Accessibility Measures for Analyses of Land-Use and Travelling with Geographical Information Systems

Maria-Christina Makrí
Department of Technology and Society
Lund Institute of Technology
Lund University
Sweden

Carolin Folkesson
Department of Spatial Planning
University of Karlskrona/Ronneby
Sweden

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

(Gould 1969, page 64)

Abstract

This paper compares existing accessibility measures and develops and varies some of these measures for comprehensive analysis of land-use impact on accessibility and on travelling patterns using GIS. The paper is based on a literature survey, a review of the geographical information in digital maps and available data on population and potential destinations. The focus is on place accessibility, but it also touches on individual accessibility. The accessibility measure chosen for the first case study is a zone-to-point distance measure, estimated separately for different types of opportunities and different road-users. The distances between origins and destinations are measured as the shortest network distance and actual driving time. A customised ArcView Network Analyst is used. Integral zon-to-zon place accessibility measures are chosen for the second case study. The main part of the calculations will be conducted in programs suitable for matrix operations and for database analyses, and the output will be processed in digital maps for presentation.

1 Introduction

The concept of accessibility has been used in a number of fields during the last few decades. Central authorities often focus on accessibility for disabled people or on passability (for example, Swedish Board of Housing, 1995, SFS 1997:652 and Proposition 1997/98:56). For the last few years the Swedish National Road Administration has been working on a definition of accessibility. This study has not yet finished but the superior definition given is *"the simplicity with which activities in the society can be reached, including needs of citizens, trade and industries and public services"* (National Road Administration, 1998 page 2). Ingram (1971) has played a key role in putting accessibility into an operational form when subdividing the concept into relative and integral accessibility. Relative accessibility was defined as *"the degree to which two places (or points) on the same surface are connected"* and integral accessibility as *"the degree of interconnexion with all other points on the same surface"* (Ingram, 1971 page 101-102). After Ingram's break through, reviews on accessibility measures have been carried out by a number of researchers, for example Pirie, 1979; Guy, 1983; Song, 1996; Handy and Niemeier, 1997 and Kwan, 1998.

This paper will compare existing accessibility measures and describe suitable developments and adjustments of the measures to make them usable for comprehensive analysis of land use impact on accessibility and with the use of GIS. It is of importance to note that our interest is at first hand the land-use impact on accessibility and not the mathematical form of the measures. In order to enable future case studies on this subject, the applicability of different measures must be evaluated. Two case studies are to be performed; the first one focuses on changes in people's accessibility to shopping and service facilities over time, and the second on the impact of land-use on travelling patterns. The paper is based on a literature survey describing accessibility measures, a review of the geographic information in digital maps and available data on population and potential destinations. The focus is on place accessibility as a property of locations, but it also includes elements of individual accessibility – a property of people.

2 General issues on accessibility

Different accessibility measures often show different approaches to accessibility. Pirie (1979) and Kwan (1998) are two studies focusing on individual accessibility, while many others more or less focus on place accessibility (for example Geertman and Ritsema van Eck, 1995; Song, 1996; Handy and Niemeier, 1997). Handy and Niemeier (1997) claim that a best approach to measuring accessibility does not exist. Different situations and purposes demand different approaches. Regardless of the approach to accessibility, Handy and Niemeier identify four interrelated issues, which must be resolved:

- the degree and type of disaggregation
- the definition of origins and destinations
- the measurement of travel impedance and
- the measurement of attractiveness

Handy and Niemeier (1997) identify three types of disaggregation. Spatial, socio-economic and the purpose of the trip or the type of opportunity. Spatial disaggregation is the grouping of individuals and households by zones. The smaller the zone, the greater the disaggregation. Some studies, for example Guy (1983), define origins and destinations as a point to point pattern. Spatial disaggregation is fully accomplished here as households or individuals are measured one by one. However, spatial disaggregation fails in solving two problems. The first is the effect of multipurpose trips and the second is that the significance of spatio-temporal constraints tends to be ignored by integral measures irrespective of spatial disaggregation (Kwan, 1998). Differences in socio-economic characteristics are taken into account by disaggregation of different segments of the population, by, for example, income, driving licence holders, gender and age. Disaggregations by the purpose of the trip or the type of opportunity distinguish, for example, between work and non-work opportunities or select one single type of opportunity such as shopping establishments. Handy and Niemeier (1997) claim that potential destinations have to be evaluated for each characteristic, by either the researcher or the residents themselves, and the weighting of each has to be acquired through surveys of residents.

The second issue concerns the origin and destination of the accessibility measure. Most measures focus on home-based indicators (Handy and Niemeier, 1997; Kwan, 1998). This way of measuring accessibility excludes multipurpose trips and trip chaining. The issue of origin and destination interrelates with the degree and type of disaggregation, as the set of destinations to include depends of assumptions on the set of potential destinations that residents perceive to be available to them, and the residents' need of opportunities (Handy and Niemeier 1997). Handy and Niemeier therefore claim that the choice set for different socio-economic groups should reflect the actual choices available to each group.

Travel impedance is commonly measured by distance or time, estimated by straight-line distance, network distance, network models simulating travel demand, field surveys of actual driving times or surveys of residents' perceived distance or travel time. The use of a generalised transport cost function, incorporating both time and monetary costs, is often an improvement over the use of time alone (Handy and Niemeier, 1997). Differences in travel time and cost by mode can be addressed by calculating accessibility separately for different modes. Another approach is to incorporate different mode times as well as the opportunity to travel by other modes into one measure of accessibility (Handy and Niemeier, 1997).

The final issue affects the attractiveness of an opportunity. Attractiveness is often measured by the existence of a particular opportunity, estimated as the number of opportunities. It is also measured by the opportunities' physical or economic size, estimated as area, employment or in other appropriate ways. Factors such as the quality and price of products and services can also be incorporated into a measure of attractiveness. Handy and Niemeier (1997), however, point out that such characteristics are highly subjective, making it difficult to specify and calibrate the accessibility measure.

3 Place accessibility measures

Place accessibility is derived from patterns of land-use, i.e. the spatial distribution of the potential destinations and the magnitude, quality and character of the activities found there. Furthermore it is derived from the transportation system, i.e. the distance, the time taken and the cost of reaching each destination by different modes of transport (Handy and Niemeier, 1997). Measures of place accessibility normally consist of two elements: a transportation (or resistance or impedance) element and an activity (or motivation or attraction or utility) element (Handy and Niemeier, 1997; Kwan, 1998). The transportation element comprises the travel distance, time, or cost for one or more modes of transport, while the activity element comprises the amount and location of various activities.

Place accessibility may be operationalized in several ways depending on the issue at hand, the area of the application, and means and limitations concerning resources and feasible data (Handy and Niemeier, 1997, Ingram, 1971). It is usually determined by integral measures comprising cumulative-opportunity measures, gravity-type measures, and utility-based measures. Irrespective of what kind of integral measure is chosen, but especially true for utility-based measures, according to Handy and Niemeier (1997) the measure must be calibrated to reflect how individuals and households perceive the travel and destination choices available to them.

3.1 Distance measures

Distance measures are the simplest accessibility measures, counting the distance from one location to different opportunities. It can be measured as average distance, weighted area distance or distance to the closest opportunity. The estimation of these distances can be performed in several ways, from simple straight-line distances to more complicated impedance formulations.

A very simple measure counts the distance from one location to a given destination, for example, the central business district. The closer the destination the higher the accessibility. The assumption is either that all opportunities are located in the destination area or that the residents only value accessibility to these opportunities (Song 1996). The maximum value derived from a single location is another simple measure, used when there is no need to choose between locations, for example hospitals or emergency services.

Measuring accessibility by average distance estimates either the average distance to one destination from all departure points in the area, or the opposite, the average distance to all destinations from one departure point or zone. The attraction of the destinations is not included in this measure. Weighted average distance makes up for this drawback by including the attractiveness of the destination.

An example of a somewhat more comprehensive application is the "shortest distance" measure, launched by Guy in 1977, that relates to goods and services required by the consumers to be close to their homes. The shortest distance travelled from a home in order to reach each of these goods and services is calculated and weighted by household mean expenditure on that good. The mean for the weighted distances is calculated and divided by total expenditure of the included goods and services.

3.2 Cumulative-opportunity measures

Cumulative-opportunity measures are evaluations of accessibility with regard to the number or proportion of opportunities accessible within certain travel distance or time from a given location. These measures are attributable to the work of several researchers, for example, Oberg (1976) and Wachs and Kumagai (1973). This kind of measure provides an idea of the range of various choices available to residents within an area. All potential destinations within the cut-off area are usually weighted equally.

As further opportunities are equally weighted with closer ones, any upward movement of the travel time limit increases the value of this index. It may therefore be prudent to lower the weighting of opportunities more distant from the origin. In order to do this, an index can be used to measure the area within a given distance from the origin. Black and Conroy (1977) were the first to draw a cumulative index, which takes the spatial distribution of opportunities into consideration.

A key factor in the calibration of cumulative opportunity measures is the cut-off travel distance or time, to which accessibility levels can be very sensitive. The literature does not contain a clear method of making this choice. Cut-offs are often calculated by means of a series of measures. Travel surveys containing frequency distributions of times or distances can suggest a suitable cut-off. Cumulative measures may be easy to calculate but they entail a somewhat arbitrary calibration.

3.3 Gravity measures

Gravity-based measures derive from the denominator of the gravity model for trip distribution (Geertman and van Eck, 1995; Sonesson, 1998). Originally the gravity was theoretically justified in the analogy to a law of physics. Subsequently, arguments from statistical theory were used to support an exponential form of the model. Gravity-based measures were first devised by Hanson (1959), and have since then been widely used. They are obtained by weighting opportunities in an area with a measure indicating their attraction and discounting them by an impedance measure (for example Geertman and van Eck, 1995; Kwan, 1998; Handy and Niemeier, 1997).

The definition of relative accessibility A_{ij} at location i is the attraction at destination j discounted by the distance decay function between these two points. The definition of

integral accessibility at location i is the sum of relative accessibility over all possible destinations divided by the total attraction of the urban area in question (Song, 1996).

The integral accessibility A_i for the residents of zone i is measured as:

$$A_i = \frac{\sum_j a_j * f(d_{ij})}{A}$$

where
a_j is the attraction in zone j
d_{ij} is the travel time, distance or cost from zone i to zone j
$f(d_{ij})$ is the impedance function
A is a standardising factor

Attractiveness represents the amount of activity at the destination point or zone. Depending on the issue at hand, it can be measured by total retail floor space, number of employees, turnover, etc. Even though gravity measures are usually calibrated from aggregate data, separate measures can be calibrated for different types of opportunities or different segments of the population.

The most commonly used variable of the impedance function is the inverse power function d_{ij}^{-x}. The most closely tied function to travel behaviour theory is the negative exponential form ($e^{-\beta d_{ij}}$) of distance or travel time d_{ij} which often produces the best results when compared with other measures (Handy and Niemeier, 1997; Kwan, 1998; Song, 1996).

Ingram (1971) indicated the tendency for a too-rapid decay close to the origin in comparison with empirical evidence. He suggested that a modified Gaussian function ($\exp(-d_{ij}^2 / v)$) is superior due to its advantage of having a slow decline close to the origin, and not so-rapid decline as measured by the negative exponential and inverse power function toward zero at a greater distance measures.

3.4 Utility-based measures

Utility-based measures are based on random utility theory, and consist of the denominator of the multinomial logit model, also known as logsum (Handy and Niemeier, 1997; Sonesson, 1998).

Utility theory is based on the assumption that individuals maximise their utility. This means that the individual gives each destination a utility value, and that the likelihood of an individual choosing a particular destination depends on the utility of that choice compared to the utility of all choices. (Berglund and Rapaport, 1999; Sonesson, 1998). The utility function contains variables representing the attributes of each choice, reflecting the attractiveness of the destination, the travel impedance, and the socio-economic characteristics of the individual or household. These measures occasionally resemble

gravity-based measures, but with theoretical and empirical advantages (Handy and Niemeier, 1997).

Accessibility A_n for individual n can for example be measured as

$$A_n = \ln\left(\sum_{\forall \in C_n} \exp(V_{n(c)})\right)$$

where

$V_{n(c)}$ is the observable temporal and spatial transportation components of indirect utility of choice c for person n

C_n is the choice set for person n

The advantage of utility measures is that they enable the testing of alternative formulations of the utility function in the search for one that best matches actual travel behaviour. The calibration determines the relative importance of various factors and need not be pre-specified as in the case of gravity-type measures.

4 Individual accessibility measures

Individual accessibility estimates the accessibility enjoyed by a particular person having particular needs, mobility and monetary and time resources. Kwan (1998) and Pirie (1979) point out the importance of accessibility measures unravelling individuals' person-specific experiences and socio-spatial contexts. Individual accessibility measures are superior to place accessibility measures in three means. Firstly they describe the individuals' experiences on the accessibility in stead of assuming that all individuals in one zone have the same level of accessibility (Kwan, 1998; Pirie, 1979). Secondly they consider the fact that many trips that contribute to individual accessibility are made in the context of the sequential unfolding of an individual's daily activity program. (Kwan, 1998; Richardson and Young, 1982). Thirdly they consider spatio-temporal constraints that may render many opportunities in the urban environment unreachable by an individual (Burnett, 1980)[1].

4.1 Space-time measures

The theory of space-time measures was first introduced by Hägerstrand (1970). Space-time measures express the feasibility of opportunities to an individual using the volumes of the space-time prism as indicators of accessibility. Hägerstrand focuses on defining the time-space mechanics of constraints, which determine how the paths are channelled or dammed up. He identifies three interrelating aggregations of constraints:

- Capability constraints
- Coupling constraints
- Authority constraints

---

[1] Referred in Kwan (1998).

Capability constraints limit the activities of the individual as a matter of his biological construction or the tools he can command. Capability constraints are either time oriented or distance oriented. Coupling constraints are defined as where, when and for how long the individual has to join other individuals, tools and materials in order to produce, consume and transact. When an individual has to join other individuals, tools and materials, his or her path in space-time has to be grouped with their paths. Hägerstrand calls these groupings of several paths a 'bundle'. The third family of constraints; Authority constraints, focus on what Hägerstrand calls the 'control area' or 'domain'. He defines the concept of a domain as a time-space entity within which things and events are under the control of a given individual or a given group.

Lenntorp (1976) refers to Hägerstrand's theories when trying to map and determine the part of an individual's environment that is physically accessible, in Lenntorp's vocabulary, within his physical reach. One important characteristic of Lenntorp's space-time measures is that they simulate an individual´s possible behaviour, not his probable future behaviour. Lenntorp is not the only one continuing Hägerstrand's theories on time-space constraints. Kwan (1998), is one recent example. She formulates a derivation of the daily PPA as:

$$PPS = \{ (k,t) \mid t_i + d_{ik}/v \le t \le t_j - d_{kj}/v \}$$

where
k = a fixed destination which is reachable if it is included in the space-time prism or potential path space (PPS)
t_i = the latest ending time of the activity at location i,
i = the origin fixed location,
t_j = the earliest starting time of the activity at location j,
j = the next fixed destination after k,
v = the average travel speed on the transport network,
d_{ik} = distance from the first fixed location i to location k,
d_{kj} = distance from k to the next fixed location j.

In order to make the space-time measures operational, Kwan performs a distance matrix for all locations using the shortest path algorithm. The feasibility of each network arc is then tested by going through the entire matrix, and identifying those arcs that are reachable within the spatio-temporal constraints for any given pair of fixed activity locations. Kwan (1998) claims that since opportunities enumerated by space-time measures are based upon their space-time feasibility, the number of opportunities included in the daily potential path area of an individual may only have a weak relation with the spatial distribution of opportunities in the urban environment. This is mainly due to space-time measures being non-single-origin indices, bearing weak relationships with the accessibility of an individual's home location. Kwan also shows that individual accessibility as experienced by men has a stronger relationship with place accessibility than that experienced by women. Conventional accessibility measures are therefore more suitable for the analysis of men's access to urban opportunities than that of women.

The major problems with space-time measures are that they depend on large amounts of information about completed activities and trips (Kwan, 1998; Pirie, 1979), that they are

best applied retrospectively (Pirie, 1979) and that they have an unwarranted property of all-or-nothing (Pirie, 1979).

The dependency on large amounts of information about completed activities and trips is troublesome in two ways. Firstly it leads to a computational intensity, which makes it difficult to use space-time measures in large-scale projects. Secondly there is a lack of feasible operational algorithms for handling the complexity of real-world transportation networks (Kwan, 1998). As space-time measures depend so heavily on large amounts of information about completed activities and trips, they are probably best applied retrospectively (Pirie, 1979). Kwan (1998), however, claims that accessibility measures incorporating the effect of space-time constraints will improve the ability to both explain and predict particular characteristics of individual travel behaviour. Further, space-time measures have an unwarranted property of all-or-nothing, as they do not consider accessibility to be created or re-created by individuals (Pirie, 1979). This creative process may involve giving up some activity entirely, asking someone else to complete it for one, rearranging the daily routine, cutting short the periods of participation or conducting activities at some new, closer location.

5 Space Syntax Analysis

Hillier and Hanson (1984) and Hillier (1993 and 1996) describe a theory of architecture called Space Syntax Analysis. The analysis focuses on theories of space. According to Hillier, the relation between spatial and social forms follows patterns in such a consistent way that he calls it *"functional laws of space"*. The analysis considers how space is organised, i.e. to what degree the architecture of the urban grid contributes to land-use.

In describing space, Hillier (1996) cites Nick Dalton, computer programmer at University College London, who said in 1994: *"The building isn't the machine. Space is the machine"*. Hillier claims that space is a key aspect of how our social and cultural worlds are constituted in the real world, but as space is built into social and cultural life, we tend to take it for granted to the point where its forms become invisible to us. A number of concepts; Convex Space, Axial Line, Syntactical Steps and Depth, Integration, Control Value, Connectivity and Intelligibility are introduced.

Hillier (1996) claims that the pattern of movement in an urban grid is mainly determined by the spatial configuration itself, in particular by the distribution of spatial integration in the axial map of the system. It is therefore, *"the architecture of the urban grid itself that is chiefly responsible for the pattern of movement, not the positioning of 'attractors' and 'magnets' as has commonly been believed."* Hillier (1996 page 26). The relationship between the architecture of the urban grid and the pattern of movement is subject to the degree of intelligibility of the grid[2]. If an urban space is intelligible, then it is predictable.

---

[2] Intelligibility is a measure of the degree to which you get information about the overall urban grid, at the same time as you get information about the visual field you experience as you move around in the grid.

As a conclusion, Hillier claims that it is likely that over time a dynamic relation develops between the evolving urban grid, its natural movement patterns and the developing pattern of land-use. For example retail service, according to Hillier, will best survive in locations both accessible and having through movements: locations that have both the spatial properties and functional effects of integration.

Klarqvist (1991) notes that Hillier's studies are made in traditional grid patterns or in a pattern that is continually connected to its surrounding urban system. It is therefore uncertain whether it is possible to achieve the same high correlation between the integration value of axial lines and the use of the space, if the urban grid includes dead-end streets frequently found in Swedish housing areas. It is also uncertain whether it is possible to foresee land-use or travelling by using Space syntax analysis as it only includes pedestrians. This limitation is due to the analysis only considering how space is organised, ignoring regulations or restrictions of the streets or roads, for example speed restrictions or one-way traffic. Theoretically it is possible to expand the analysis to include regulations of the streets, and thereby include road-users other than pedestrians. There are, however, complicated computational problems in developing the analysis in this direction. A third important limitation of using Space syntax analysis as an accessibility measure is that the analysis does not consider distance between activities. Syntactical steps used in the analysis do not consider the length of the axial lines. They only consider the connections between the nodes of the lines. Not considering the distance between functions, either in units of time or length, distinguishes Space syntax analysis from all other accessibility measures. It is questionable whether a measure ignoring distance between activities is usable as a measure of either place or individual accessibility.

6 A comparison between different accessibility measures

Accessibility measures are closely connected with land-use and transport models. At the time of the introduction of transport models in the 1950s and -60s they were an expression of the need to understand the intricate workings of urban development. It was hoped that this understanding would help to forecast and control the future of cities and regions (Wegener, 1998). Accessibility measures on the other hand, do not primary focus on forecasting development but rather on explaining the effects of different urban or regional land-use systems on social and economic interaction (Geertman and van Eck, 1995). Transport models are technically superior accessibility measures as they are able to handle a lot of data, but shortcoming regarding that they are expensive and difficult to interpret and use. Accessibility measures on the other hand, have the advantage of being easier interpreted and used.

The on-going discussion among researchers is whether it is better to apply a more quantitative or a more qualitative approach for characterising accessibility when the usual measures prove to be inadequate. It is also discussed if complexity can be added by series

of simple measures. According to Handy and Niemeier (1997) it is possible to combine quantitative measures with qualitative evaluations, in order to obtain a fuller understanding of the accessibility characteristics. The aim is hereby to reduce the gap between the results of the measures and the citizens' perceived accessibility to activities. It should be emphasised that different accessibility measures capture different dimensions of accessibility, and that the choice of method affects the results. In addition methods ought to be chosen in awareness of the assumptions upon which each method is based (Guy, 1983; Kwan, 1998; and Song, 1996).

Regarding place accessibility, several studies have shown that integral measures (gravity and cumulative measures) are superior of more simple ones measuring nothing but impedance. Other studies show that gravity measures perform little better results than cumulative measures, all else being equal. When using integral measures, the type of measure chosen is more important in determining the spatial patterns than the impedance function. Integral measures are useful for comparing accessibility between different locations. In most cases they use aggregate data and zone-based methods, where the residents homes are the point of departure. Hereby they attribute the same accessibility to all various individuals within the same zone. Zonal accessibility measures ascribe all the residents of a zone the same accessibility and are therefore not appropriate for evaluating individual accessibility (Kwan 1998; Pirie, 1979). Therefore, a more appropriate approach to individual accessibility is in many cases to regard residents and opportunities as point patterns. With the aid of the GIS tool and with the rapidly increasing computational capacity of computers, working on a point-to-point basis is becoming increasingly more feasible.

In order to restrict the limitations of integral measures it is necessary to change to more space-time oriented measures. Apart from enhancing the explanation and forecasting of particular characteristics of individual travel behaviour, the later measures can intercept interpersonal differences in individual accessibility. But the operationalisation of space-time measures is still confronted by problems, such as their requirement of detailed information on completed activities and trips, that they are best applied retrospectively and that they have an unwarranted property of all or nothing. It also has to be remembered that while gravity and cumulative measures produce distinctive spatial patterns of accessibility, the patterns for space-time measures are difficult to generalise.

7 Case studies

In order to conduct the case studies a review of the geographical information in digital maps, a review of available data on population and potential destinations and a review of travel diary data including individual background characteristics had to be performed. The results of the reviews are summarised here.

7.1 Case study 1

The first case study is to be carried-out on a municipal level in Blekinge, Sweden. Ronneby and Karlshamn population centres are to be included in the case study covering the years 1976, 1980, 1985, 1990, 1995 and 1998. Two small population centres close to Ronneby and Karlshamn is also included in the study; Kallinge just outside Ronneby and Asarum just outside Karlshamn. Both Ronneby and Karlshamn have a well-defined historical shopping centre. During the last decades shopping and service facilities have been set up in peripheral locations on the edges of the built up areas. The pattern of shopping and service facilities is therefore changed.

Measure and data used

The accessibility measure used is as mentioned a distance measure combined with some indices of attractiveness of the facilities. The distances between origins and destinations are measured as the shortest network distance and actual driving time. Both these measures are estimated separately for pedestrians/cyclists and cars.

Origins i.e. the homes of the population, are clustered into zones; 303 zones in Ronneby and 270 zones in Karlshamn. The population data can be spatially disaggregated down to the level of property, but this does not seem to improve the distance measure between origin and destination in a crucial way. If the focus would have been on the populations' perceived accessibility this disaggregation probably would had been of importance. One important complication with the population data is that it only allows inferences about accessibility for individuals, not for households. As purchasing trips, to a great extent, are made on the household's account, this is an unwarranted limitation as a consequence of the lack of more appropriate data.

Destinations, i.e. shops and service facilities, are measured in their precise locations. Data on shops and services locations allows disaggregation on type and size (number of employees) of the facility. This implies a kind of measure of the attractiveness of the facility. By calculating different types of destinations separately, changes in accessibility over time to different kinds of shops and services can be explored. Geographical Information Systems (GIS) is a useful tool for the calculations.

Geographical Information Systems – GIS

Origins, destinations and the transportation network must be geo-coded in x- and y-co-ordinates. Data on boundaries of the properties and the transportation network are to be found in the GSD Land-Use Map (Ekonomiska kartan). Estimating the shortest network distance demands data on regulations of streets, such as one-way streets and closed streets. This is received from the municipalities. Estimating actual driving times in the transportation network demands data on actual driving speeds in the network. This is received from Ericsson (1999).

Two alternative ways of computing the geographical information have been taken into consideration.

1. Writing a separate modelling programme
2. Using a customised ArcView Network Analyst.

Writing a separate modelling programme involves creating a network in which nodes and links describe the transportation network structure. Geertman and van Eck (1995) claims that this option is attractive as many existing modelling programmes can be used without much change. One condition is that the program can get its data from the GIS database and output its results so that they can be processed in the GIS.

The other way of computing the geographical information is via a customised ArcView Network Analyst. The differences compared to writing a separate modelling programme is that the model is built entirely within the GIS package by making use of a built-in programming language; Avenue. By customising Network Analyst the network problems can be solved with a greater degree of automation than possible with the user interface. In this case study it implies that all distances between origins and destinations can be computed in one single step in stead of one distance at the time. One problem using a built-in programming language is according to Geertman and van Eck (1995) that most GIS lack the appropriate data structures to handle interaction and other matrix data.

In this case study different types of destinations and different road-users are estimated separately. ArcView Network Analyst's lack of appropriate data structures to handle matrix data is therefore a minor problem. The advantages of a built-in programme language settled that a customised ArcView Network Analyst would be used in this case study.

7.1 Case study 2

This case study is to be carried-out on a regional level in the county of Scania, in the south of Sweden. The county is devided in approximately 1 000 zones. A set of measures describing accessibility at a regional level will be developed for each of these zones. After evaluation some of the measures will be chosen and combined with individual background characteristics as well as with travel diary data in order to study the impact of accessibility on daily travelling patterns.

Measures and data used

The measures that will be constructed and evaluated for this study are all integral measures for place accessibility. In other words, they will not measure the accessibility between zones but from one zone to all other zones in Scania, and they will be composed of elements of impedance and elements of attraction but not with individual characteristics.

The studied area is divided into approximately 1000 zones containing 1000 inhabitants each. The zoning used is named SAMS and was produced by Statistics Sweden in the early 90´s for statistical purposes. Background characteristics will be obtained for this statistical unit and will be used for the estimation of the attraction elements. The population statistics characteristics that will be used, are primarily the number of working places and the number of employees working there, divided into professional categories. This in order to

estimate each zone´s attractiveness concerning job opportunities on the one hand and shopping opportunities on the other.

The impedance elements will be estimated by using two EMME/2 matrixes describing the time needed to travel between the zones by car and by public transport. Unfortunately, a computation of matrixes for the modes of walking and cycling is not feasible for the present, because databases describing walking and bicycling networks are not developed yet.

Use of accessibility measures with geographical information

The elements of attraction and impedance will be combined with chosen indices to make up a series of place accessibility measures for all zones. The accessibility measures will be evaluated qualitatively and quantitatively.

Polygons describing SAMS zoning will be obtained from Statistic Sweden and added as a layer on a digital map. By assigning one value for each measure of accessibility to all the zones in the studied area, a series of digital maps describing the performance of each measure will be produced. The maps will be presented to planners in the region for discussion and a qualitative evaluation will be made.

For the quantitative evaluation, the accessibility measures will be combined with travel diary data from the travel survey RiksRVU, conducted by Statistics Sweden. The survey covers travelling patterns in Sweden for the period 1994-1998 relatively well in the SAMS level. The applicability of the chosen measures will be evaluated by making a comparison between the different accessibility measures and the actual travel behaviour of the inhabitants of the zones.

8 Conclusions

Accessibility as a term has long been used by politicians and planners in descriptions of planning goals. However, accessibility as a concept has seldom been an integral part of the performance measures used to evaluate policies. Consequently, it has had little practical effect on policies. There is thus a need to translate the concept into measures of accessibility so that it can be used to evaluate different alternative policies.

Since different situations and purposes demand different approaches, there is no best approach to measuring accessibility. An awareness of the assumptions upon which each method is based is a prerequisite when choosing a method to determine accessibility. The acknowledgement that aggregate measures neglect many important details has contributed to a trend towards disaggregate and complex representations of accessibility. Accessibility measures reflecting personal dimensions are important in making certain that infrastructure improvements and land use policies take into account the individual activity needs.

In spite of this, the choice in both case studies is to work with different forms of aggregated place accessibility measures, at least at this stage of our research. There are several reasons for this. Firstly, we were confronted by a number of practical limitations that still exist. Examples are incomplete or imperfect digital maps and background characteristics as well as non-existent or fragmentary representation of individual choices and preferences for travel. Secondly, we choose to develop measures, which are relatively plain and easy to understand and work with. In spite of these simplifications the measures will provide us with a general understanding of the accessibility situation in the studied areas and provide planners with a usable tool.

References

Alvesund (1998) *Att minska beroendet av motoriserade transporter – En fråga om att kunna och vilja!* Bulletin 161, Department of Traffic Planning and Engineering, Lund Institute of Technology, (in Swedish).

Black and Conroy (1977) *Accessiblity measures and the social evaluation of urban structure.* Environment and Planning A vol. 9, pp. 1013-1031.

Dalvi and Martin (1976) *The measurement of accessibility: some preliminary results.* Transportation vol. 5, pp. 17-42.

Ericsson (1999) *Variability in Urban Driving Paterns.* In Sturm (ed.) (1999) *8th International Symposium Transport and Air Pollution including Cost 319 Final Conference.* Technical University Graz, Institute for Internal Combustion Engines and Thermodynamics, Austria. Volume 76.

ESRI (1996) *ArcView Network Analyst: Optimum Routing, Closest Facility and Service Area Analysis.* Environmental Systems Research Institute, Inc. USA.

Geertman and Ritsema van Eck (1995) *GIS and models of accessibility potential: an application in planning.* Int. J. Geographical Information Systems, vol. 9, no. 1, pp. 67-80.

Guy (1983) *The assessment of access to local shopping opportunities: a comparison of accessibility measures.* Environment and Planning B vol. 10, pp. 219-238.

Handy and Niemeier (1997) *Measuring accessibility: an exploration of issues and alternatives.* Environment and Planning A vol. 29, pp. 1175-1194.

Hillier and Hansson (1984) *The social logic of Space.* Cambridge University Press.

Hillier (1993) *Specifically Architectural Knowledge.* Nordic Journal of Architectural Research 1993:2, pp. 13-37.

Hillier (1996) *Space is the machine : a configurational theory of architecture.* Cambridge University Press.

Hägerstrand (1970) *What about People in Regional Science?* Ninth European Congress of the Regional Sience Association. Regional Science Association Papers. In Om tidens vidd och tingens ordning, edited by Carlestam and Sollbe (1991). The Swedish Council for Building Research, Stockholm.

Ingram (1971) *The Concept of Accessibility: A Search for an Operational Form.* Regional Studies, vol.5, pp. 101-107.

Klarqvist (1991) *Manual för rumslig analys av städer och byggnader.* Report 1991:1, Department of Urban design and planning, Chalmers University of Technology, (in Swedish).

Kwan (1998) *Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework.* Geographical Analysis, vol. 30, no.3, pp. 191-216.

Kwan and Hong (1998) *Network-Based Constraints-Oriented Choice Set Formation Using GIS.* Geographical Systems.

Lenntorp (1976) *Paths in Space-Time Environments: A Time-geographical Study of Movement Possibilities of Individuals.* Ser. B. Human Geography No. 44, Department of Geography, the Royal University of Lund.

Linneker and Spence (1992) *Accessibility Measures Compared in an Analysis og th e Impact of the M25 London Orbital Motorway on Britain.* Environment and Planning A 24, pp.1137-1154.

Malmström and Wellving (1994) *Introduktion till GIS.* Utvecklingsrådet för Landskapsinformation. Gävle, (in Swedish).

National Road Administration (1998) *Utveckling av mått för tillgänglighet.* Information från Enheten för planering av vägtransportsystemet 1998-03-23, beteckning PP10A 98:632, (in Swedish).

Pirie (1979) *Measuring accessibility: a review and proposal.* Environment and Planning A, vol. 11, pp. 299-312.

Proposition 1997/98:56, *Transportpolitik för en hållbar utveckling.* The Swedish Government, Stockholm, (in Swedish).

Reneland (1998) *Begreppet tillgänglighet. GIS-projektet Tillgänglighet i svenska städer 1980 och 1995.* The Swedish Transport and Communications Research Board, report KFB 1998:4, Department of Urban design and planning, Chalmers University of Technology, (in Swedish).

Richardson and Young (1982) *A Measure of Linked-Trip Accessibility.* Transportation Planning and Technology vol. 7, pp.73.82.

SFS (1997:652) *Förordning (1997:652) med instruktioner för Vägverket,* Stockholm, (in Swedish).

Sonesson (1998) *Estimering av efterfrågan på långväga persontransporter: En ekonomisk-teoretisk belysning av gängse modeller samt en ny ansats till uppskattning av efterfrågesamband.* Linköping Studies in Management and Economics, Dissertations No. 36, University of Linköping, (in Swedish).

Song (1996) *Some tests of alternative accessibility measures: A population density approach.* Land Economics, 72(4), pp. 474-482.

Swedish Board of Housing (1995) *Boverkets Byggregler.* Report 1995:17, (in Swedish).

Talen and Anselin (1998) *Assessing spatial equity: an evaluation of measures of accessibility to public playgrounds.* Environment and Planning A 1998, vol. 30, pp. 595-613.

Vilhelmsson (1997) *Tidsanvändning och resor. Att analysera befolkningens rörlighet med hjälp av en tidsanvändningsundersökning.* The Swedish Transport and Communications Research Board, report KFB 1997:12, School of Economics and Commercial Law, Göteborg University, (in Swedish).

Wachs and Kumagai (1973) *Physical accessibility as a social indicator.* Socio-Economic Planning Science, vol. 7, pp. 437-456.

Wegener (1998) *Applied Models of Urban Land Use, Transport and Environment: State of the Art and Future Developments.* In Network Infrastructure and the Urban Environment: Advances in Spatial Systems Modelling, edited by Lundqvist, Mattsson and Kim (1998). Springer-Verlag Berlin, Heidelberg, New York, pp. 245-267.