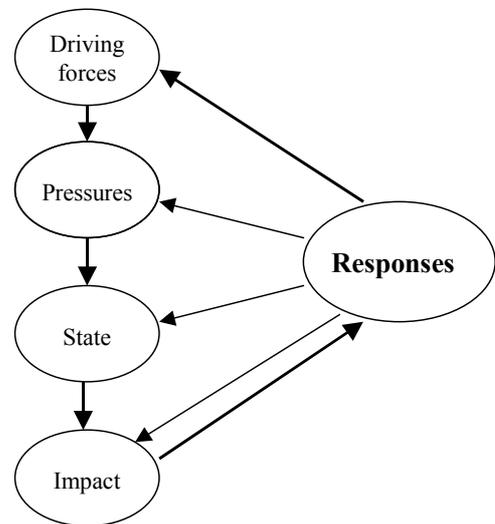
- all transport modes must be equally valued;
- do not use mobility (how much we travel) but accessibility as a measure of standard and welfare;
- improve accessibility for people without car – especially the elderly, children and disabled;
- mix urban functions (homes, jobs, service and recreation) instead of separating them;
- offer pedestrians and bikers a traffic environment with as high standards as the one offered to car drivers;
- make sure that all plans and decisions concerning land use changes take pedestrians, bikers and public transport into account as well as create conditions for reduced car traffic.

With growing bike path networks and public transport networks (Figure 5), there will be less pollution, health problems and congestion, a nicer and safer urban environment, and the socio-economic costs for both the society and the individual will be reduced. Accessibility will continue to increase and people need to travel less and shorter. While automobility planning focuses on *saving time*, accessibility planning focuses on *time well spent*. Moreover, we all know that we do not always *save time* when travelling by car due to congestion and other traffic hinders.

To enable this transition towards a more sustainable society it is necessary to control and supervise the progress. The Swedish Government has in year 2000 adopted an internationally accepted model called DPSIR (Figure 6). This model has been developed within the European Union to provide environmental information and describe the interactions between various factors affecting the environmental status. The driving force (D) shows what activities (for instance transports) that give rise to an environmental problem. Pressures (P) describe what causes the problem (e.g. emissions and deposition). State (S) shows how the environment has been affected (e.g. pH in lakes). Impacts (I) describe the consequences on health (e.g. number of cancer cases), cultural environment (e.g. corrosion), biodiversity (e.g. number of threatened species), socio-economics (e.g. lost forest production due to emissions) and recreation (for instance poor fishing waters). The responses (R) are the measures taken to reduce or solve the environmental problem (e.g. air quality restrictions). The DPSIR model is hence used as a tool to assess sustainability. Environmental indicators are one way of keeping track of a city's or a region's environmental and sustainability status. They help policy makers to plan for the environment and should be updated regularly (SOU 2000).



**Figure 5.** An accessibility-based approach. When the accessibility grows in a city, due to a more compact planning structure and shorter trips, car riders can switch to biking or public transport. In the long run, the socio-economic costs will decrease.



**Figure 6.** The DPSIR model. Driving forces – D, Pressures – P, State – S, Impacts – I and Responses – R.

### 3 Measuring accessibility with GIS

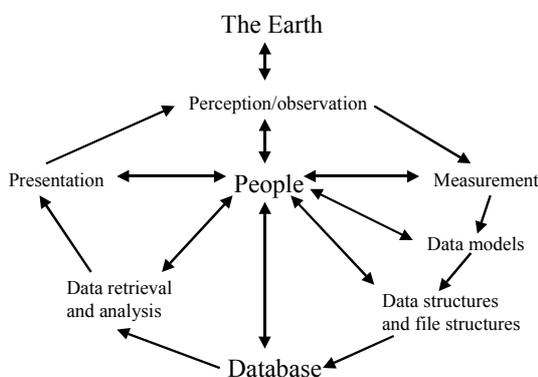
The effects of infrastructure investments on accessibility have up to now been shown to a very small extent in Sweden. Some of the reasons have been discussed in Chapters 1 and 2 and others are (Inregia 2000):

- the distinction between different alternatives is often so small that the effects are hard to illustrate;
- the easily understood accessibility measures can give a much too simplified message and may be misleading and misused;
- some of the more developed measures are intuitively difficult to understand and therefore tough to communicate to decision makers and;
- it has been time consuming to produce accessibility descriptions.

With the help of GIS, some of these issues can be solved. In order to understand how, a short introduction of GIS is at hand.

#### 3.1 Introduction of GIS

Although a relatively young working method, GIS has been defined in numerous ways. One definition used by Burrough & McDonnell (1998) is that a GIS is a “*powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes*”. The geographical (e.g. spatial) data are defined by a) positions with respect to a known coordinate system, b) attributes (such as colour, cost, pH etc.) and c) the spatial interrelations, which describe how the data (points, lines or polygons) are related to each other (known as topology). Several researchers also think of the GIS as a platform to add functionality to a specific problem (Berglund 1998). Furthermore, people need to be involved in all steps of the GIS process (Figure 7).



**Figure 7.** All aspects of dealing with geographical information involve interactions with people (Adapted from Burrough & McDonnell 1998).

With a GIS, large and complex datasets can be simplified, analysed and presented to decision-makers in a simple way that is easy-to-grasp. It also provides a highly interactive environment for editing and updating data. The results of the GIS are most often implemented somewhere between the first detailed studies and the political decisions. The GIS analysis can be a part of the preparations for a planning issue, with a specific task of presenting the geographic relations or the consequences of a decision (Hillman & Pool 1997, Eklundh 1999).

### 3.2 Overview of similar studies

Handy & Niemeier published in 1997 an article that discusses various measures of accessibility and how they should be implemented practically. According to the authors, distance or time in accessibility analyses can be estimated by straight-line distance, network models, field surveys of actual driving times, or field surveys of the perceived travel time. If travel time is used, one has to choose between uncongested (off-peak) times or congested (peak) times. Typically, accessibility is also measured from different zones of the investigated area. The smaller the zone, the greater the disaggregation. Smaller zones should thus result in more accurate estimates of accessibility for the individuals and the households in the zone. Handy & Niemeier (1997) also refer to two counties in the United States that are trying to implement accessibility into their planning processes. Santa Clara County, California, has measured accessibility as the percentage of the employed population in a zone within 20 minutes of employment activity comparing four different transport modes. Montgomery County in Maryland has performed a similar but extended study.

In recent years, the department of Urban and Traffic Planning at the Chalmers' Technical University in Gothenburg, Sweden, has created a very extensive GIS to illustrate the changes in accessibility between 1980 and 1995 in Swedish cities with more than 20,000 inhabitants. The database has enabled descriptions of the walking distance accessibility to shopping, private and public services and recreation. All studies investigate the distances from housing areas to certain destinations based on air distance multiplied with a factor of 1.3 to correspond to a theoretical real distance (Reneland 1998b, 1998c and 1999). In the year of 2000 Reneland has published two similar studies. These are, however, based on a digital version of the road network, which is more accurate than using a theoretical distance (Reneland 2000 a and b).

Another large Swedish study has been performed by Inregia AB (2000). This investigation examines both 'real' and 'potential' accessibility measures on a regional and national level for trips between job and home and from different cities and regions to Stockholm or other regional centres. The transport modes examined are public transport and car. A digital road network has been used. Real accessibility is measured in travel time or cost whereas potential accessibility is a measure of how many destinations you can reach within a certain amount of time. Inregia AB has come to the conclusion that 'real accessibility' is less appropriate than potential. The main reason is that families can move a little bit further out of the city to find a less expensive and safer neighbourhood for their children to grow up in. This makes it difficult to set a goal for just the travel time. The potential accessibility, on the other hand, shows that the transport system is improving when a growing number of job opportunities can be reached within a certain amount of time and vice versa. The accessibility has then been changed either due to altered travel times or when the amount of job opportunities is changed (Inregia 2000). Of course, altered travel times should not be reached by an increase in velocity, but through more effective planning of roads and new constructions.

Real accessibility studies, similar to Reneland's study, have also been performed by several other researchers internationally, for instance O'Sullivan and colleagues (2000) in Glasgow, Scotland, Hillman & Pool (1997) in Croydon, UK and Geertman & Ritsema van Eck (1995) in the Netherlands. The measures are somewhat different and of various complexity but the principles are the same – to measure travel time to destinations. The accessibility study performed in this thesis is a mixture of several measures used above.

## 4 Methodology of the Växjö case study

An accessibility analysis can be performed in several different ways. In this case study GIS is used as the main tool to analyse and present the results. The accessibility is for instance measured as the number of job opportunities that can be reached within a certain time period from all residential areas within Växjö city, comparing car, public transport and bike speed. A digital copy of the Växjö road network enables realistic driving patterns. For this type of study, relevant data has to be collected and analysed and then a network analysis has to be performed. The output is maps showing ratios, e.g. the proportion of job opportunities that can be reached by public transport compared to car within a time period. Data is presented in a few different ways to show how GIS can be used to give different outputs.

### 4.1 The study area

Växjö city was chosen as the study area for several reasons. First, the city has a relatively dispersed built structure compared to many other average sized Swedish cities, and can therefore be subject of a more compact spatial planning. This is an important aspect since there is a clear relationship between low population densities and high facility costs and operational costs for infrastructure and public transport (Hagson 1999). Växjö has about 7 inhabitants/hectare compared to the compact city of Lund which has more than 25 inhabitants/ha (Hagson 1999). Second, the municipality is involved in various types of projects towards a more sustainable community. Third, some of the departments use GIS and have come quite far in the process. Hence, they already had most of the digital material required for this study, which was one of the main reasons for choosing the city. Växjö city has about 50,000 inhabitants, which equals 67% of the population in the municipality. Almost 30,000 job opportunities are located within the city border and there is a growing university with about 8,000 students in the southern part (Växjö kommun 1997). It should also be mentioned that the departments of spatial planning and traffic planning department cooperate a lot.

### 4.2 Collection of data

All relevant digital material has been collected from Växjö municipality in Sweden (Stadsbyggnadskontoret if not stated otherwise). The most important data are:

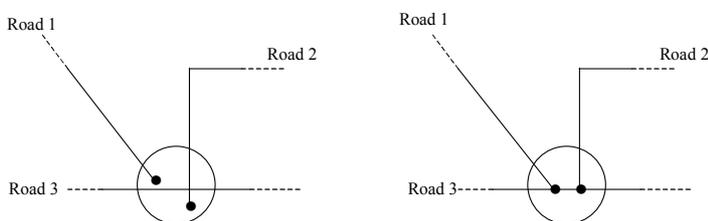
- A GIS-based **street layer** (poly-lines) of Växjö city with associated attributes, such as street names. This layer was produced in 1999 by screen digitalisation of primary maps (with a scale of 1:10,000) and Statistics Sweden's economic map. Statistics Sweden is the official statistical organisation in Sweden.
- A GIS-based **polygon layer** of coded municipal districts, where different districts of the municipality are assigned codes for the purpose of statistical reporting. Statistics Sweden uses these statistical areas when they collect and analyse material for different districts in Sweden. There are six levels of statistical information, where level 1 only divides the municipality into a few areas while level 6 consists of small statistical areas. The Växjö polygon layer is based on the 6<sup>th</sup> level of division and contains areas ranging in size from one residential block to large countryside areas in the periphery. Only 147 of these polygons, the ones located within the city borders, were used in the analysis. The peripheral areas within the city borders had to be cut
- A "**real estate database**" (from 1999) for the municipality from Statistics Sweden, containing information about the number of properties in each statistical area. For each property there are also attribute data on the number of people living there as well as the distribution in age.

- A database covering all job locations and the number of **job opportunities** within every company in Väjö city (from 2000). This data is an excerpt from the information Väjö municipality has bought from Statistics Sweden. The data also contains information about in which statistical area each business is located. This field has been used as the common field between the polygon layer described above and the business database.
- A GIS layer of all “official” **bicycle paths** within the city limits. This layer was produced in 1998 and is updated on a regular basis.
- A GIS-based layer of **bus routes**, produced in 1998 by the regional bus company Länstrafiken Kronoberg.

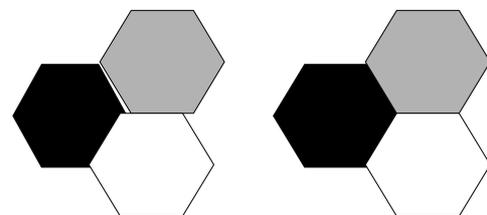
All GIS data are projected in the Swedish coordinate system called “Rikets nät”.

### 4.3 Data management and preparation

The GIS material received from Väjö was delivered in MapInfo® format, so the first step was to import it into the GIS software ArcView® where all the analyses were performed. The quality of the data is very important. This applies especially to network analyses, where it is crucial that all intersections and roads are interconnected. The digital street layer received from Väjö did not have this topological consistency. It therefore had to be “cleaned” from dangling nodes (Figure 8) and new nodes had to be established in all intersections (Figure 8) before any analysis could take place. The polygon layer of the statistical areas also needed some adjustments due to the existence of slivers and misshaped polygon boundaries (Figure 9). Some peripheral polygons needed to be cut since their borders were located in surrounding lakes (Figure 10).



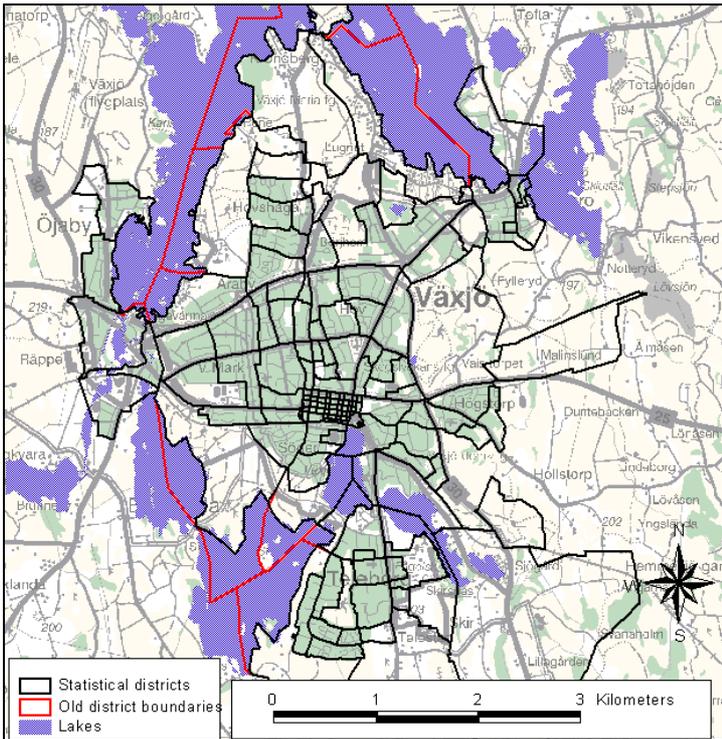
**Figure 8.** In the left-hand figure dangling nodes are shown, while the right-hand figure shows how the dangling nodes have been “cleaned” and that there are proper intersections between the roads.



**Figure 9.** In the left-hand figure there are overlapping polygons and slivers between the polygons. In the right-hand figure these errors have been corrected.

Bridges, under- and overpasses, one-way streets and streets closed for car and bicycle traffic are other important features of the network. These limits had to be added in the digital network with different functions within the GIS software.

Since the network analysis is only focusing on Väjö city and not the municipality, the digital layers had to be cut from unnecessary data, such as roads and statistical districts outside the city. The job opportunity database was joined with the polygon layer to create a layer with all the business information. A similar layer was produced for the real property data, so that each polygon contains information on the number of people living there as well as the number of job locations and job opportunities.

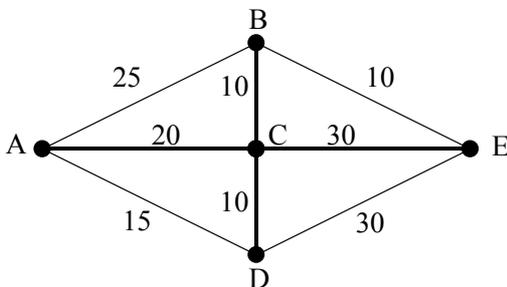


**Figure 10.** The original district boundaries were located in lakes surrounding Växjö city and therefore had to be cut.

#### 4.4 Network analysis

When measuring accessibility in a digital environment, several studies are based on the air distance multiplied with a factor as an estimate of the real distance between two places or within a certain radius. However, with ArcView's software NetWork Analyst a digital version of the real street network can be used to calculate the closest or the fastest route between two points.

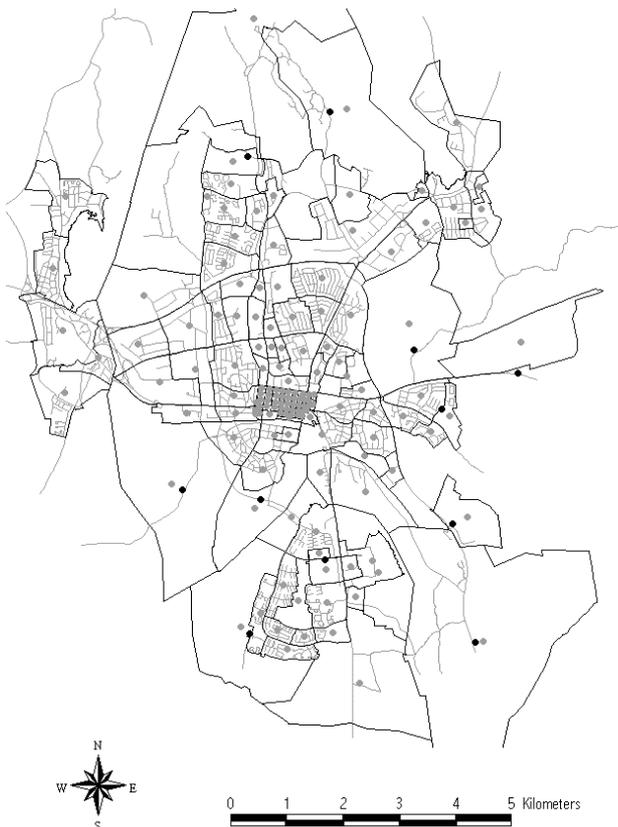
One basic necessity for a network to be analysed is that all roads are linked and that there is information on how the links are interconnected. There must also exist some kind of distance information for each road segment. With knowledge about the length and speed of each road segment, the time it takes to travel along the road can be calculated. Once this is done, the network can be analysed. An example of a network is shown below (Figure 11).



**Figure 11.** A topological network consisting of five nodes interconnected by roads. Travel time is given at each road segment (Adapted from Pilesjö et al. 1999). Travel time and distance are not the same in the network, since you are allowed to travel faster on some roads.

An algorithm is needed to find the optimal road between two nodes in a network. The one used in the ArcView NetWork Analyst was written by Dijkstra (1959). With this algorithm it is possible to step-by-step find the quickest route from A to E to be A-B-E. A further explanation of the algorithm can be found in Pilesjö et al. (1999).

Since this study is based on a “many-to-many” relationship, a multiple network analysis had to be performed. This requires a modified ArcView Network Analyst that can compute all distances between origins and destinations in one single step instead of one distance at a time. The modification has been provided by Klaus Neudecker and can be collected at ArcView’s official web site. It is an Avenue script that automates the process in ArcView (ESRI 2000). A multiple network analysis requires two point layers – one origin layer and one destination layer – and the polyline layer. The statistical areas were therefore converted into centroids, which means that a point was created in the centre of each polygon. Since the network analysis requires that these centroids are fairly close to a street, eleven of the 147 centroids had to be moved to the nearest street (Figure 12). These eleven centroids covered larger peripheral statistical areas where most of the jobs and houses were located close to the nearest road. It should therefore not affect the analysis noticeably. Five centroids in the central area of the city also had to be moved one building block out (Figure 13) since they were surrounded by pedestrian streets where no car traffic is allowed.



**Figure 12.** The 11 centroids that were moved in the peripheral areas are shown in black. The original centroids (grey) are located close to the moved centroids but further away from a road. The polygons with black outline represent the statistical areas and the grey polylines represent the street network.



**Figure 13.** The central business district has a few streets for pedestrians only. Before running the network analysis the five centroids located inside or around these streets had to be moved closer to one of the streets where car traffic is allowed.

#### 4.4.1 Network analysis for cars

New attributes had to be created for the topologically consistent street layer. The length of each road segment was calculated with a function in ArcView. Another attribute field was created to give each road segment a speed limit. These limits have been retrieved from a study undertaken in Västerås by Lic. Dr. Eva Ericsson at the Department of Technology and Society, Traffic Planning, Lund Institute of Technology. Ericsson has measured (among other factors) the speed from the beginning of the road to the end, including if the cars have to stop in intersections and also the acceleration and deceleration phase (Ericsson 2000b).

Since both Västerås and Växjö are considered to be average sized Swedish cities, the Västerås dataset is the best available speed data there is to be applied to the Växjö case. There has actually been extensive speed investigations performed in Växjö in the beginning of the 1990's when several intersections were changed into roundabouts. However, these speed investigations are only covering a small part of the city and can therefore not be applied to the entire study area. The Västerås study, on the other hand, gives a more realistic interpretation of the actual speed patterns in the Växjö network. There can, however, be a small difference in the actual speed patterns since Västerås mainly has traffic signals and Växjö has more roundabouts. Another source of error is that the streets with a speed limit of 30 km/h had few cases and a biased sample of drivers in Ericsson's study. However, they are included in this study since they are the best general measure of the actual speed on 30 km/h roads.

The digital map of the Växjö street network was divided into the same subgroups (i.e. street type, area type, speed limit and number of lanes) as the Västerås material. This was made possible with help from the traffic planning department in Växjö. After insertion of all the data into the Växjö GIS database 15 street types (Table 1) could be distinguished out of the 21 used in the Västerås study. Unfortunately there were two street types in Växjö that were not found in the Västerås study: "Main residential street, 2 lanes, with 30 km speed limit" and "local residential street, 2 lanes, with 70 km speed limit". For simplicity and the similarity the first one was classified as street type number 1, and the second one as street type number 4 (Table 1). In the Västerås study there were no 2-lane arterial road with speed limit of 90 km/h, which there were in the Växjö study. These roads were therefore added to the 15<sup>th</sup> street type. Figure 14 maps the different street types present in Växjö.

**Table 1.** The 15 street types with average speed results from the Västerås study (Ericsson 2000b) used in this study (res. = residential, ind. = industrial, CBD = Central Business District). The street types in *italic* letters are specific for Växjö.

Number	Street type	No of lanes	Speed limit (km/h)	Average speed (km/h)	Standard error (km/h)
1	Local/Main res. street	2	30	20.2*	4.2
2	Local res. street	2	50	26.6	0.5
3	Main res. street	2	50	46.6	0.5
4	Main/Local res. street	2	70	52.9	1.1
5	Main res. street	4	50	35.6	0.8
6	Main res. street	4	70	35.7	1.5
7	Local ind. street	2	50	27.1	1.2
8	Main ind. street	2	50	46.7	1.6
9	Local CBD street	2	50	14.3	0.8
10	Main CBD street	2	50	26.6	1.0
11	Arterial	2	50	42.1	0.9
12	Arterial	2	70	53.6	1.4
13	Arterial	4	50	38.6	0.6
14	Arterial	4	70	52.1	0.5
15	Arterial, Freeway	2/4	90	86.5	0.7

\*Standard error of 4.2 km/h compared to an average of 0.9 km/h for the other 14 street types.

Since the case study is based on peak-hour traffic, when most people go to and from work, a speed reduction could be needed. However, according to Ericsson (2000a) there is only a slight change (~ 1km/h reduction) in speed during peak-hours in Lund, which is also an average-sized Swedish town. The reduction is not larger than the standard error presented in Table 1 and will therefore be ignored in this study. This would of course be more important in a heavily trafficked larger city.

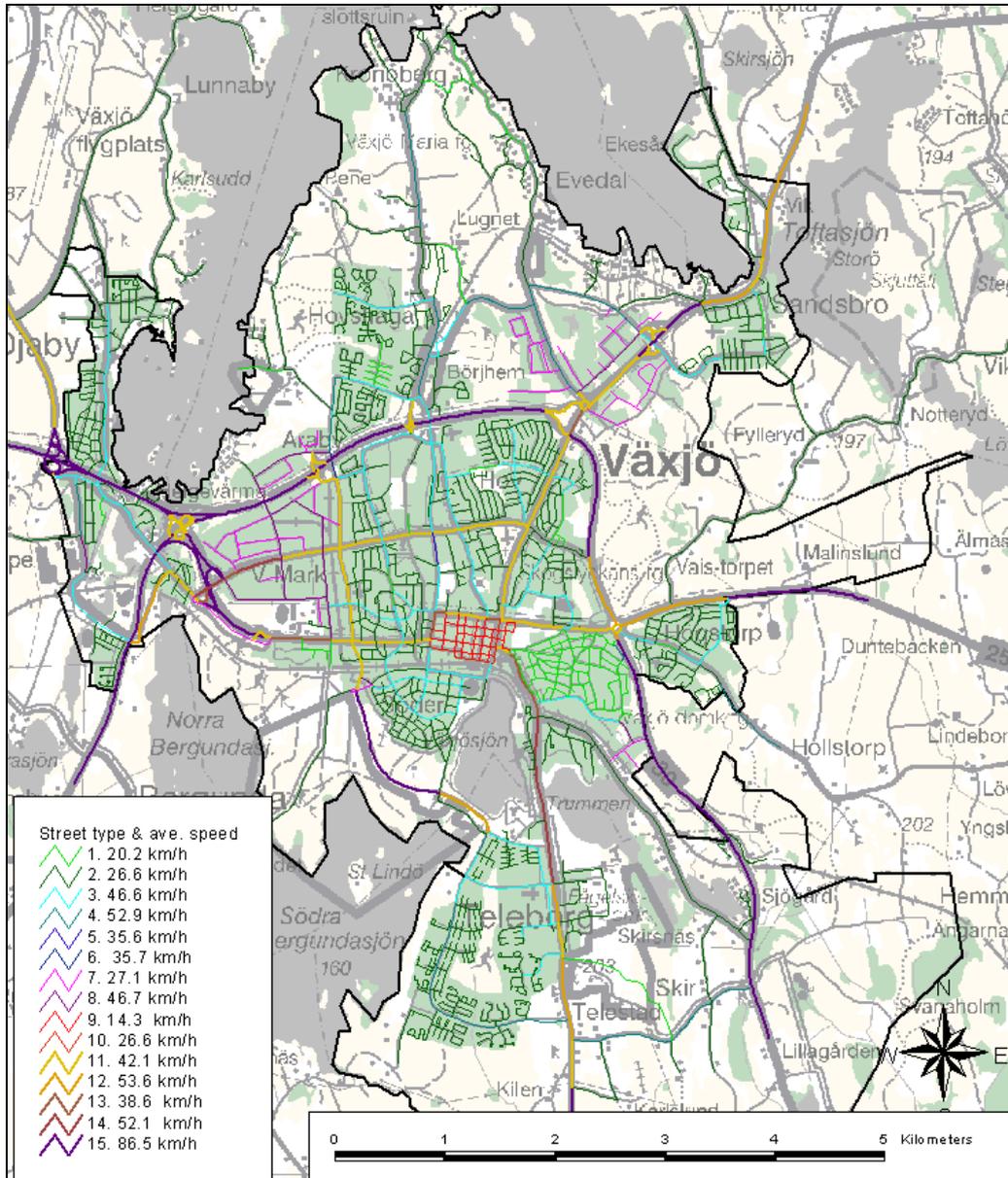


Figure 14. The 15 street types with average speed for the Växjö road net.

When each road segment had been assigned a speed value, a time field could be created by dividing the length of each road segment with the speed. Thereafter all the necessary data was in place and the network analysis could be performed. The resulting table consisted of 147x147 routes, with data about origin centroid, destination centroid and the time it took to travel along the route. Another 2 minutes were added to each of the trips to account for the time it takes to walk to and from the car. The table was then converted into an Access database format, for the actual accessibility analysis.

#### 4.4.2 Network analysis for bikes

The digital bike network was created by adding all separate bike paths to the car network, assuming that bikes can travel along the road network. The freeway was excluded since no bikes are allowed on that type of road. Another feature not included in the digital layer was bike paths located on each or one side of a road, since that does not affect the network analysis.

The bike network analysis is similar to the car network analysis, except for the fact that the layer was not divided into several different street types for correct speed measures. Instead, a general speed limit was set. Several studies have been performed regarding general bicycle speed. Bikers' actual speed usually varies between 12 and 25 km/h, but investigations in Great Britain, Germany and Japan have found the typical average speed to be around 15 km/h (Hudson 1982, Ljungberg 1982). According to Ljungberg (1987), it can be assumed that the general bike speed in Swedish cities is about 17 km/h. For this study, Ljungberg's bike speed has been used. Once speed and length of each road segment was known, a time field could be produced and the network analysis could be undertaken.

#### 4.4.3 Network analysis for buses

When creating the bus network, a Swedish/German software called VIPS was used. This software is a comprehensive tool for public transport planning that enables advanced calculations of different route alternatives (VIPS AB 2000). A digital version of the bus route network (Figure 15) was produced where all bus stops (nodes) and the time it takes to travel (links) along the link were added. All in all, there are 187 bus stops serving the public transport network. The data is based on the wintertime table and for the time periods 6.30-8.30 and 16.00-18.00, when most work trips are undertaken. The periodicity, i.e. how many times per hour the bus leaves or passes, waiting time and transfer time were also specified. For some routes the periodicity is 15 minutes during this time of day, while other routes only have about 2 buses passing every hour.

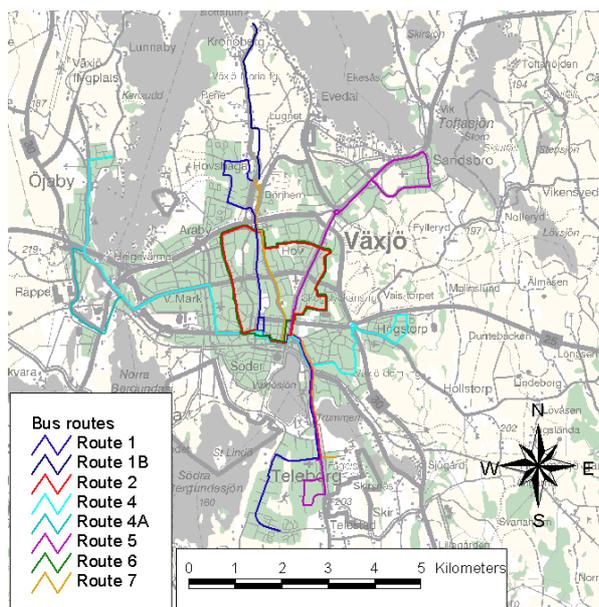


Figure 15. Bus routes in Växjö city.

One generalisation had to be made regarding the walking distance between the centroid of each statistical area and adjacent bus stops. Instead of using the street/bike network it is assumed that a person walks with a speed of 5 km/h and that the distance is the crow's flight multiplied with a factor of 130%. The added 30% has been chosen since it is a generally accepted factor from the Swedish governmental transport planning division from 1982 (Statens Planverk 1982). Since the study focuses on work trips, it is assumed that people know when and from where the bus leaves. Five minutes are therefore added to all trips as a waiting time.

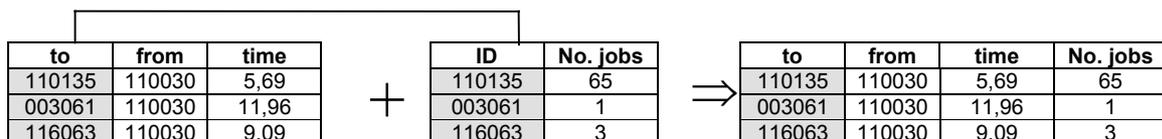
The software then assesses the travel time from each statistical area to every other area based on:

- the time it takes to walk to and from the bus stops (air distance multiplied with 1.30 and a speed of 5km/h);
- a set time for waiting on the bus in the beginning of the trip (5 minutes);
- a calculated time for waiting if bus transfer(s) is/are necessary;
- the actual time spent on the bus(es).

The public transport network analysis differs a bit from the car and the bike network analyses. The main purpose of VIPS is to evaluate and model existing and planned public transport networks in a way that closely resemble the real world situation. For instance, passengers may often be in a position to choose among a set of parallel routes in order to reach their destinations. Their decisions depend in general on many variables, e.g. the in-vehicle travel times, walk time, transfer time, number of transfers, the headways and the irregularity of the routes. VIPS takes these choices into consideration, thus giving an *average* travel time per trip and not the *fastest* (VIPS AB 2000). Unfortunately, the software does not allow alterations of this mechanism, since an evaluation of the fastest routes is not the purpose of the model. The approach is therefore rather different from a car network, where the drivers try to find the fastest path from origin to their destination. One should be aware of this when interpreting and comparing the results of the three network analyses.

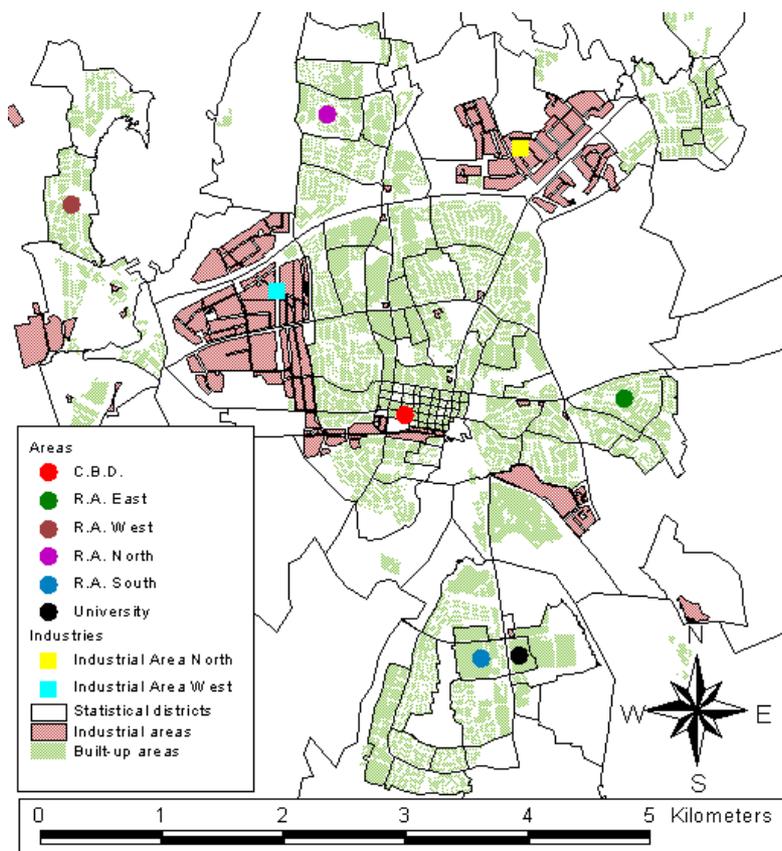
#### 4.5 Accessibility analysis

The resulting tables obtained from the three network analyses were imported into Microsoft Access. The relevant fields for the actual accessibility analysis were the origin, destination and the time it took to travel between those two. A fourth field was added so that the amount of job opportunities could be joined to the destination field (Figure 16). Since there are 147 investigated areas in the study, there are 147x147 (21,609) relations for each of the three network analyses. The tables shown in Figure 16 are therefore just a very small part of the entire table.



**Figure 16.** The table to the left is a small part of the car network analysis result. The table in the centre is the job opportunity data. When joining the fields "to" in the left-hand table with the "ID" in the middle table, the right-hand table is obtained.

The next step was to import the data back into ArcView for the actual accessibility analyses. First, the datasets for bicycle and public transport were arranged to present the proportion of job opportunities that can be reached within 15 and 20 minutes compared to the car. Second, data for eight specific areas were extracted for a more focused accessibility analysis. These areas were chosen to represent typical elements of the city, i.e. the two largest industrial areas, the central business district (CBD) and the university where a lot of people work and study. The two industrial areas are from hereon referred to as the Industrial Area West and North. Four residential areas were also chosen. These four areas are located in different parts of the city and have the highest population densities in their surroundings. They are called Residential Areas East, West, North and South (Figure 17). One measure used is the investigation of how long it takes to reach half of all job opportunities, from hereon referred to as  $AT_{50}$  (Accessibility Time 50%).



**Figure 17.** The eight areas chosen for a more focused accessibility analysis.

## 5 Results and discussion of the Växjö case study

The results are divided into three subchapters depending on the type of accessibility measures used. In Chapter 5.1 bus and bicycle accessibility for the entire city are investigated. In Chapter 5.2 the accessibility to a few commercially dense areas is assessed and in Chapter 5.3 the number of job opportunities that can be reached from residential areas are evaluated. Some statistics about the length of the trips for the three transport modes are presented in Table 2. It should be noted that the car can reach any of the 147 districts in less than 20 minutes, from wherever it starts within the city limits. The maximum time a bicycle trip takes is about twice as long as the car trip, while the maximum length for going by bus is more than six times as long. However, Table 2 shows that 90% of the trips can be performed in about 12 minutes with car, 22 minutes with bicycle and 43 minutes by bus. This implies that there are a number of bus trips that are very time consuming, but that most of the trips can be performed in about 40 minutes. The AT<sub>50</sub> is reached in less than 8 minutes by car, about 11 minutes by bicycle and just above 20 minutes by bus.

**Table 2.** Statistics about the trip lengths for the transport modes car, public transport and bicycle.

Trip length	Car (min)	Bike (min)	Bus (min)
Maximum	19.0	42.9	122.0
Average	7.7	12.0	24.3
Median	7.5	11.2	20.9
25th percentile	5.1	5.6	14.2
75th percentile	9.7	17.1	30.5
90th percentile	11.6	22.3	43.3

### 5.1 How accessible are job opportunities in general?

Figures 18-21 present the accessibility by bike compared to car. High bike accessibility is achieved in the dark purple areas. From these areas the bicycle can reach 90-100% of the job opportunities that can be reached by car in the same time. In Figure 18 the time limit is set to 15 minutes, since that is an easily accepted bike trip length (about 4 km). It is only from the central areas where the accessibility is above 90%. Grey areas are districts with very low accessibility. In public transport planning the bus travel time is acceptable if it is less than twice as high as the car travel time. That is the main reason for showing everything less than 50% of accessibility as grey. Note that from Residential Area South (see Figure 17 for information), the bike accessibility is only around 60%.

When the time limit is set to 20 minutes (Figure 19) the area from which more than 90 % of the job opportunities can be reached compared with car has grown remarkably larger. There are only a few peripheral areas where the bike accessibility is lower than 50 %. The maximum time of 20 minutes is used for two reasons. First, if travelling by car, the entire city is reachable in this time period. Second, if using a general bike speed of 17 km/h, then 20 minutes correspond to a 5 km trip, which is quite acceptable for the average Swede.

In Figure 20, the same principles apply. Dark purple areas are the ones with high bicycle accessibility, whereas grey areas have accessibility below acceptance. The red symbols represent the number of inhabitants per district; while the blue symbols in Figure 21 are the numbers of job opportunities in each district. The larger the symbol, the higher the number of inhabitants or job opportunities. The figure illustrates that the industrial areas as well as the central business district and the University area are the ones with a high number of job opportunities. These should therefore be of interest from a transport planning point of view. They should preferably be easily accessible with public transport.

Figure 20 shows that most districts of high population have high bike accessibility at a time limit of 20 minutes. There are, however, some areas that have a fairly low accessibility. From Residential Area West less than 50% of the job opportunities can be reached in 20 minutes. This is probably a direct consequence of the lake situated between the peripheral west and the city region. Bikers need to travel on a restricted number of bike paths and roads, which results in a detour. From Residential Area North and South the bike accessibility is about 80-85% compared with travelling by car.

When looking at the same ratios for public transport and car, the general patterns are very different. In Figure 22, where the time limit is set to 15 minutes, it is clear that only the very central areas have an acceptable bus accessibility. The ones with the highest public transport accessibility are located just around the bus terminal. These do not reach more than about 60-65% of the job opportunities reached by car in 15 minutes. When another 5 minutes are added to the time limit the entire central business district reaches a bus accessibility level of 70-85% (Figure 23). Observe that from the University area the accessibility is just above 50%. This is probably due to a combination of a fairly frequent bus schedule and that many job opportunities are located in the specific area. If comparing Figure 23 with Figure 15, which depicts the bus routes, the accessibility pattern shown in Figure 23 corresponds well with the paths of the bus routes.

In Figure 24, the number of inhabitants (red) for each district has been added. The same rules apply in this figure as in Figure 21. It is evident that neither the high-populated districts (Residential Areas West, East, North and South) have a high bus accessibility in 20 minutes, nor do the industrial areas. Nevertheless, most of the high-populated areas closer to the city centre have acceptable levels of accessibility by bus.

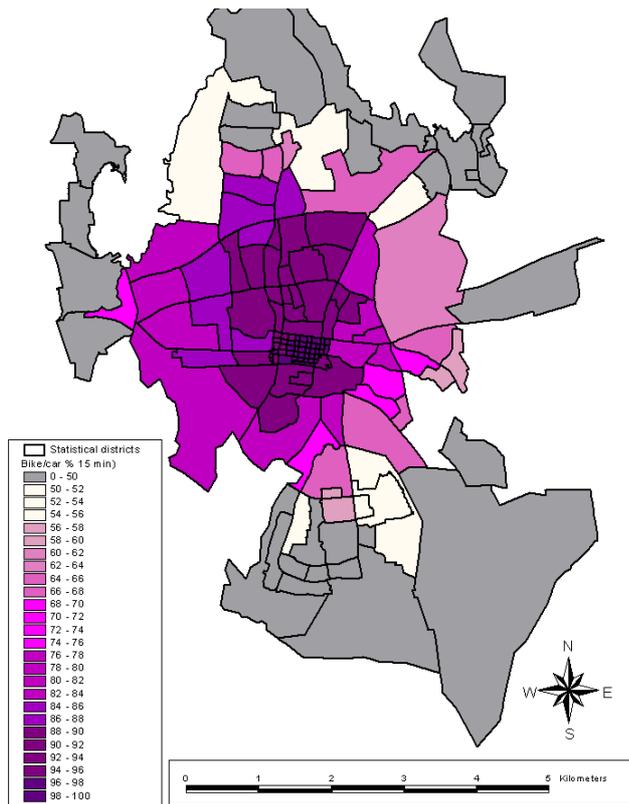


Figure 18. Percentage of job opportunities that can be reached from each district within 15 minutes by bike compared to car.

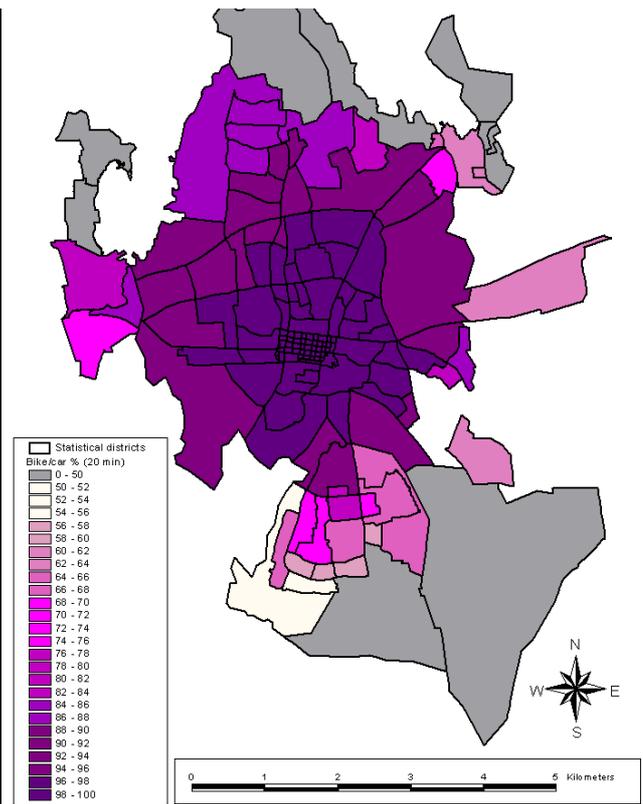


Figure 19. Percentage of job opportunities that can be reached from each district within 20 minutes by bike compared to car.

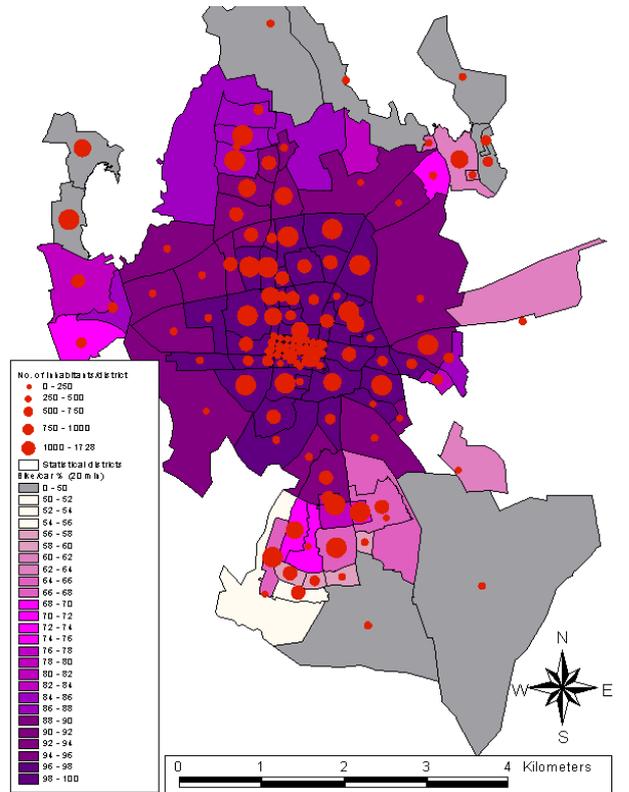


Figure 20. Percentage of job opportunities that can be reached within 20 minutes comparing bike and car. The red point symbols represent the number of residents in the district.

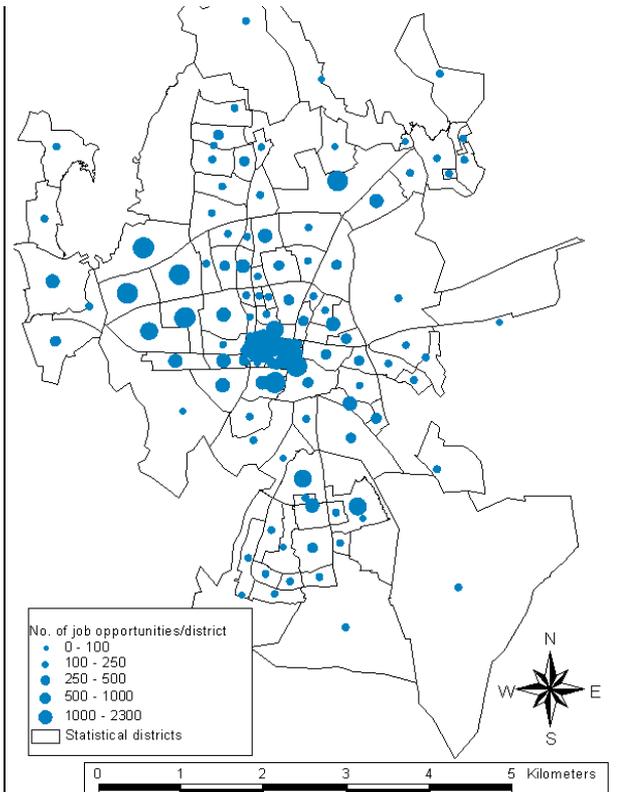


Figure 21. The blue point symbols represent the number of job opportunities located in each district.

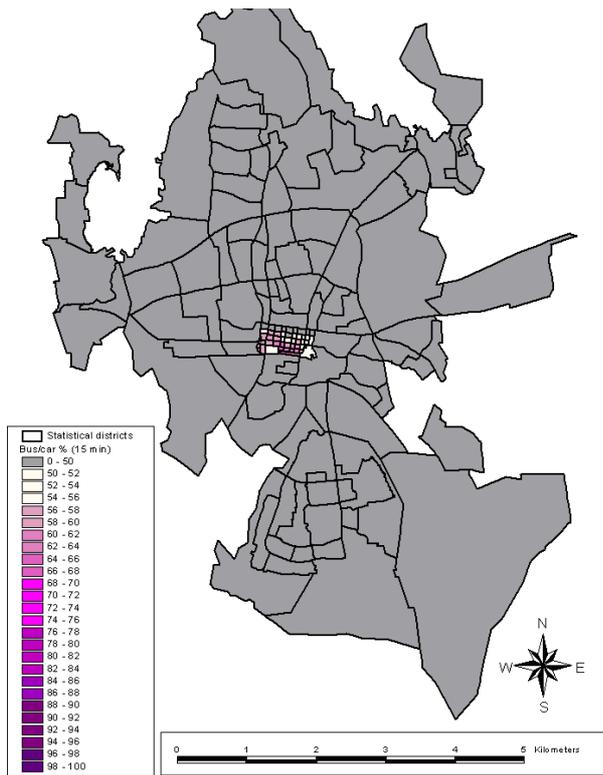


Figure 22. Percentage of job opportunities that can be reached from each district within 15 minutes by bus compared to car.

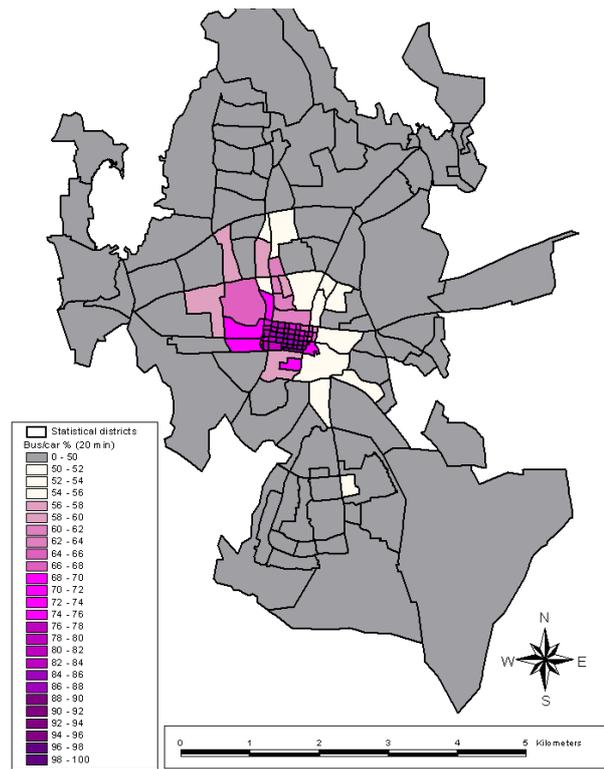


Figure 23. Percentage of job opportunities that can be reached from each district within 20 minutes by bus compared to car.

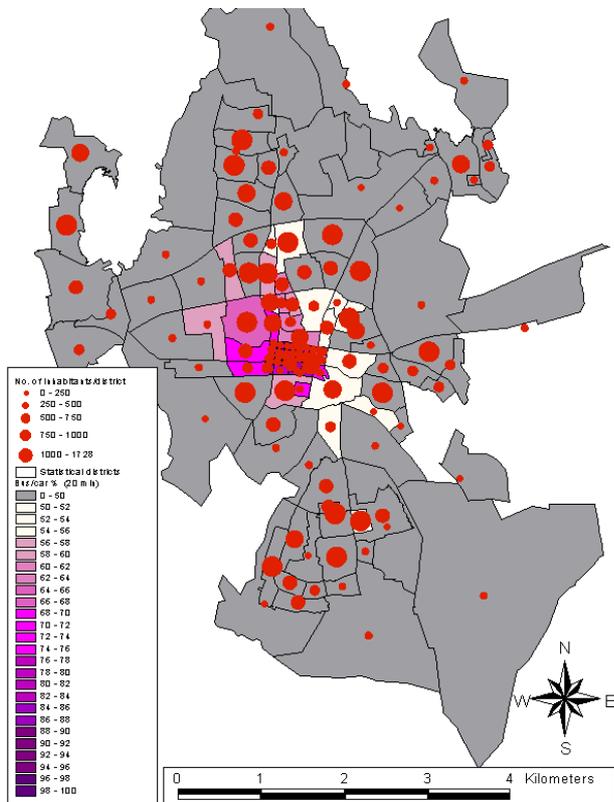


Figure 24. Percentage of job opportunities that can be reached within 20 minutes comparing bus and car. The red point symbols represent the number of residents in each district. It is preferable if the accessibility is high in districts where many people live.

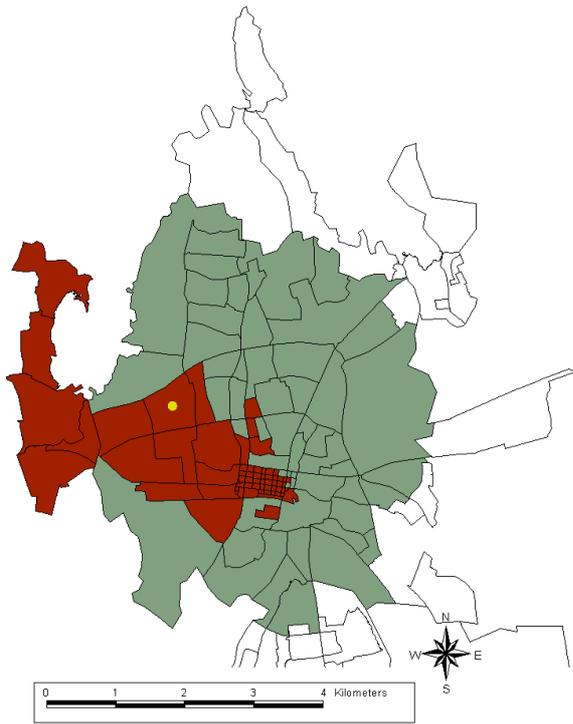
## 5.2 How accessible are commercially dense areas?

The accessibility measure used in this chapter only focuses on specific districts. It is an investigation of the ease with which commercially dense districts can be reached from other areas. The four districts assessed are the Industrial Areas West and North, the central business district and the University. The choice of these four districts was made on the basis that they are areas where a large proportion of the job opportunities and the University are located. All in all, these areas hold approximately 50% of the job opportunities and 8000 students.

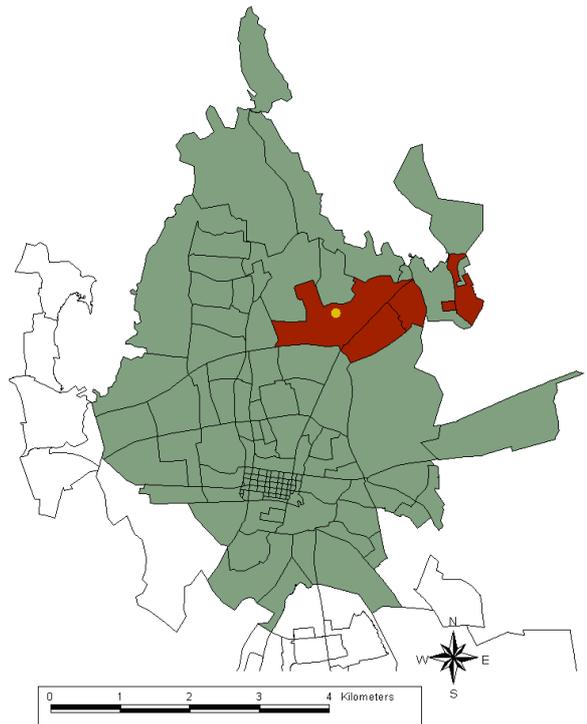
Figures 25-28 illustrate bicycle and public transport accessibility to the four commercially dense areas. *Green areas show from which districts one can travel by bike to the yellow centroid in 20 minutes. The yellow centroid represents one of the commercially dense areas. Red areas are districts from which one can travel by bus and bike to the yellow centroid in 20 minutes.* The car can travel anywhere within the city boundaries in 20 minutes. It is clear that the bus has much lower accessibility than the bike, since it covers only a part of all the areas you can bike from. Industrial Area West (Figure 25) has a fairly acceptable bus accessibility. You can travel from all western residential districts as well as the central business district to the industrial area in less than 20 minutes. The Industrial Area North (Figure 26) has the lowest bus accessibility of all four commercially dense districts. This is probably a result of long walk time in combination with a less frequent bus schedule.

In terms of proportions, you can travel from about 80% of the districts by bike and 35% of the areas by bus to reach the Industrial Area West in 20 minutes. If you want to go by bike to the Industrial Area North, you can travel from about 80% of the districts as well. However, less than 5% of the districts have access to the Area North in 20 minutes with bus.

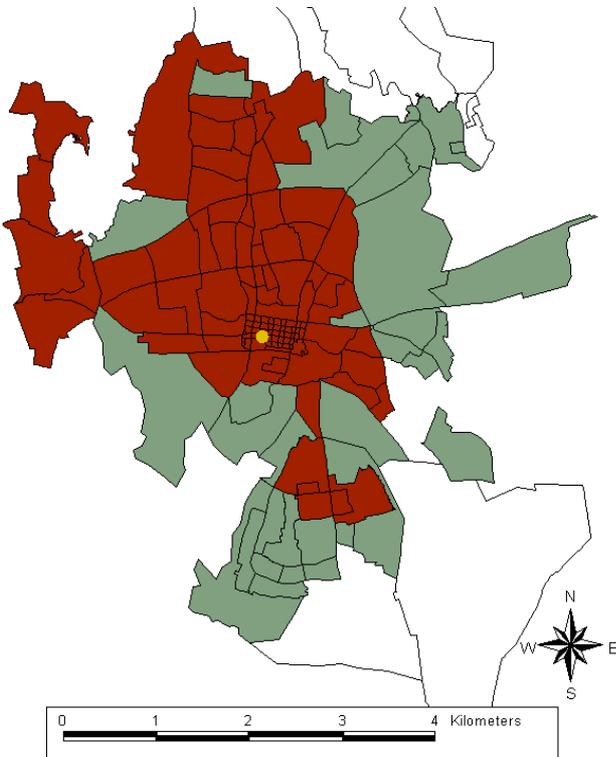
Figures 27 and 28 show the accessibility to the central business district and the University, respectively. If you want to go to the CBD by bike in less than 20 minutes, you have access from almost all districts within the city limit (Figure 27). 95% of the areas can reach the CBD in that time period. Bus accessibility to this area is also high (Figure 28), 79% of the areas have access to the CBD in 20 minutes. The University is also reachable from most districts in 20 minutes by bike (78%), while only half of the districts have access to the University in 20 minutes by bus.



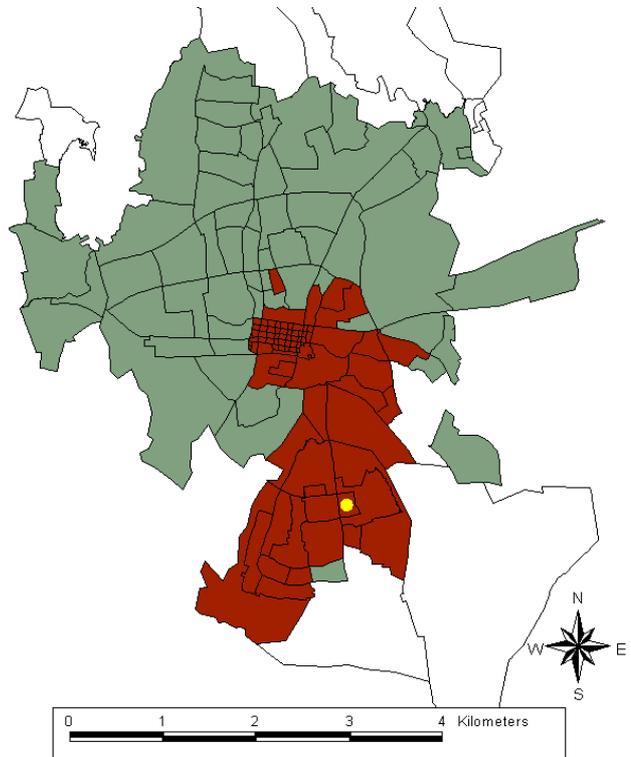
**Figure 25.** Accessibility to Industrial Area West. From all green and red areas you can go by bike to the yellow symbol, representing the industries, in 20 minutes. From all red areas you have access to the industries by bus in 20 minutes.



**Figure 26.** Accessibility to Industrial Area North. From all green and red areas you can go by bike to the yellow symbol, representing the industries, in 20 minutes. From all red areas you have access to the industries by bus in 20 minutes.



**Figure 27.** Accessibility to the CBD. From all green and red areas you can go by bike to the yellow symbol, representing the CBD, in 20 minutes. From all red areas you have access to the CBD in 20 minutes by bus.



**Figure 28.** Accessibility to the University. From all green and red areas you can go by bike to the yellow symbol, representing the University, in 20 minutes. From all red areas you have access to the University in 20 minutes by bus.

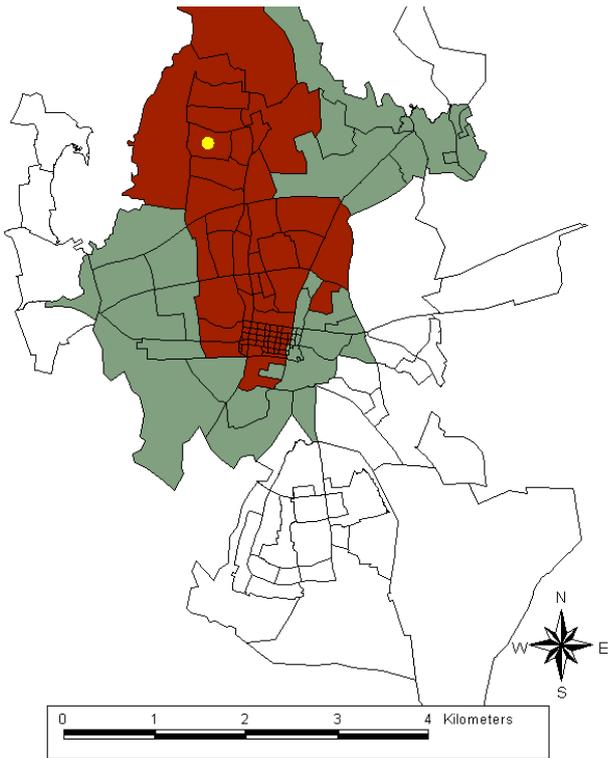
### 5.3 How many job opportunities can be reached from the residential areas?

The accessibility measure used in this chapter is approximately the same as the one used in Chapter 5.2. However, now the focus is on a few residential areas and how many job opportunities you can reach from these districts. Residential Areas West and East have about 20 inhabitants/hectare whereas Residential Areas North and South have a population density that is twice as high. These four areas have the highest population density in their surroundings. Note that *green areas are accessible by bike and red areas are accessible by bus and bike from the yellow centroid in 20 minutes*. The centroid represents Residential Area North in Figure 29, Residential Area South in Figure 30, Residential Area West in Figure 31 and Residential Area East in Figure 32.

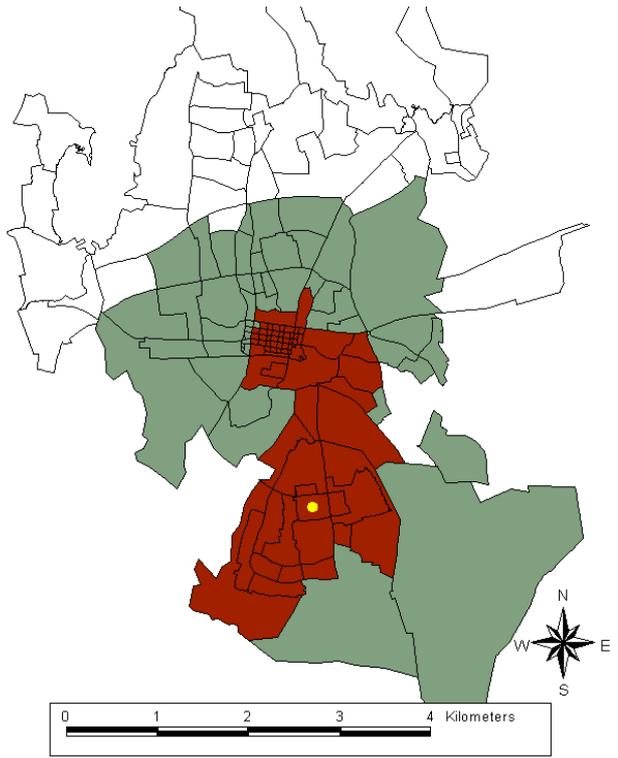
Figures 33-37 illustrate the proportion of job opportunities that can be reached at different time periods from the residential areas and the central business district. The CBD is certainly a commercial area, but at the same time it is one of the most high-populated areas in the city (30 inhabitants/hectare). This is the main reason for showing Figure 37. Figures 38-40 demonstrate the relations between the five areas in terms of the trip lengths for car, bicycle and public transport, respectively.

From Residential Area North (Figure 29) you can reach the central business district in less than 20 minutes by public transport. However, neither of the two Industrial areas, nor the University can be accessed in this time period. This results in a job opportunity access of only 33% (Figure 33). The bus accessibility for Residential Area South is a little bit higher, mainly because the University area can be reached (Figure 30). About half of all job opportunities are therefore accessed in 20 minutes by bus. If traveling by bicycle, on the other hand, both Industrial Areas North and West can be reached in 20 minutes from Residential Area North. This yields an accessibility rate of almost 90% (Figure 33), although almost none of the districts in the south and southeast of the city can be reached (Figure 29). When biking from Residential Area South (Figure 30), all investigated commercial areas except Industrial Area North are reached in less than 20 minutes. You can therefore reach about three quarters of all job opportunities within the time limit (Figure 34). If the trip is undertaken by car you can reach more than 90% of the job opportunities in less than 10 minutes.

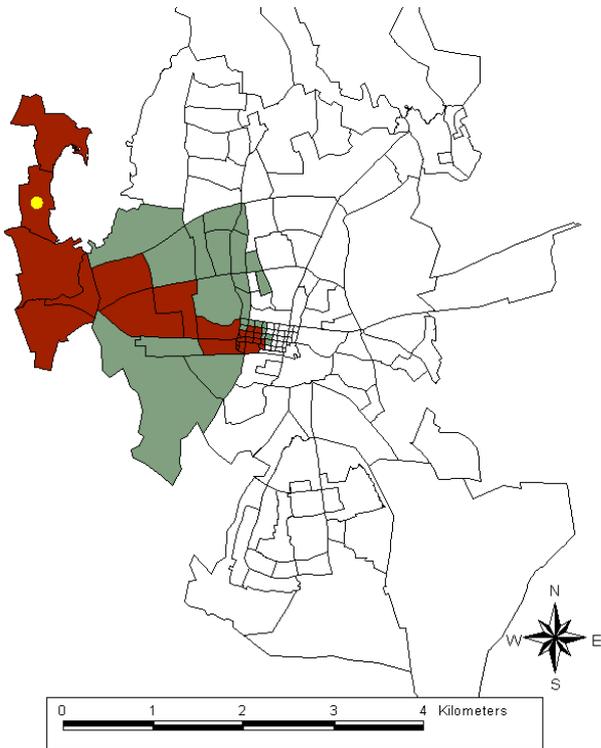
In Figures 31 and 32 there is quite a large difference, especially concerning the accessibility by bike. From Residential Area East, all commercial areas can be reached by bike in 20 minutes (Figure 32). 90% of the job opportunities are accessed within the time limit (Figure 36). From the Residential Area West, not even all districts of the CBD can be reached (Figure 31). The difference is a result of the lake that efficiently shuts off the western part from the rest of the city. It therefore negatively affects the possibility to bike from this area and gives a low accessibility of 45% (Figure 35), which is about half as high as for Residential Area East. The number of areas reachable by bus in 20 minutes is fairly similar for Residential Areas West and East. However, neither of them reaches any of the major industrial areas or the University within the set time limit. Moreover, only some of the districts in the city centre are reached (Figures 31 and 32) and less than a quarter of the job opportunities are accessed within the 20 minutes (Figures 35 and 36). This should be compared to the accessibility with car – in 15 minutes almost all of the job opportunities are accessed.



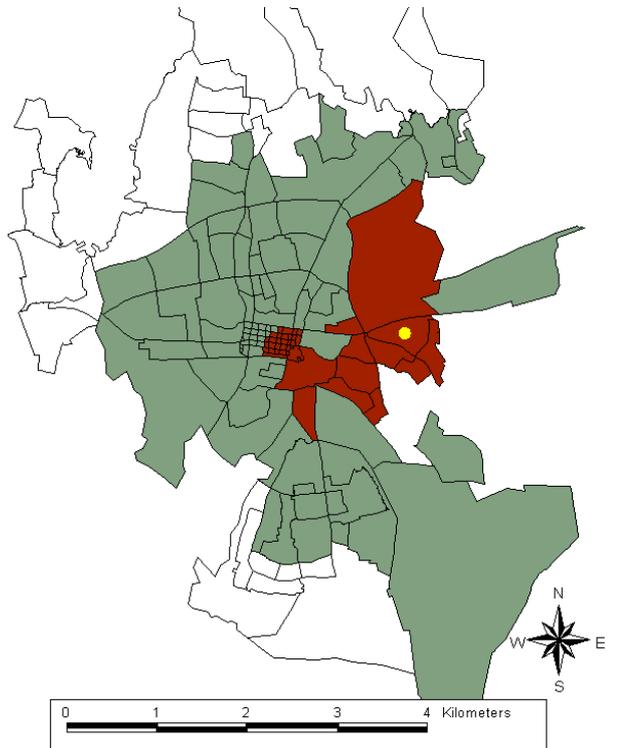
**Figure 29.** Accessibility from Residential Area North. From the yellow mark (R.A. North) you can reach all green and red areas by bike and all red areas by bus in 20 minutes.



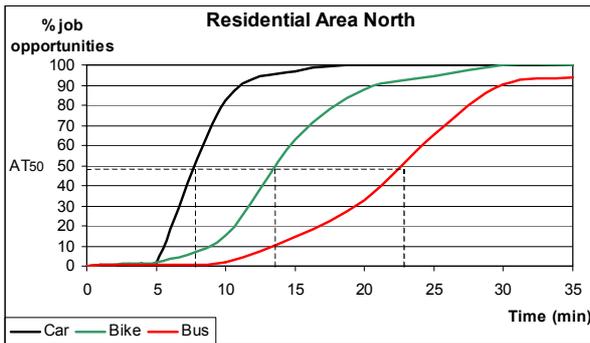
**Figure 30.** Accessibility from Residential Area South. From the yellow mark (R.A. South) you can reach all green and red areas by bike and all red areas by bus in 20 minutes.



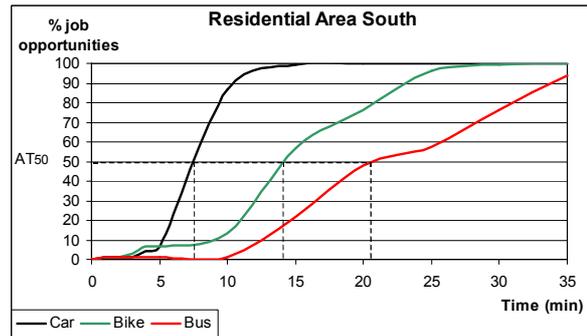
**Figure 31.** Accessibility from Residential Area West. From the yellow mark (R.A. West) you can reach all green and red areas by bike and all red areas by bus in 20 minutes.



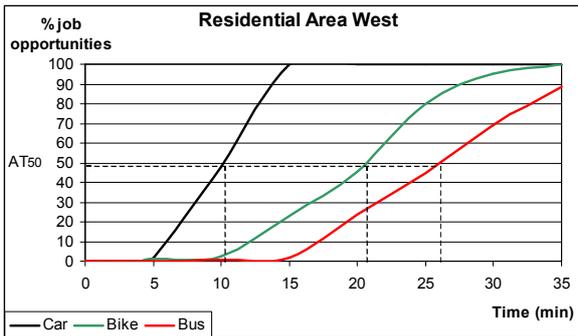
**Figure 32.** Accessibility from Residential Area West. From the yellow mark (R.A. West) you can reach all green and red areas by bike and all red areas by bus in 20 minutes.



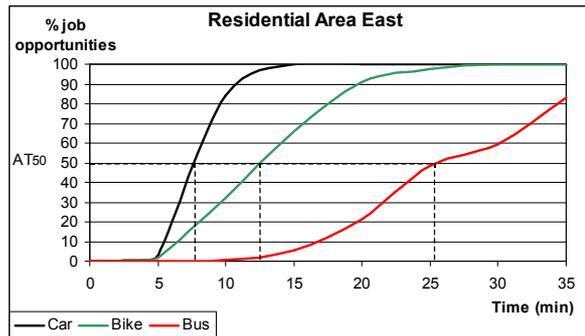
**Figure 33.** The proportion of job opportunities that can be reached at different time periods from Residential Area North.



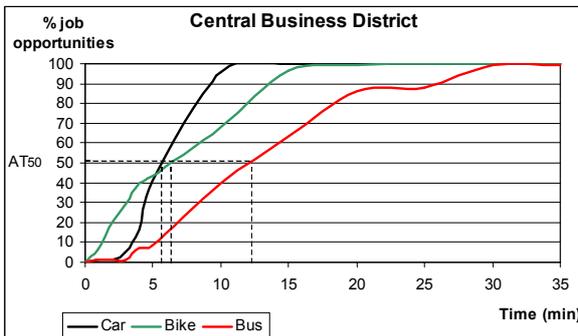
**Figure 34.** The proportion of job opportunities that can be reached at different time periods from Residential Area South.



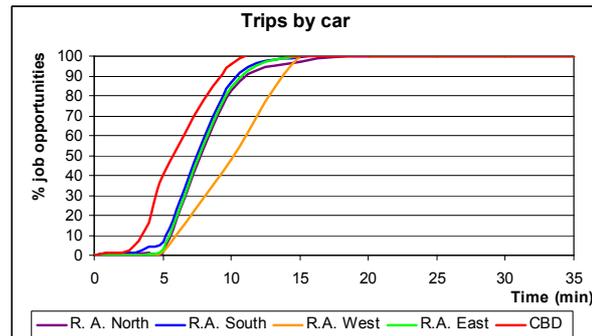
**Figure 35.** The proportion of job opportunities that can be reached at different time periods from Residential Area West.



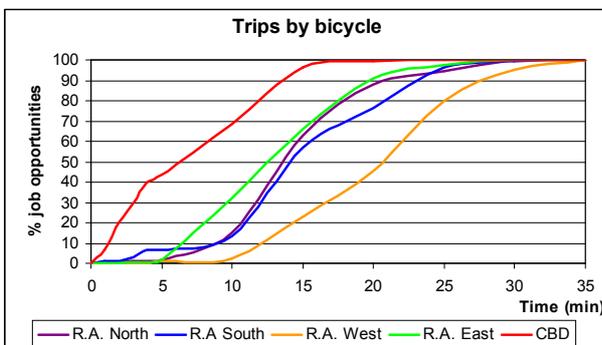
**Figure 36.** The proportion of job opportunities that can be reached at different time periods from Residential Area East.



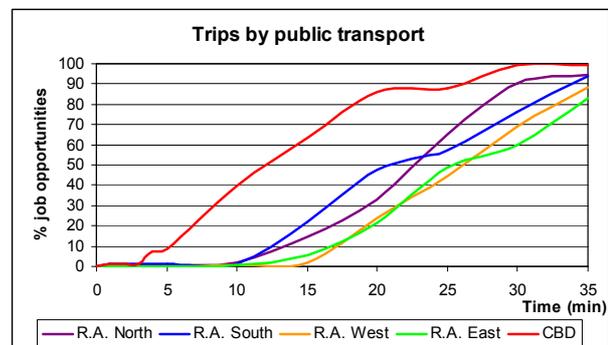
**Figure 37.** The proportion of job opportunities that can be reached at different time periods from the central business district.



**Figure 38.** The proportion of job opportunities that can be reached at different time periods from the four residential areas and the CBD (Central Business District) by car.



**Figure 39.** The proportion of job opportunities that can be reached at different time periods from the four residential areas and the CBD (Central Business District) by bicycle.



**Figure 40.** The proportion of job opportunities that can be reached at different time periods from the four residential areas and the CBD (Central Business District) by bus.

The accessibility pattern in the CBD is different compared to all residential areas (Figure 37). First of all, you can reach all job opportunities faster than the other areas can. Even the bus accessibility is high – all job opportunities are accessed in less than 30 minutes. Moreover, since it is assumed that it takes about two minutes for the driver to reach and start the car, the bicycle gets a head start and can efficiently compete with the car, reaching 40% of the surrounding job opportunities before the car can. Finally, the car reaches 100% accessibility in 10 minutes, while the bike only takes five minutes longer.

Figures 38-39 and Table 3 illustrate well what has already been mentioned. The CBD has the highest accessibility, whereas the Residential Area West has the lowest due to the obstacle of a lake. In Figure 38 the remarkable similarity between the profiles for Residential Areas North, South and West should be noted.

**Table 3.** AT<sub>50</sub> – the Accessibility Time in which 50% of all job opportunities can be reached.

<b>District</b>	<b>Car (min)</b>	<b>Bike (min)</b>	<b>Bus (min)</b>
Res. Area North	7.9	13.6	23.0
Res. Area South	7.5	14.0	20.8
Res. Area West	10.2	21.0	26.2
Res. Area East	7.9	12.6	25.4
Res. CBD	5.8	6.5	12.6

## 5.4 Concluding remarks

When having all the results in mind, it is quite remarkable how competitive the bike can be to the car. It is, however, apparent how much an obstacle such as a lake (and therefore also a highway or railway) can affect the bike's competitiveness. The bus also loses a lot of time on long walk times and wait times. This can be seen in Figures 33-37 where the bus riders do not reach any job opportunities until 15-20 minutes have passed. Not surprisingly, the central business district has the highest accessibility for all three transport modes. The AT<sub>50</sub> measure seems to be a good complement to the maps and graphs.

## 6 Evaluation

From an environmental and socio-economic perspective it is desirable to reduce the amount of motorized transports in cities. At the same time the city must fulfill several functions: products must be delivered, people need to travel to and from work, emergency service vehicles must have access to all districts, aesthetics are important, the traffic must be as safe as possible etc. Some of the functions are in conflict with each other, while others interact. For instance, if people switch to other transport modes to reduce car traffic, both emissions and accessibility problems are reduced. On the other hand, a densely built urban structure and short distances for minimized mobility dependence are sometimes difficult to unite with a green urban structure that is important in the city for both environmental and social reasons.

However, as Owens (1986) states, the shape of the city is of much less importance than the location of activities. It is the latter that mainly influences transport demand and thus energy consumption. This is confirmed by the Dutch planning strategy – service areas should be easily reached by public transports and bicycle, whereas warehouses are in need of lower accessibility by these transport modes (Ministry of Housing 1997). With the development of accessibility instruments it will perhaps be easier for public authorities to plan for the right business in the right place. Swedes travel about 40 km per day compared to only a few kilometers in the beginning of the 20<sup>th</sup> Century. This is a result of automobility planning, often integrated into society in small steps. Today, about half of all Swedish women and 30% of the men use other transport modes than the car when traveling to work. With the right type of planning and information more people will see the benefits arising from switching transport mode away from car. As Figure 5 illustrates, a well-maintained bicycle network and an efficient public transport system are necessary.

### 6.1 Use of accessibility measures in spatial planning

According to a report recently published by the Swedish Road Administration (Vägverket 2000), one of the largest obstacles for the transition of our societal structure towards a transport and resource efficient society is of a mental kind. The car has characterized generations of politicians and planners who have been (and still are) responsible for spatial planning. It might therefore be difficult to change spatial planning towards a structure that promotes biking and public transport. Apparently, of the US\$ 1 billion that are invested by the Swedish government in transport infrastructure every year only 1% are used for bicycle infrastructure. The municipalities are therefore more or less solely responsible for the bicycle network.

Within the municipalities there is another problem. Spatial planning is most often handled by a planning department while traffic planning is pursued by a traffic department. In general, the traffic planners are responsible for the technical and economic aspects of planning, whereas the spatial planners take care of the more humanistic, social and aesthetic aspects. Accessibility measures may have a great impact in the area of both landuse and traffic planning. First of all, they can be a part of the early stages of planning, evaluating current land-use distributions and transportation services and identifying inequities and substandard conditions. The accessibility measures can also provide planners and decision-makers with a better assessment of the implications of potential investments. However, this requires a close cooperation between the departments of spatial and traffic planning. As already mentioned, the built environment and location of activities have a high influence on transport demand.

The case study performed in this thesis presents results that can be useful in the process of planning. Chapter 5.1 gives a general overview of the current situation that Växjö is in, regarding trips to work. Decision-makers can hopefully use the maps to become aware of how new constructions affect the possibilities to use bicycle or public transport as the daily means of transportation. Low accessibility areas can then be “upgraded” by adding new or improved bike paths and/or a new or altered bus route in order to increase the accessibility. In addition, one can pinpoint areas that today might be unexploited, that are suitable for either residential or commercial development.

The maps in Chapter 5.2 show what the potential is to reach the major commercially dense areas. This presentation can also be useful to illustrate where new housing estates can be developed. Moreover, for instance Figure 26 shows that especially this industrial area has little potential to be reached by public transport. It is not in the scope of this study to state if an improvement is necessary, but the results show what the situation looks like.

Chapter 5.3 focuses on a few residential areas and their potentials to reach job opportunities. The maps show about the same message as the ones in Chapter 5.2. The graphs showing the accumulated distribution of job opportunities over time and the  $AT_{50}$  are good complements to the maps. Especially the  $AT_{50}$  measure can be a suitable tool in the future. It can be developed for all residential areas and give an overall picture of which areas that might need an upgrade or that could be suitable for further development. However, it is suggested that more research is needed to confirm and validate the potentials and effects of using the  $AT_{50}$  measure.

With the existing GIS database there is also material suitable for simulations and comparisons of different alternatives. Environmental Impact Assessments, EIAs, are becoming a more important and integrated tool in planning. Concerning locations of new residential and/or commercial areas, simulations showing the variation in accessibility could be useful. Furthermore, the possibility of presenting maps is also positive in this sense.

Overall, bus accessibility is fairly low compared to travelling by bicycle and car in Växjö. This may indicate that the periodicity is too low, especially on some bus routes. Concerning biking it is often believed that it takes longer to bike than going by car. If the distance is less than five kilometers, traveling by bicycle usually does not take that much longer than traveling by car. It is important to present this to make the public aware of the actual situation, and not what is believed to be the situation. Mobility Management is a relatively new concept gaining interest in several European countries, involving Sweden. It promotes sustainable transport and strives to reduce single car use by means of “soft” measures (e.g. information and coordination of existing user services) to enhance the effectiveness of “hard” measures (e.g. new bus routes and new bike paths). Mobility Management tools are thought to be a cost-efficient tool to change mobility behavior (EPOMM 2000). The results presented in this thesis can probably be one way of informing the public of the often small differences between travel time with car and bicycle. Moreover, if the accessibility analysis is performed in a few years again it can also be used to measure if we are moving in the right direction.

## **6.2 Can this be used as an environmental indicator?**

Policymakers all over the world are today becoming more and more aware of and interested in the concept of “internalisation of the external costs”, i.e. to bring the environmental costs into the price of transports. This yields for instance higher taxes on fossil fuel and car possession. However, for this to work efficiently there must be alternatives to the car, e.g. well-developed public transport systems and possibilities to bike. One way of keeping track of this is to use environmental indicators, in this case the accessibility measures proposed in this thesis. With the DPSIR model fresh in mind (Chapter 2.2), instead of having automobility planning as a driving force we should switch to accessibility planning in that “box”. With the accessibility measures used as environmental indicators we can determine if the society gives people, who either prefer or become in need of other transport modes than the car, an opportunity to choose. This is necessary for us to struggle towards a less car-dependent society, which will lead to both environmental and socio-economic benefits.

The measures presented in this study could therefore build a useful base for environmental indicators concerning accessibility. The maps are appropriate as overviews and for presentations. They can also be converted into percentages of the surface that can be classified as for instance low- and high-accessibility areas. A progress towards a more sustainable society would then be a larger percentage of areas with high accessibility. This measure is suitable for an entire city or a larger area.

Another measure, but on a district level, would be to use the  $AT_{50}$ . Measures like these are usually easily interpreted and can be useful for a specific residential area. Say that an area has an  $AT_{50}$  of 9 minutes by bike in year 2000 and that it is reduced to 7.5 minutes in year 2005. Then we know that the area has improved its accessibility, either because there is a better mixture of homes and jobs or because the bicycle network has been improved.

## **6.3 Is this a cost-effective method?**

The most time-consuming parts of the case study have been data management and analysis. This is one of the pitfalls with GIS – it can become very time-consuming and thus expensive depending on the existing data as well as the skills of the operator. However, once the data has been produced digitally, updates can more easily and quickly be made. Moreover, the initial costs of implementing GIS software into an organisation may be considered high, but in the long run it can be considered cost-efficient. Eklundh (1999) discusses the positive effects for organisations that have used GIS, especially on the workload. Large financial gains, often four times the invested capital but also higher, have been reported. Other positive outcomes are of more strategic type (development of new services, better marketing, competition advantages, higher quality, better customer service etc.), or of organisational character (better working environment, more efficient working terms, more flexible work tasks etc). Investments in GIS are therefore often profitable for the individual organisation and they have a large socio-economic value.

Regarding the actual accessibility analysis using GIS, it should be considered cost-effective. It would almost be impossible to perform such a study differently, from both a financial and time-efficiency perspective. GIS can manage large amounts of spatial data that are hard to manage in any other way. The process used in this study can also be made even more efficient by production of scripts and macros that can automate some of the steps that otherwise are time-consuming. In addition, the financial costs involved in the study have been the time it took to manage and evaluate the data. All data have been distributed without any costs by the Växjö municipality.

## **6.4 Quality of data**

The lasting value of a GIS analysis is highly dependent on the quality of the data and if the techniques have been used in the right way. Results from GIS-based studies must therefore always be used with certain caution, since visual professional presentations can be based on low-quality data. In this study a lot of data were collected from different places and the question is how reliable they are.

First, is the Västerås speed data applicable to Växjö? The two cities are of approximately the same size and structure, and there is no better data available. One could have performed a similar study in Växjö as in Västerås, but it would be very time-consuming and financially expensive. Considering the amount of data and the difficulties that were experienced in the Västerås study it would not be feasible to perform such a collection of data in a thesis study. Nevertheless, some kind of evaluation of the data would have been preferable. Hence, if the Västerås data is to be used in a future larger research study, it is suggested that some kind of evaluation is performed.

Second, using the statistical zones of various sizes brings a certain degree of lack in quality of the geographical coverage. The central parts have a finer division than peripheral zones do. The peripheral areas should therefore have a larger variation in accessibility that is left out. It would have been better to use for instance 1 by 1 km squares to avoid this problem. However, the job opportunity data could only be provided based on the statistical zones, which therefore was the lowest level of disaggregation.

Third, the quality of the business register should also be mentioned. Companies close and new people are hired. It does not take very long for a business register to become outdated. Some of the districts have been updated in 1999, for other districts the data was a few years old. Without being in the scope of this paper, it is important to investigate this further in other studies when implementing the method. Another aspect that is not covered in the business register is the University and its students. Even though the study places are not actual job opportunities, they serve the same function. The number of 8,000 students is therefore rather general, since no more exact data was found.

Fourth, the bicycle speed has been set to 17 km/h in this study. However, there is a great variability in cycling speeds. One suggestion is to make a model that reflects on the actual conditions on the ground. For instance, on links where cycling is not allowed, but which are likely to be part of a cycle route (e.g. as a shortcut), a speed of 5 km/h could be assigned. On bike paths shared with pedestrians the speed can be set to 10-15 km/h due to the risk of conflicts and less confident bikers and children.

On completely separate cycle routes a speed of at least 20 km/h would be reasonable. Other factors influencing are the surface material and the maintenance of the link, as well as topography and congestion. All of these aspects should preferably be taken into consideration when estimating the biking speed. However, Ljungberg's conclusions from 1987 are still one of the best estimates, without making the model too complex. Moreover, complexity adds uncertainty.

It is always of great importance that the data used is of good quality. Data precision and accuracy depend on the size of the project and the size of the study area. For the purpose of this study, the data have been of sufficient quality, although many datasets could have been more accurate. The outcome of the results is satisfactory and shows the potential of accessibility measures in planning.

## 7 Conclusions

Automobile use cannot only be controlled through congestion pricing and economic penalties. Instead, urban accessibility, environment and safety must control the development of the transport system. This requires a coordinated urban and traffic planning, which handle developments of housing, job opportunities, service and recreation as well as investments and restrictions in the traffic net.

GIS-based accessibility measures can help policy-makers and planners to make the right decisions. Not only do the maps present possible development sites but also suggestions to improvements in public transport network and possibilities to bike. Furthermore, since the data is stored in a GIS, opportunity is given for further investigations outside the scope of this paper. For instance, there is a potential to easily switch all residential streets with a speed limit of 50 km/h down to 30 km/h. How would this affect the car accessibility? A decreased speed would most probably increase traffic safety. If all residential streets have a 30 km/h limit, there will be a better environment for pedestrians and bikers. There are possibilities for a number of different studies when having a database like this.

Similar GIS-based accessibility analyses have been performed in different parts of the world in recent years. For instance, the study performed by Inregia AB (2000) is analogous to the one presented in this thesis, although on a different scale. However, there seem to be difficulties taking the results from the academic society into the actual planning process. New and more developed tools are probably needed for this to happen. A more complex class of potential accessibility measures than the one used in this study is the gravity-based measure. This type of measure takes into consideration how far away the destination is. The closer the opportunity, the more it contributes to accessibility; the larger the opportunity, the more it contributes to accessibility (Handy & Niemeier 1997). This measure can give an even more realistic indication of the accessibility. However, perhaps simple measures are as effective or even more effective than complex ones in characterising the physical structure of a community? Otherwise there is a risk that further uncertainty is added and that the results become difficult to interpret. This should be further investigated.

Although just investigated in an average-sized Swedish town, this type of measure can probably be applied on any scale and anywhere, as long as the relevant data can be collected. GIS as a planning tool is becoming more and more common, and it is constantly being improved with new analytical possibilities. Thus, the potentials of using GIS in accessibility planning are large. There seem to be possibilities to use this type of measures in both spatial and traffic planning, as well as in Environmental Impact Analyses and Mobility Management. More research is however needed and new appropriate instruments must be developed. It must also be agreed upon what accessibility really is and how it should be defined. One of the first steps must be to realize the differences between the concepts of mobility and accessibility. These should be considered as each other's opposites, as Ross (2000) argues. Just because the accessibility by car is high, does not mean that the general accessibility is acceptable. As we are moving towards a more sustainable society, a growing accessibility for all societal groups should be one of the driving forces.

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