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Geographic Accessibility Analysis - Methods and Application

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Abstract

Geographic accessibility to services is important. Having a grocery store and a school nearby are important living conditions and having a rescue station close by could be a life-saver. Costs for transportation are high and are predicted to increase, new environmental demands are being imposed on transportation and rationalizations are centralizing public and commercial services. These facts make monitoring and planning accessibility increasingly important.

Efficient computer systems for accessibility monitoring and planning could be used to improve accessibility to services. The aim of this study is to establish such efficient methods for geographic accessibility analysis and test them in computer applications. This was performed by studying effective ways of structuring data, algorithms for network searches and implementing these theories in test benches and application prototypes.

Geographic accessibility to services is essential, especially when long distances must be covered, as in rural areas. The Swedish National Rural Development Agency (SNRDA) analyses accessibility to services from a national perspective, with the focus on rural areas. This is done using a computer model that is implemented in a Geographical Information System (GIS). This study investigates the foundations of the representation of road networks, connecting points to a network and accessibility studies through network searches. The results of this dissertation are meant to be used to develop the next generation of the system.

Three papers are presented in this dissertation. The first deals with an evaluation of an existing accessibility analysis system at the Swedish National Rural Development Agency. The focus of the study was to identify performance bottlenecks in the SNRDA's accessibility system and the problem areas that were found would then guide further research. One of the bottlenecks found in the study was the process of connecting points to large networks. This is investigated in the second paper and suggestions for solutions of the problem are presented. The third study is an applied study for planning accessibility to rescue services. This study concentrates on an application prototype called the Rescue Unit Planner (RUP) used for planning accessibility for non-stationary rescue units.

The conclusions of this dissertation are that it is possible to build more efficient systems to perform accessibility analysis. The studies in this dissertation will support the further development of the SNRDA accessibility analysis system, which also was the overall goal.

Sammanfattning

Geografisk tillgänglighet till service är viktigt för människor. Att ha en livsmedelsbutik och en skola i närheten är viktigt för levnadsvillkoren. Att ha en räddningsstation nära kan rädda liv. När kostnader för transporter är dyra och förväntas öka än mer, när nya miljökrav på transporter tas fram och när rationaliseringar gör att offentlig och kommersiell service centraliserar, blir övervakning och planering av tillgänglighet viktigare.

Om effektiva system för övervakning och planering av tillgänglighet tas fram kan de hjälpa till att förbättra tillgängligheten till service. Målet med denna studie är att fastställa effektiva metoder för geografisk tillgänglighetsanalys och testa dessa i datorprogram. Detta genomfördes genom att studera effektiva sätt att strukturera data, algoritmer för nätverkssökning och implementera dessa teorier i testbänkar och prototyper.

När avstånden blir långa som de blir i glesbygd blir den geografiska tillgängligheten till olika typer service än mer viktig. Glesbygdsverket gör tillgänglighetsberäkningar till service i ett nationellt perspektiv med fokus på områden i glesbygd. Detta görs på en datamodell som är implementerad i ett geografiskt informationssystem (GIS). Denna studie undersöker särskilt denna datamodell, dess implementation i det geografiska informationssystemet och de tillgänglighetsberäkningar som utförs. Resultatet av studien skall användas för att utveckla nästa generation av systemet.

Tre artiklar presenteras i denna avhandling. Den första är en utvärdering av det existerande systemet för beräkning av tillgänglighet som finns på Glesbygdsverket. Fokus på denna studie var att hitta flaskhalsar i Glesbygdsverkets system som påverkar prestanda och när dessa problemområden var funna, låta detta styra den kommande forskningen. En av flaskhalsarna som hittades berörde anslutningen av punkter till ett stort nätverk. Detta studerades i den andra artikeln och förslag på lösningar las fram. I den tredje artikeln presenteras en

tillämpad studie av en prototyp till ett planeringsverktyg kallat Räddnings Enhets Planeraren. Prototypen användes för att studera planering av tillgänglighet av rörliga räddningsenheter.

Slutsatserna av denna avhandling är att det är möjligt att bygga ett mer effektivt system för att göra tillgänglighetsanalys. Studierna i denna avhandling kommer att bidra vid utvecklingen av nästa generation av Glesbygdsverkets tillgänglighetsmodell.

Acknowledgements

When I started out working with GIS models for accessibility in the beginning of 90s, little did I guess that it would be a large part of my professional life 15 years later. Working with a subject for so many years means there is a lot of influence from people you meet and texts that you read. Therefore it is a hard task to acknowledge all the people that should be acknowledged.

I have had the privilege of getting the best of three different worlds. The first is the world of the SNRDA where the tools that we develop are used on a daily basis. Here I would like to begin by thanking my three consecutive directors at the SNRDA: Jan Molde, Jan Cederwärn and Inger Normark. They have all three shown patience with me and my research. My colleagues have helped me and been important discussion partners. Imber Råbock, Erik Fransson and Wolfgang Pichler, thank you. From this world, but that of the Swedish Rescue Services Agency, I would also like to thank Anders Axelsson who also is my co-writer in one of the articles in the dissertation.

From the world of computer application development I would like to thank Stefan Hagström, Mattias Sjölén and Joakim Svensberg. You have all have taught me a great deal about computer programming and I am always impressed by the work you accomplish.

From the third and, in this context, the most important world, the academic world, I would like to thank my main supervisor Anders Östman for his vital support. I would also like to thank Martin Palm and Owen Knoote for their work on the projects we have cooperated on. Most of all I would like to thank my assisting supervisor Lars Harrie, because without you this dissertation would not exist.

I think that much of my work has been building bridges between these three worlds, which has been an interesting and inspiring task.

I am grateful to the two organizations that financed the project, the Swedish National Rural Development Agency and the Swedish Rescue Services Agency.

Before I started my studies I wondered why all writers thought it was important to thank their family in their acknowledgements. Now I understand why. Thank you, Inger, Tua, Ida and Gry.

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1 Introduction

1.1 Geographic accessibility

There are several definitions of the word accessibility. Accessibility could be used in a broad perspective, as in Svensson (2007 p.4) "Since the design of our cities tends to constrain people with impairments from performing their daily activities, removing barriers and making public spaces accessible for everyone is becoming a human rights-issue". In this context accessibility would in depend on several parameters (e.g. stairs, narrow passages and high pavements).

Accessibility could also be time related. The opening hours of a grocery store limits accessibility to the store. An ice road is accessible only in winter. In the rush hour a road could lead to low accessibility, while travelling the same road at weekends could give good accessibility.

In this licentiate dissertation the term accessibility is defined as the cost to access a specific set of services, public or commercial. The accessibility is measured as travel distance along a road, in time or space.

1.2 Background

The Swedish National Rural Development Agency (SNRDA) was founded in 1991. The agency's main task was to monitor conditions for people living in the rural parts of Sweden. One problem was how to define and analyse these rural areas. It soon became obvious that areas defined by administrative boundaries were not sufficient as the smallest geographic unit in the analysis the SNRDA wanted to perform.

At this time Statistics Sweden released a new way of describing geocoded statistics in a grid. This meant that statistics like population size, age distribution, employment and education level were available at high resolution with no connection to administrative subdivisions. The SNRDA started to order data using a resolution of 1km tiles.

The next step was to introduce a measure of geographic accessibility to different occurrences to these statistics in order to analyse whether geographical distance had an impact on them. For example, in what way does distance to a university affect the level of higher education in an area? This meant that accessibility analysis had to be performed on a vast amount of grid points. In order to cover Sweden with populated 1km tiles, 120,000 of them are needed.

It also became clear that Euclidian distance did not provide the necessary quality in rural parts of Sweden with its sparse road network. Distances measured in driving time or in spatial distance should be calculated along a road network to obtain results of an appropriate quality. Tests using COTS (Commercial software Off The Shelf) where performed, but none of the tested tools fulfilled the requirements for performance, handling large source databases and transparency. A decision was taken to develop a tool that would fulfil these requirements. A first version of the NetRider function library was developed in 1993 and was put into production the same year. Years went by and in 2000 it was time to start the development of NetRider 2.0 to meet the demand for higher resolution of both statistics on 250-metre population grids and the new Swedish National Road Database (Swedish Road Administration 2007). These higher dataset resolutions meant that the amount of data quadrupled. NetRider 2.0 was put into production in 2002.

In 2003 a decision was taken to develop a third version of the NetRider. This time the developmental approach was to divide it into two parts. The first part was done by taking the initiative to a research project. The result of that project would support the second part of the project, which was the actual software development. The result of the first part, the research, is partly presented in this licentiate dissertation.

1.3 Description of the problem

To get to the heart of the problem that SNRDA has with its accessibility analysis it is important to understand the task the SNRDA has been given by the Swedish government.

"Work for good living conditions and development opportunities for those living in rural areas and the countryside throughout the country, by influencing various sectors of society, with the emphasis on the interior regions of the forest counties and the archipelago areas"

The interpretation of this task is that the population that is in focus lives in geographically remote places. An early presumption in this dissertation is that geographic distance is the most significant accessibility problem for people living in rural areas. This means that measuring accessibility in rural areas is mainly a straightforward geographical distance problem that needs solving. Accessibility analysis in urban areas becomes more complex as regards the classification of target points and the more detailed infrastructure networks that are used for transport. One example of the classification of the target points in urban areas that need dealing with are problems like supermarket chains, meaning that a few extra kilometres of transport is no problem for someone with a preferred supermarket. Whereas for a person living in a rural area where distances between food stores can be 100 kilometres or more, the preferred supermarket chain is of secondary interest. Infrastructure networks also become very complex to deal with in urban areas. The impact of public transportation, one-way roads, turning restrictions and different traffic situations during the day are only some examples of parameters that affect the accessibility. Of course some parameters, like the difference between winter and summer roads, have an impact on accessibility in rural areas.

But generally geographical distance is a good measure of accessibility in rural areas.

So, is it an easy task to perform accessibility analysis in the rural areas? In the sense that it is a simple measurement of time or length between points it is an easy task. But what happens when there is a large area that is monitored using high resolution source data, perhaps even a whole country? The analysis that was previously performed from a national perspective had meant that either the source data had to be generalized to get a level of resolution that the existing accessibility analysis tools could manage or that the source dataset had to be divided into sub areas. When using generalization as a method for solving the problem it is important to understand the original task, where it was the people living furthest out in the rural areas that was the main focus. They are often small in number and will disappear or have a low weighting in a generalized study.

A road network can be simplified by removing the smallest roads, giving a road network that a tool can handle. The problem with this is similar to the last one. People in rural areas often live along these small roads, meaning that the actual situation for these people is not monitored if the small roads are removed. Examining the other possibility, that of dividing the area into sub areas and treating every sub area separately in an accessibility analysis we see that this possibility is viable, but it is ineffective because of the large effort that is needed in the subdivision of the source data. However, this is not the main objection to the method. The main problem is how the division should be carried out.

It is important to include a large enough road network and enough target points to guarantee that the target point that is noted as the closest actually is the closest. If there is only one target point (e.g. a national accessibility analysis to the capital of the country) this means that the whole or at least large parts of the road network must be analysed in one calculation. Note that this method of subdividing the area into two or more separate calculations cannot be compared to the methods of subdivision within a calculation that are suggested later on in this licentiate dissertation.

The conclusion of the reasoning above is that a tool that can handle large amounts of high resolution source data, and also have reasonable performance, is needed to perform accessibility analysis with the focus on rural areas from a national perspective.

1.4 Objectives

The main objective with the study is to investigate and develop efficient methods for geographic accessibility analysis and propose future development actions in an existing computer system (Paper I and II). Part of the study also deals with evaluating tools that use these methods in rescue service planning, especially when dealing with non-stationary units (Paper III).

1.5 Structure

This licentiate dissertation begins with an introduction followed by a background to the project. The dissertation then gives a theoretical and practical overview of the research area and ends with an appendix with three papers. The papers are:

Paper I

Dahlgren, A., and Harrie, L., 2006. Development of a tool for proximity applications, *Proceedings of the 10th AGILE. International Conference on Geographic Information Science*, Aalborg, Denmark.

Paper II

Dahlgren, A., and Harrie, L., 2006. Evaluation of computational methods for connecting points to large networks. *Mapping and Image Science*, Swedish Cartographic Society, 2006:4, pp. 45-54.

Paper III

Dahlgren, A., Harrie, L., and Axelsson, A., 2008. Planning rescue services with non-stationary rescue units. *Fire Technology*, In Print, Published online May 1, 2008, The article is published in this licentiate dissertation with the kind permission of Springer Science and Business Media.

In papers I and II the author conducted the studies, apart from the implementation of the Morton Code in study II. The paper was equally prepared with the co-writer.

In paper III the author and the co-writer Lars Harrie conducted the studies and prepared the paper equally. Co-writer Anders Axelsson wrote the background chapter.

2 Principles of accessibility analysis

2.1 Introduction

Accessibility analysis is a common task in GIS. It could be a very simple analysis using Euclidian distances or a very advanced analysis that uses road networks with complex restrictions (i.e. turning restrictions or one-way roads). Accessibility calculations are even described in introductory books on GIS (e.g. Bernhardsen 1999). Accessibility analysis can be said to be one of the fundamental analyses of GIS.

In chapter 1.1 we provide the definition of accessibility used in this project. This geographic distance is discussed at the beginning of this chapter. The chapter continues by giving examples of how the results of accessibility analyses are presented.

2.2 Measures of accessibility.

It is both possible and quite common to use Euclidian distances to measure geographic accessibility. In areas where there is a dense infrastructure network this works quite well. It is also common to introduce a factor that compensates for the fact that the roads do not go straight between the points between which the distance is measured.

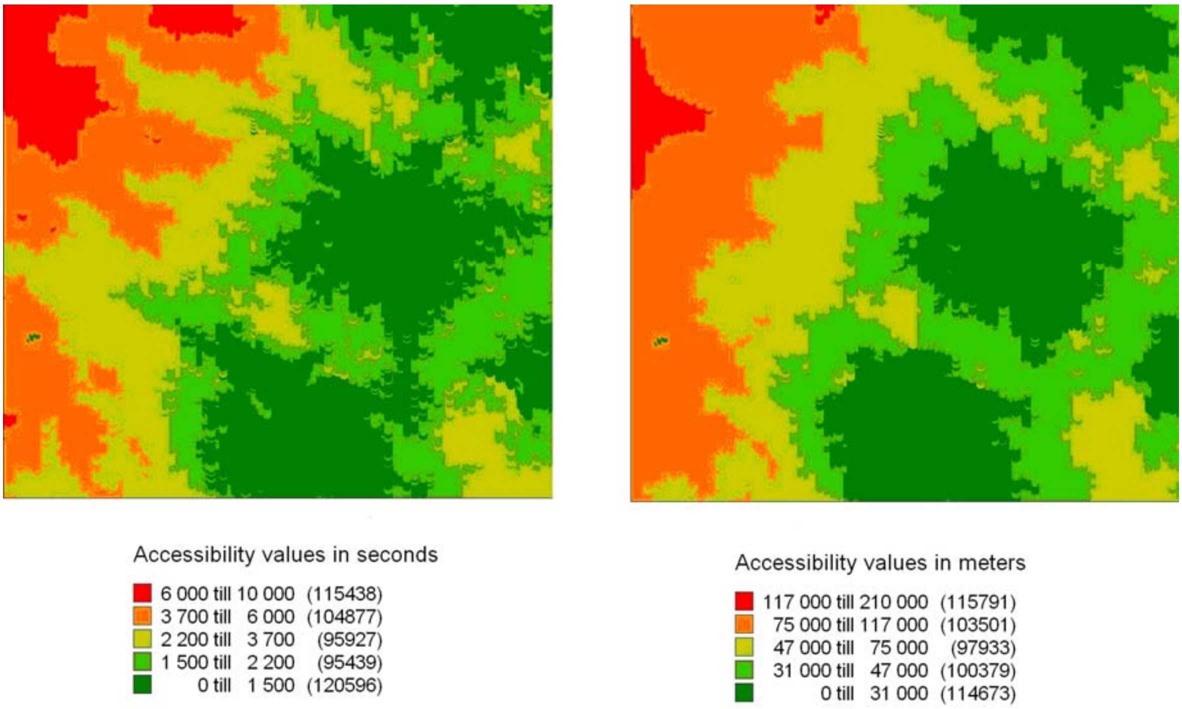
It is not optimal to use this method in rural areas. Rural areas, with their sparse road network and natural obstacles like lakes and mountains make it harder to model accessibility using Euclidian distances. Of course, natural obstacles may also be a problem in urban areas, but those problems are more often solved with new roads, tunnels or bridges.

2.3 Measure in space or in time

For the common user of accessibility analysis systems it is intuitive to measure distances using a spatial measure. It is easy to interpret such a measure when it is outlined on a map. The problem with spatial measures is that they do not take account to the speed at which you can travel along the road network.

Measuring accessibility in units of time often provides a more realistic analysis, but it will also place higher demands on the source data and the parameters used in the calculation. Source data in the form of road networks with an attribute describing the road class is needed. The road class that is given to a road segment is then used in a speed table to calculate how long it takes for a vehicle to travel that segment. If different vehicles travel at different speeds depending on the road class, each vehicle should have their own speed table.

If time is used to the centre of a town in the analysis (Figure 2.1a) the thematic maps often give a “star-like” shape of the iso-layers in the map, due to the major, fast roads that take people long distances in a short time. If a spatial measurement is used (Figure 2.1b) the map has a more “rounded” shape, where all roads, independent of class, are treated equally.



(a) (b)

Figure 2.1 *The difference in measuring accessibility in time distances (seconds) and in spatial distances (meters).*

2.4 Barrier problems

Barrier problems in accessibility studies are studied by Berglund (2001, p.121), for example. He defines barriers as “a discontinuity in travel costs that leads to a corresponding discontinuity in travel flows”.

It is interesting to study the effect that administrative boundaries, such as national borders or municipal boundaries, have on accessibility analysis. Boundaries can act as barriers that make obstacles for people. When dealing with accessibility to grocery services the administrative boundaries have no impact. A person who wants to buy groceries does not mind passing a boundary on his way to the closest grocery store.

When analysing accessibility to labour markets a national border could be an obstacle due to different tax systems on either side of the border. If the accessibility study deals with a municipal service, such as stations for waste disposal, the accessibility study is naturally limited by the municipal boundaries. The interesting fact is that if you only perform accessibility studies within a municipality, there is certainly no problem with the performance of the tools that calculate the accessibility. Even when performing a nationwide calculation, where the municipal boundaries define small geographic areas, there should be no problem in setting up a batch to conduct the calculations individually for each municipality. If there are no barriers the nationwide study becomes more of a challenge from a performance point of view; large source datasets must be handled in one analysis.

Boundaries that affect accessibility analysis but are not strict barriers are called weak barriers. Weak barriers are hard to analyse when they are difficult to model.

2.5 Navigation versus accessibility

There is a difference between navigation and accessibility studies. When you look at the tasks they initially appear to be very similar. Calculating the distance between a start point and a target point is fundamental to both tasks. One major difference is that in navigation you have to describe a route to the user. This is not necessary in accessibility calculations. This implies that there is a more efficient way of generalizing the network.

Whereas in navigation you need to keep track of the original network to produce the route for the user, you are able to discard all the unnecessary data in accessibility analysis (internal nodes, dangling nodes). In navigation it is common to produce a simplified network to perform the network search, but you still need to keep track of the original network through a mapping table.

2.6 Visualization of results

The results of accessibility calculations can be presented in several ways. Let us presume that we are interested in the accessibility from a start point to the closest of many target points. When a distance from the start point to the closest target point is calculated, the value of this distance is added to the start point object as an attribute. This value can then be put into a number interval to aggregate other attributes of the start point into groups according to their accessibility to the target point. An example of this is given in table 2.1 where accessibility to cash dispensers is analysed in differently populated areas of Sweden. The area definition given in the type of area column is an example of an area definition that is based on accessibility (Figure 3.1).

Table 2.1 *Travel distance by car in minutes to the closest cash dispenser for the Swedish population..*

Type of area	Population 2006	10 — < 20 minutes	20 — < 30 minutes	30 — < 40 minutes	40 minutes or more
Sparsely populated areas	147,283	30,004	24,259	17,948	11,137
More accessible rural areas	1,969,151	739,538	82,861	4,249	26
Urban areas	6,965,194	17,376	141	0	0
Total	9,081,628	786,918	107,261	22,197	11,163

It is often convenient to present accessibility data in thematic maps. In accessibility analysis neighbouring points often have similar accessibility values which give the maps an appealing appearance. Deviation from an expected pattern is easily detected in a thematic map.

Examples of thematic maps are given in Figures 2.2 and 2.3. Figure 2.2 shows the national accessibility to airports in a national perspective. Figure 2.3 shows accessibility from rescue units in a municipality in a municipality perspective.

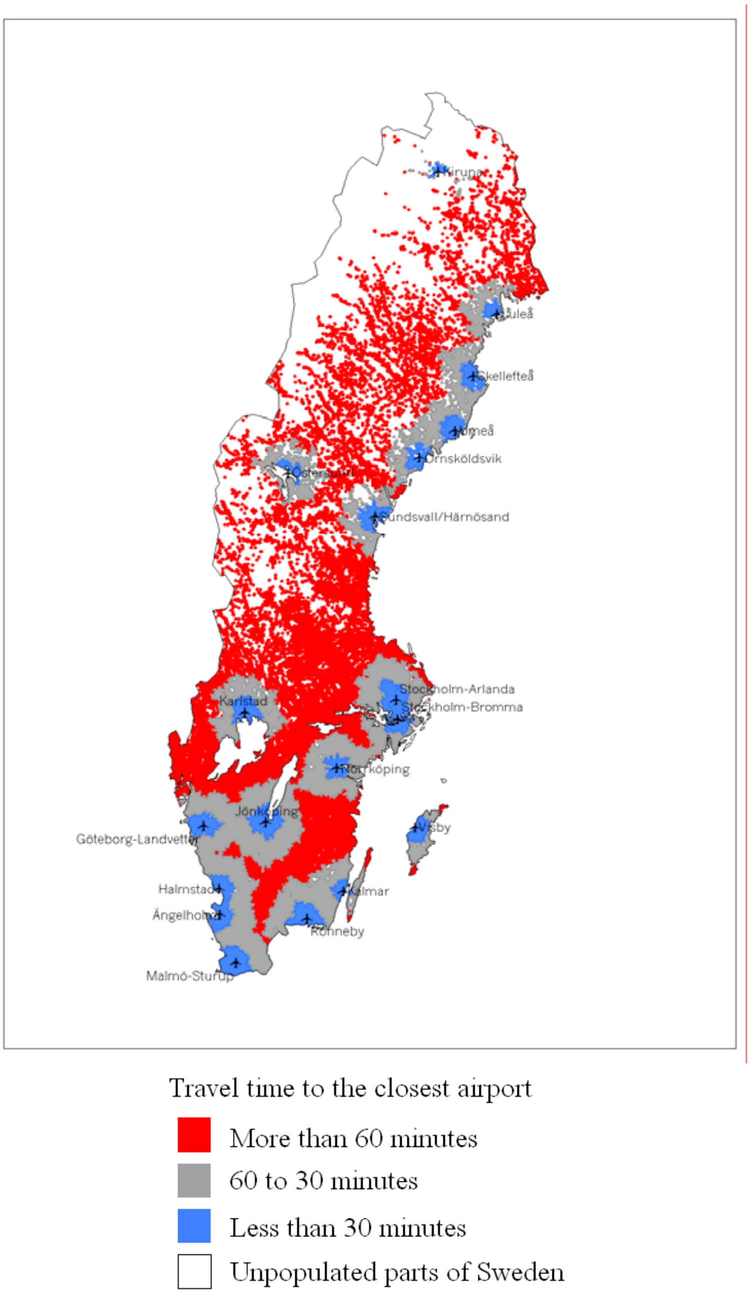


***Figure 2.2a** Accessibility to airports in Sweden, Glesbygdsverket (2007, p.62). Airports owned by the state.*

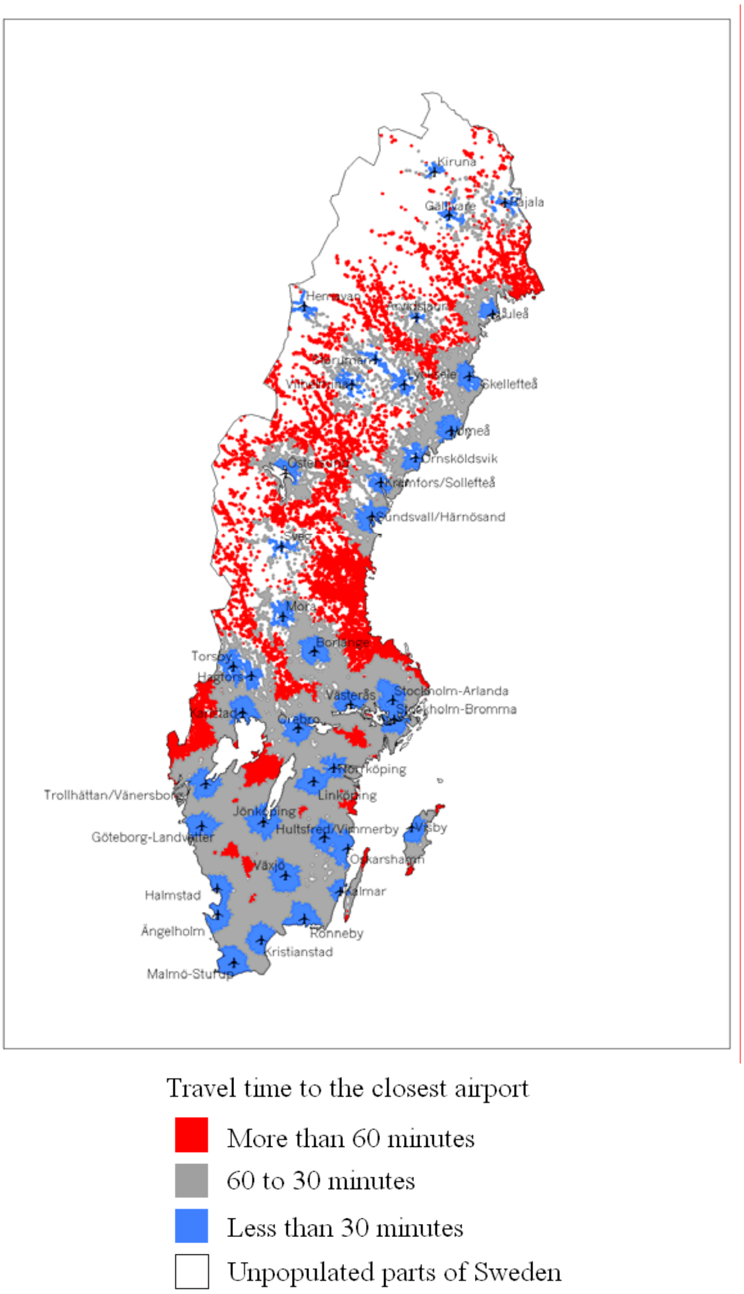


***Figure 2.2b** Accessibility to airports in Sweden, Glesbygdsverket (2007, p.62). Airports owned by the state and airports owned by municipalities but financially supported by the state.*

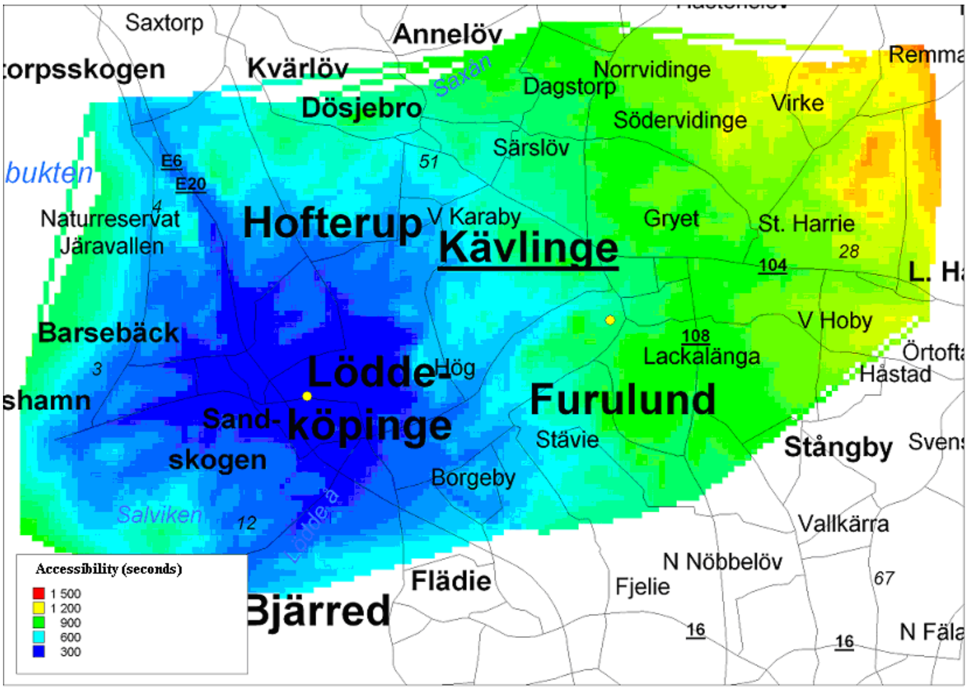


Figure 2.3 *The map shows the time in seconds for a rescue unit stationed in Löddeköping to reach different parts of the municipality, Adavi (2007, p.13).*

Up to now the presentation methods can be seen as standard GIS-presentations, often supported by functions in desktop mapping systems. There are also more unusual presentation methods. If such presentations are used in the right way it could help to enhance something of interest in the accessibility analysis. The connectivity diagram or, as it is also called, a "spider" diagram qualifies for this category, see Figure 2.4. The diagram focuses the connectivity between towns above a certain size in northern Sweden. The presentation is built on an ordinary accessibility analysis but the connectivity between the towns is accentuated by selecting some data from a larger dataset and presenting it in the diagram.

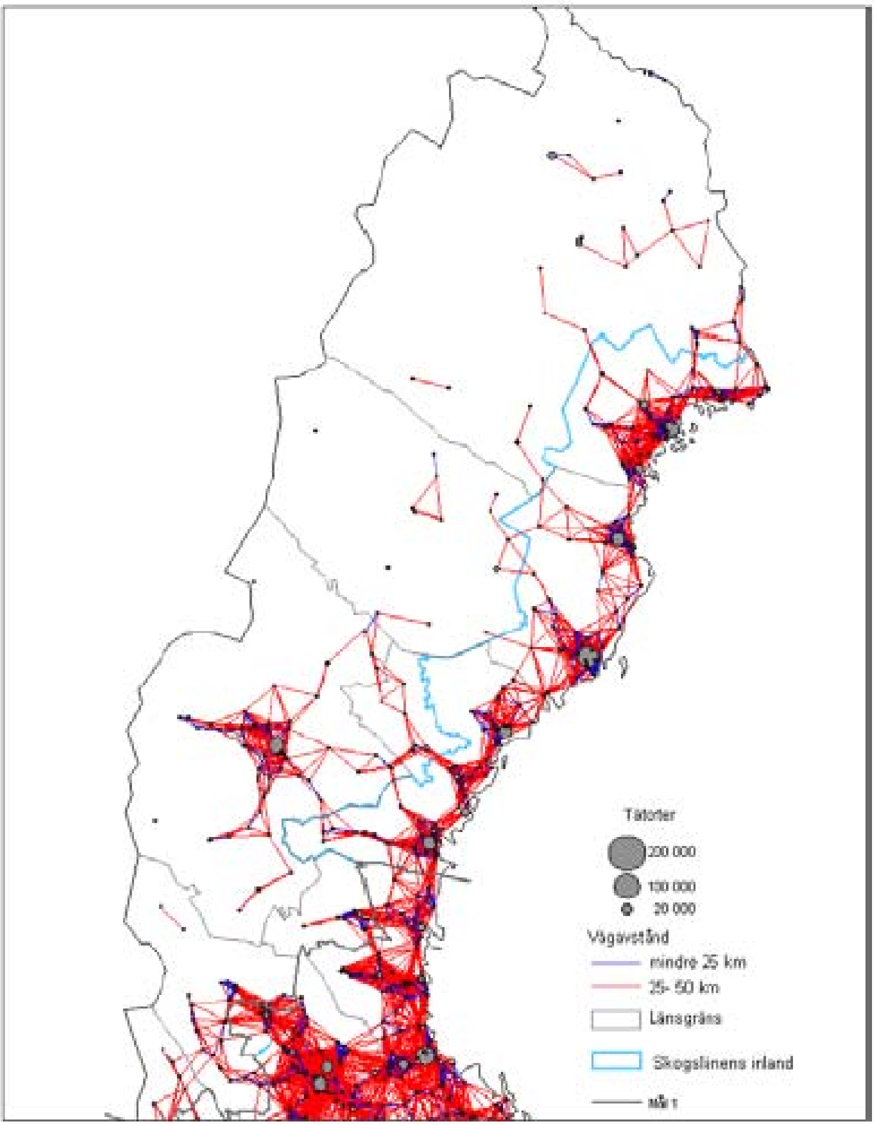


Figure 2.4 *Connectivity diagram that indicates the level of connectivity for towns in northern Sweden, SNRDA (2003b,p.17). The red lines illustrate a distance interval of 25-50 kilometres and the blue lines a distance less than 25 kilometres.*

3 Accessibility analysis in practice

3.1 Introduction

In this chapter some examples of accessibility analysis in practice are presented.

What these examples have in common is that they would benefit from getting access to an effective platform for accessibility calculations in the analysis.

3.2 Classification of geographic areas

Accessibility is often used to define areas. Governmental agencies use these classifications in order to distribute different kinds of funds, for example. One of the SNRDA's classifications uses travel time to towns with more than 3,000 inhabitants, according to Figure 3.1.

- The first intervals are inside or less than 5 minutes travel time outside the border of a town with no less than 3,000 inhabitants. These are called urban areas.
- The second interval is between 5 and 45 minutes travel time from a town with no less than 3,000 inhabitants. These are called more accessible rural areas.
- The third interval is over 45 minutes travel time from the 3,000 inhabitant towns. These are called rural areas.

This definition can then be used for examining statistics that are geocoded. An example of this could be investigating whether trends in grocery store closures are exaggerated due to a rural location. See table 1 for another example.

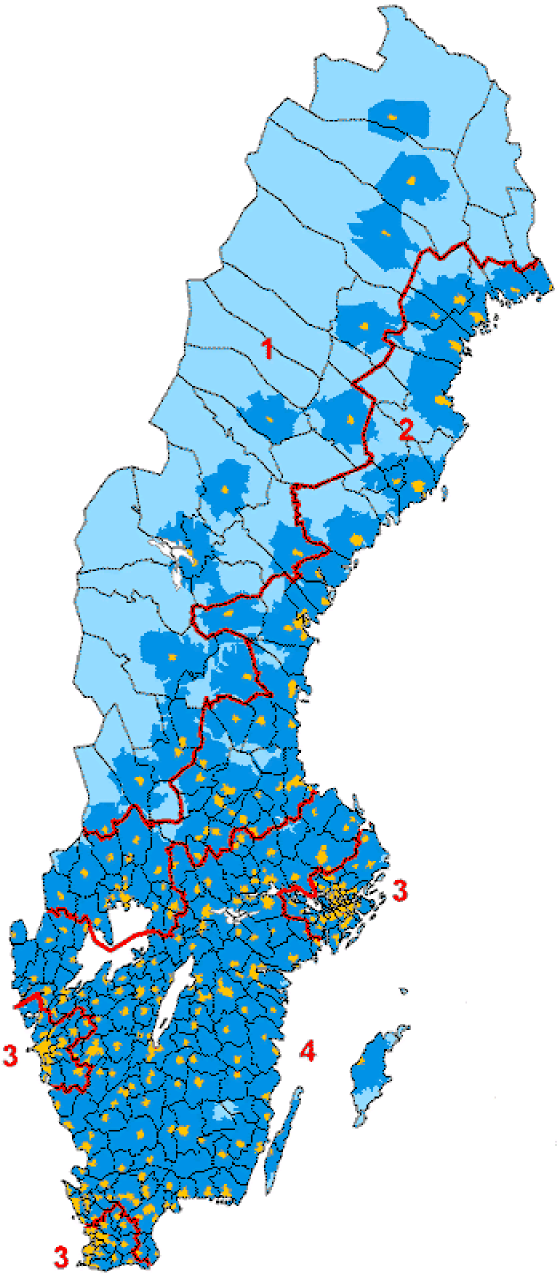


Figure 3.1 *The SNRDA´s definition of rural (light blue), accessible rural (dark blue) and urban areas (yellow) in Sweden, SNDRA (2006, p.2)*

The European Spatial Planning Observation Network (ESPON) also uses geographic accessibility to define areas, at a European level. Figure 3.2 presents the potential accessibility by road to the centre of Europe. These kinds of classifications are used in analysis and as a base for distributing European funds.

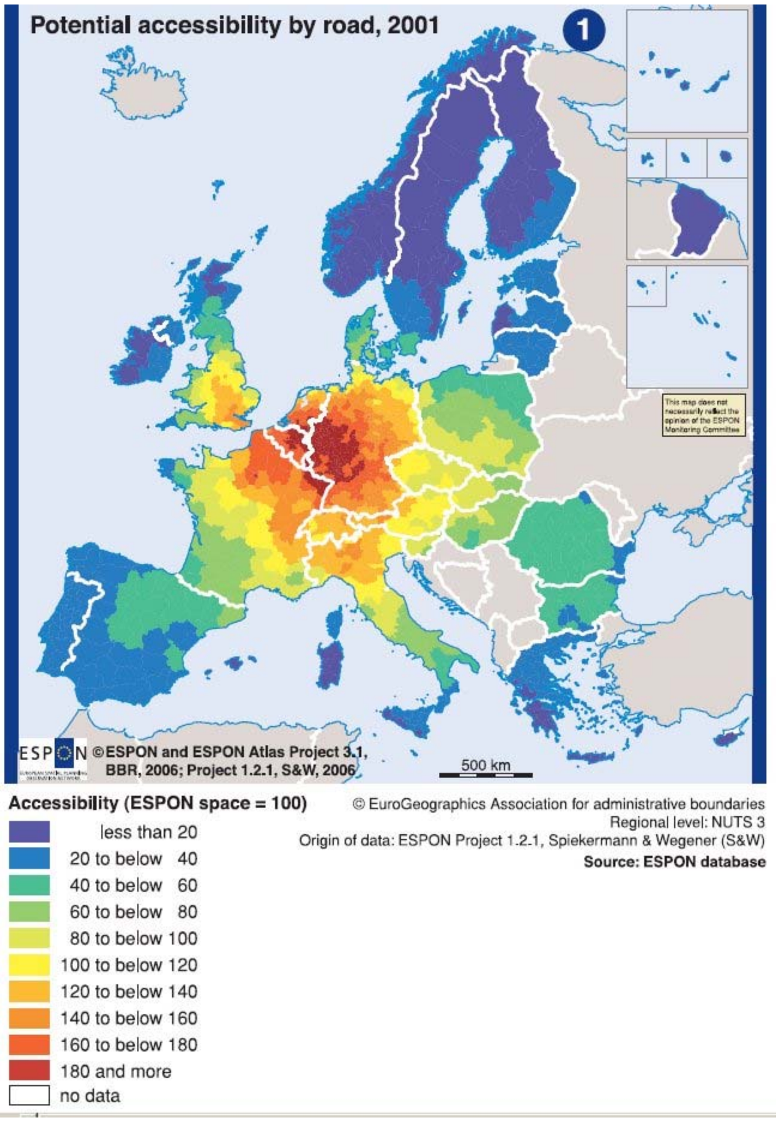
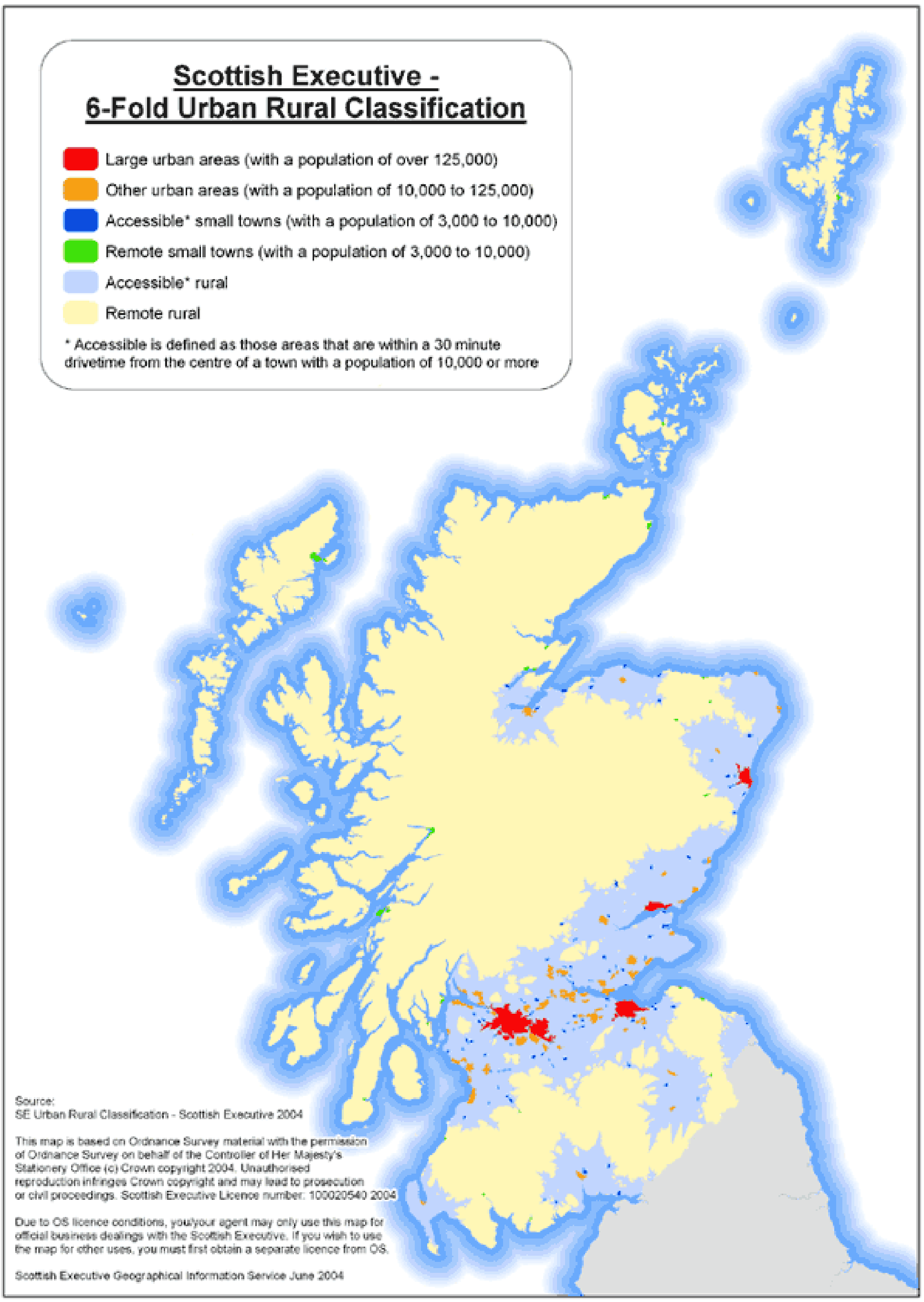


***Figure 3.2** Potential accessibility by road, ESPON (2006, p.33)*

The Scottish definition of rural areas is based on an accessibility measure (Scottish Government 2004). It resembles the SNRDA definition when based on travel distances to towns. The distance is measured from towns with more than 10,000 inhabitants and areas that are more than 30 minutes travel distance by car are considered remote. Smaller towns in the interval between 3,000 and 10,000 inhabitants are added to this accessibility measure in their own categories. Large urban areas over 125,000 inhabitants are also defined in their own categories. This makes a total of 6 categories shown in Figure 3.3, compared to the 3 defined by SNRDA (Figure 3.1).



Scottish Executive - 6-Fold Urban Rural Classification

* Accessible is defined as those areas that are within a 30 minute drivetime from the centre of a town with a population of 10,000 or more

Source:
SE Urban Rural Classification - Scottish Executive 2004

This map is based on Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office (c) Crown copyright 2004. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. Scottish Executive Licence number: 100020540 2004

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Scottish Executive Geographical Information Service June 2004

Figure 3.3 *The Scottish area definition based on an accessibility measure. Scottish executive (2004) p.10.*

3.3 Governmental agencies

The SNRDA (Glesbygdsverket) (2001–2006) uses accessibility analysis to monitor the accessibility in rural areas. This monitoring can be used to evaluate political decisions. The government can decide on a fund to support e.g. small grocery stores. To evaluate if this funding got the proper result the SNRDA can study if the accessibility improved for the people the founding was aimed for.

In 2003 a new Swedish law (SFS 2003:778 *Swedish Civil Protection Act*) stated that the population should have equivalent accessibility to rescue services and emergency care. The SNRDA can evaluate if this law is complied with. One indicator of this is the accessibility to ambulance centrals. In Figure 3.4 is the accessibility to ambulance centrals presented. This national wide data could then be broken down on the areas of the responsible county's and detailed statistics can be presented.

The British equivalent of the SNRDA monitors the state of the British countryside every year in the report "The state of the countryside" (Countryside Agency 2005). Also in this publication accessibility studies are studied in an prominent manner.

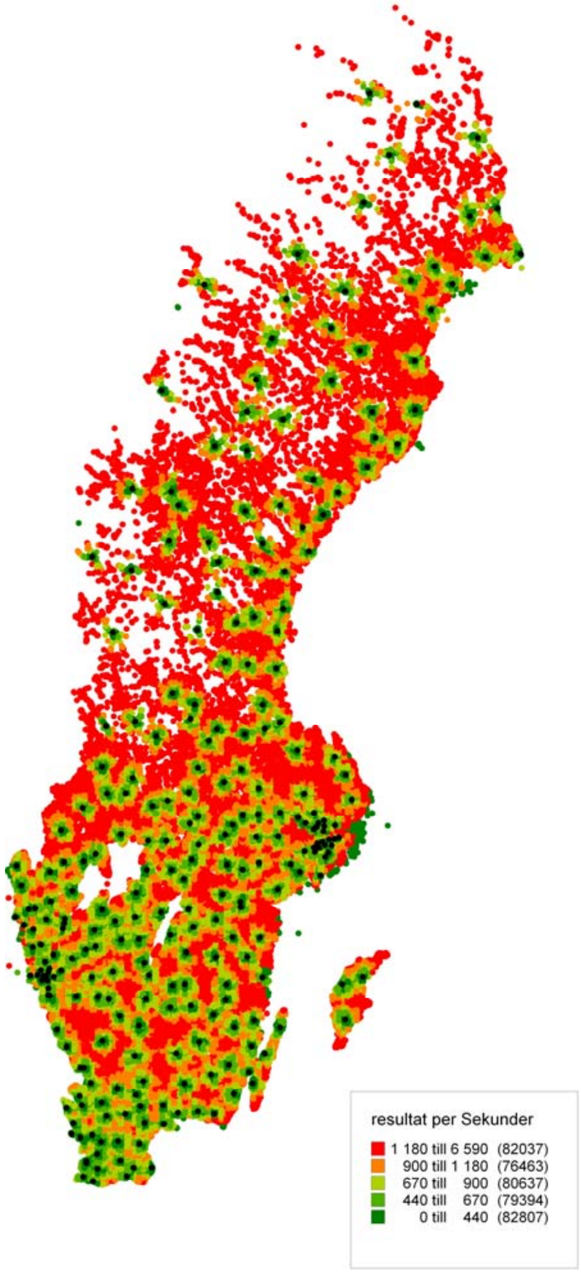


Figure 3.4 *The accessibility to ambulances measured in seconds (adapted from SNRDA 2006,p.12)*

3.4 Rescue Services planning

Accessibility is important for rescue service planning. Arriving at traffic accidents or fires as fast as possible could be the difference between life and death. At the least, access to rescue services can save things of great financial value (Jadell 2004). Rescue services have, after being fairly conservative and static in their planning, started to make organisational changes. These changes are being driven by technical developments (e.g. non-stationary rescue units), reductions in funding and new legislation. See paper III for a more thorough explanation of this. Accessibility within rescue services as a part of the planning process is studied in Palm (2006), Andersson (2007, 2008), Adawi (2007) and Svensson (2006), for example.

3.5 Transport Modelling

It is common to use a GIS with functions for accessibility analysis in transport modelling. Berglund (2001) models transports with a GIS where he addresses subjects like detecting barrier and travel demands. Liu (2004) studies urban transport planning by developing an accessibility analysis framework built on a commercial GIS platform.

Both studies devote a significant part of their research to discussing the platforms they use to conduct their studies. Berglund (2001, p.15) establishes that "in most GIS applications, data are used for display and simple manipulations. Transport models on the other hand are computationally very intensive, which requires efficient storage and fast access to data". Berglund chose to use the specialised tool TransCAD (2008). Liu (2004) states that the functionally that they require cannot be found in commercial software and develops their own functions in the ArcView GIS environment ESRI (2008). The decision was made due to the importance of having functions already present within the

ArcView GIS environment, such as standardized database handling and visualization, at the cost of less efficient calculations.

3.6 Simulations

A common way of finding the best solution to a location problem is to compare scenarios. The comparison could be performed by using a measure of accessibility. This measure is calculated for each scenario and the scenario that gives the best value in the accessibility measure is considered to be the best solution. Two examples of this are the BeRädd project (Svensson 2006) where rescue units are placed according to an optimization and the other is the tax distribution application described in 6.3.

What these scenarios have in common is that a number of accessibility scenarios are evaluated. If effective engines for these calculations are used, then more scenarios can be evaluated and a better solution can be found.

3.7 Accessibility index

One problem when calculating accessibility is categorizing the service points. For example, if we want to calculate the rural population's accessibility to groceries. Should we calculate the distances to the closest grocery store independently of the size of the store? Does a petrol station that sells some groceries fulfil the demands? One way of getting around this problem is to look at the accessibility to different size intervals of stores and combine these distances into an index. This, combined with other visualization methods, can help to provide an overview of the accessibility situation.

As an example of the above an index was calculated for the whole country with the distance to different sizes of cities/villages. Distances to five size levels of cities/villages are measured. The size levels are:

- Level 1 over 3,000 inhabitants
- Level 2 over 10,000 inhabitants
- Level 3 over 20,000 inhabitants
- Level 4 over 50,000 inhabitants
- Level 5 over 75,000 inhabitants

The distances are then normalized to a value between 0-100. The five values are then added together into an index and presented as in the thematic map in Figure 3.4.

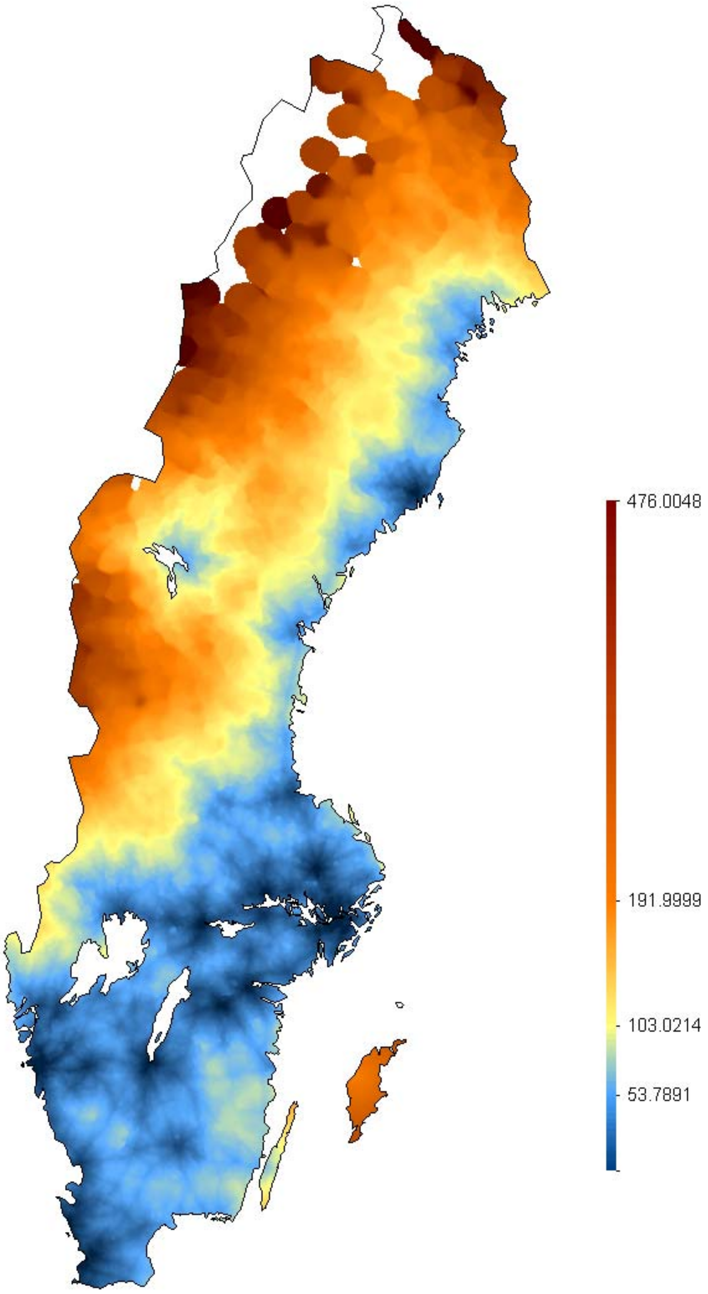


Figure 3.4 *A thematic map of an accessibility index to five different sizes of cities/villages.*

4 Spatial data structures

4.1 Introduction

In this chapter we look at some of the fundamentals of spatial data structures that have an impact on the work in this study. A multi-purpose GIS needs to select a carefully weighted type of spatial data structure. The various tasks that the multi-purpose GIS needs to handle makes compromise inevitable regarding performance enhancing choices for spatial data structures. One of the presumptions in this study is that if a careful selection of spatial data structures is carried out and adapted for the sole purpose of calculating accessibility, better performance could be gained.

4.2 Spatial indexing

As with any index the spatial index is way of structuring data for the efficient retrieval of data. This can be performed by building a separate data structure with the purpose of pointing at an already existing dataset. It can also mean that the actual dataset is sorted in a way so that fast searches in the dataset are possible. Samet (2006, p.27) states that "This means that the representation involves sorting the data in some manner to make it more accessible". Using ordinary methods for indexation in the Cartesian plane becomes difficult because the plane lacks order in one dimension. This means that an artificial order must be constructed. This is studied in Paper II.

When the index is in place it becomes possible to make selections in the spatial database with common spatial selections, such as within or closest. These questions require a linear search without a spatial index. The foundations for a spatial indexing and suggestions for spatial indexation methods can be found mainly in the specialised book Samet

(2006) but also in more general books as Worboys (1995), and de Berg (2000).

In large spatial datasets the problem with performance becomes exaggerated. When the performance requirement for implementation increases, the choice and implementation of a spatial indexation becomes a delicate task.

In order to test and fine-tune searches in large databases a test bench was implemented, the *Geographic Index Laboratory* (GIL), which is presented in detail in paper II. In this test bench it is easy to choose implement indexation methods and parameter values. It is even possible to implement new indexation methods and compare them to the existing ones when the code to the application can be freely downloaded at MapProx (2008). Comparisons could then be made with a focus on the methods, with little interference from underlying systems.

4.3 Graph theory

The last step in the calculation of accessibility is the network search. If a network search is to be performed it is necessary to structure the data in a way that supports network searches. We need to build a *graph*. *Graphs* are defined as “a highly abstracted model of spatial relationships, and represents only connectedness between elements of the space” (Worboys 2000, p 134). The fundamentals of *Graph theory* have been well studied and documented in mathematics and computer science (e.g. Ahuja 1993, Samet 2006 and Gross 2004).

5 The accessibility calculation process.

5.1 Introduction

In this study seven-steps are used to describe the process of calculating accessibility. This process is used in the NetRider described in chapter 6. It is important to understand that the flow through the steps is not necessarily performed in the order stated below. Some of the steps can be performed as pre-processes or in a different order to the one suggested. It could also enhance performance to perform more than one step in one calculation step when linear searches of the datasets are performed. All steps must be considered in some way in order to obtain a complete and effective calculation solution for large source data sets. The steps are:

1) Import the network
2) Add a spatial index
3) Connect points to the network
4) Build topology in the network
5) Generalize the network
6) Perform network search
7) Export the results

5.2 Import the network

A network that is delivered from the network producers is most often delivered in an unstructured format. In this case unstructured means that no spatial index or topological connections between objects are included. Selecting parts of the geometry or changing attributes in a desktop GIS is a fairly simple task using this format. However these formats do not support network computations like connecting points or finding the shortest route.

If the accessibility analysis application uses advanced functions such as turning restrictions and one-way roads, the demands on the attributes on the network increase. Measures for accessibility analysis that use time need to have information about the travelling speed on the road segments. This is normally given by allocating a class to each road segment and a description of each class with the delivery. It is then up to the user to allocate a speed to each network segment class.

If the network is large it is common to divide it into smaller geographic areas and then perform further calculations on each of the sub-areas (see paper I). The import function should aim at making the sub-areas in same size and trying to minimize the network connections between the sub-areas.

5.3 Add a spatial index

The network sub-areas imported in the previous step now need to be complemented with a spatial index. The spatial index is an auxiliary data structure, as described in 4.2. The performance of the spatial indexation methods differs a lot between the datasets involved. For example can a dataset where the spatial object are distributed evenly could benefit from using one type of a spatial index while a dataset with unevenly distributed spatial object could benefit from another.

The implementation of two spatial indexation methods has two purposes. Firstly the user can choose the indexation method that fits the source datasets and secondly a reference is needed in the development of routines for creating the spatial index and the parameter settings of the methods. Using small datasets this reference could be constituted by a brute force search of the network, but in large datasets this is impossible because of the long calculation times.

5.4 Connect points to the network

In this step the start and target points are defined. The spatial index is now used to connect the points to the network. It is important to maintain a representation of the original geometry of the network in this step to make it possible to connect the points to the network in the right place. Points can be connected to the network at nodes or at the closest position on an edge. See Figure 5.1. Note that when a node is connected on a edge the edge must be parted into two edges and a new node is introduced.

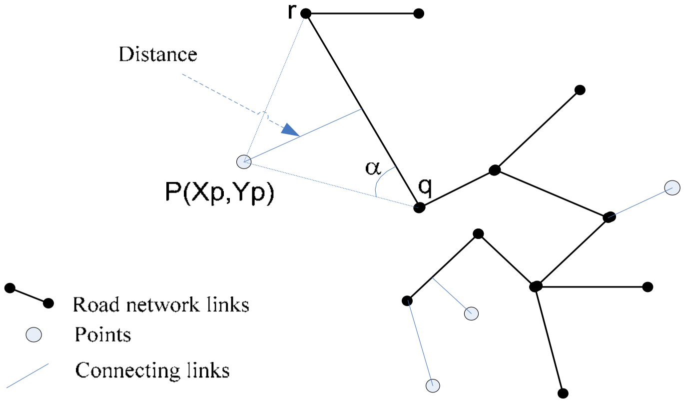


***Figure 5.1** Connecting points to a network. The points (e.g. P) are connected to the closest line segment (e.g. q->r) in the network. The points are linked to the network through a connecting link. (Figure from paper II).*

5.5 Build graph structure from the network

A graph structure is now built from the unstructured network. A graph structure consists of nodes and edges. Each node knows what edges are connected to it. Each edge knows what nodes are connected to the ends of the edge. The nodes and edges are often implemented in object orientated programming as objects. The connections between the object are implemented as pointer attributes within the objects. Another way of storing these connections is to use an *adjacency-matrix*. (See Cormen 2001, p.529).

It is important to use an effective structure to describe the graph. If the size of the graph is minimized, larger geographic areas can be held in the internal memory at the same time. This leads to less reading and writing to a secondary memory during a calculation that covers a large geographic area.

5.6 Generalize the network

At the beginning of this step the source data is a graph with connected points. The network normally contains unnecessary information that should be removed before moving on to the next step. Internal nodes and dangling nodes can be removed without the negatively affecting the results of distance calculations in the network search. In Figure 5.2 the illustration shows an original network before the process of generalization. Figure 5.3 shows the same network after the generalization process of removing dangling and internal nodes.

Instead of letting the geometry of the network describe the distances between nodes it is now convenient to remove all internal nodes and store the distance as an attribute of the edges. Note that for time values a valid speed table must be available at this stage. One of the generalizations is that all nodes connecting two edges should be removed, leaving the network with start and target nodes and nodes with more than two edges connected to them.

***Figure 5.2** An original network before generalization.*

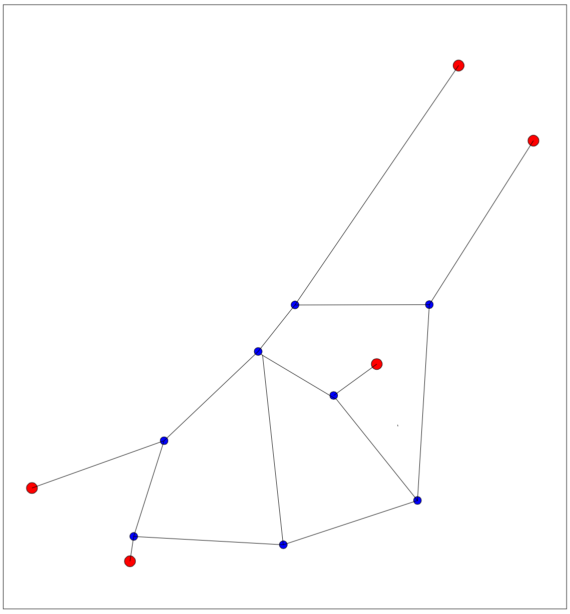


***Figure 5.3** The same network shown in Figure 5.2 after generalization.*

5.7 Perform network search

Network search algorithms are often divided into two groups, depth first and breadth first.

The depth first algorithms are convenient when a fast solution is needed to a distance calculation between two known points. These algorithms are commonly used in navigation. One example of an algorithm that uses a depth first approach is the A*-algorithm. When using a depth first algorithm it is common to be satisfied with an approximate solution in order to obtain short calculation times.

Breadth first algorithms, like the Dijkstra's algorithm, Dijkstra (1959), are more commonly used in accessibility analysis. In accessibility analysis it is common to have calculations between many start points and the unknown closest target point. This fits the behaviour of the breadth first algorithm. The breadth first algorithms give broadly correct answers and are generally slower than depth first algorithms if only one distance is to be calculated. Modifications leading to improvements in the Dijkstra's algorithm have recently been developed. Some of these developments are summarized and evaluated in Sanders (2005).

When the points are connected to the network and a graph structure is built the spatial index is no longer needed. If the following network calculations are memory consuming it may be rational to remove the structures for spatial indexation from the computer's internal memory.

Network searches are treated in many places in GIS related literature. For example, Bernhardsen (1999), Ahuja (1993), de Berg (2000) and Worboys (1995).

5.8 Export the results

After the network search the results are stored in the graph structure as attributes in the start nodes. The values must be exported to a results file or database in a format that is convenient for the user to analyse. One way of performing this is to add the accessibility values to the start point dataset as an attribute. Giving the accessibility as an attribute to the spatial object start point will make it easy for the user to analyse the result using visualization in thematic maps, for example.

6 The NetRider function library

6.1 Introduction

The NetRider function library is the accessibility analysis engine that has been developed and used at the SNRDA. The NetRider implements the seven steps that are given in chapter 5. The library was originally developed in the beginning of the 90s; the aim of the development of NetRider has always been to have an accessibility analysis function library that can handle large amounts of source data sets in an effective manner.

Some important decisions were made when the second generation of the NetRider function library was developed. In the first generation the tool was built as a stand-alone application. This meant that the accessibility calculation functionality and the user interface were built together in one binary file. At this time it was clear that the accessibility functionality could be used by other applications or systems and it was decided to separate the user interface from the function library. The application that uses the functionality of the NetRider library for straightforward accessibility is called MapProx. This has the same functionalities as the earlier versions of the accessibility tool.

One demand on the tool performing accessibility analysis was that it should be a part of larger systems that would use NetRider as a component. The SNRDA has opened up the opportunity for other organizations to carry out development using NetRider. Figure 6.1 shows a schematic overview of the NetRider function library and the applications that are dependent on the functions offered in the function library. It is important to define the interface between the system and underlying functions. This allows changes on both sides of the interface without them interfering with each other. An example of this could be that the introduction of a new version of

NetRider should be no problem as long as the interface's definition is complied with.

It could be discussed whether source datasets (e.g. road networks and population) are part of the function library. The applications that currently use NetRider also use the source data that are part of the datasets supplied by the SNRDA. Future developers of applications built on NetRider can use their own source data and then the data should be described as being handled outside NetRider.

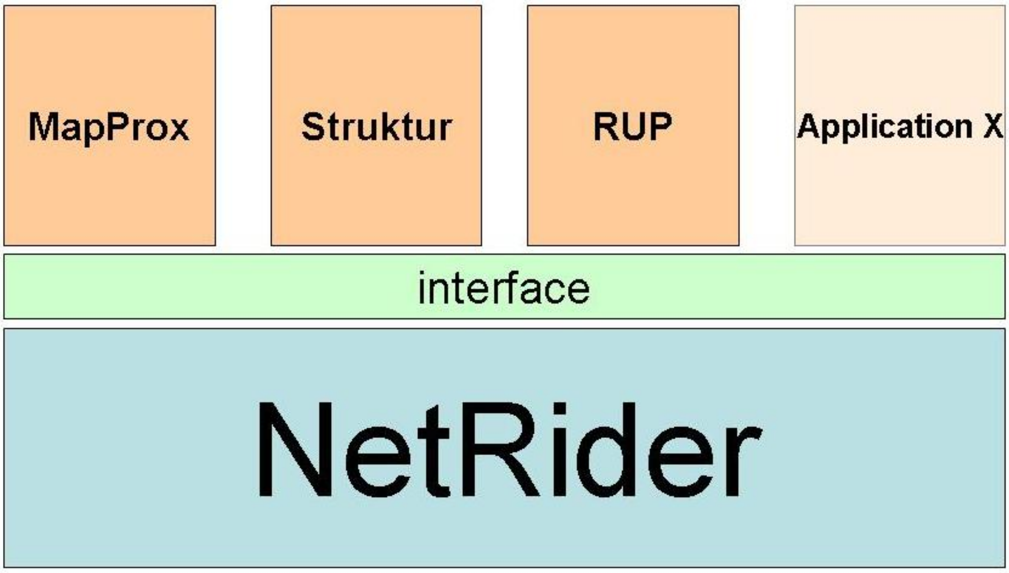
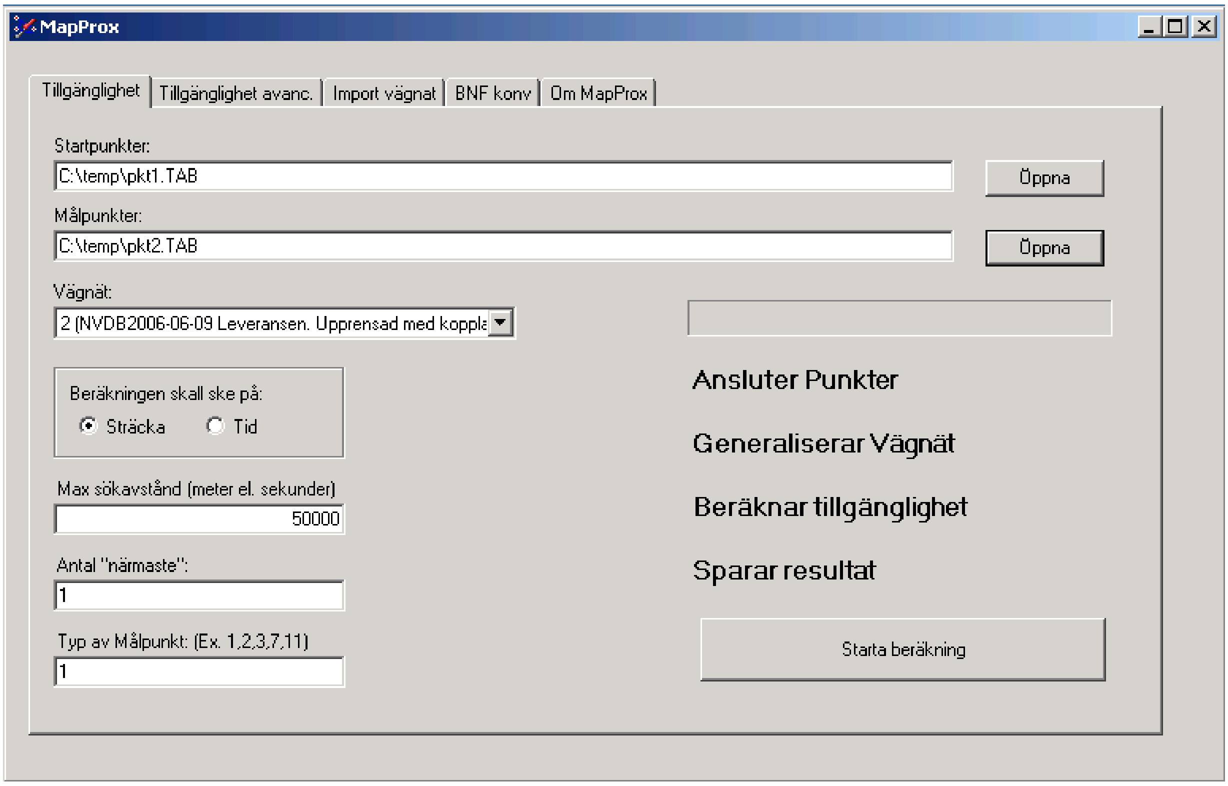


Figure 6.1 *Outline of the NetRider function library and the applications built on it.*

6.2 The MapProx application

MapProx is a small user interface developed as a tool for officers at the SNRDA when performing accessibility analysis. As shown in Figure 6.1, the box describing MapProx is an application that relies on the functionality in NetRider.

The user interface in Figure 6.2 is used for setting the parameters of the accessibility analysis, such as what source data should be used, whether the calculation should be done as a time or spatial measurement. When large calculations are made, with calculation times in the magnitude of hours, it is important to continually inform the user of progression of the calculation. Examples of output from MapProx are shown in Figures 2.1, 2.2 and 7.1.



Startpunkter: C:\temp\pkt1.TAB

Målpunkter: C:\temp\pkt2.TAB

Vägnät: 2 (NVDB2006-06-09 Leveransen. Upprensad med koppl

Beräkningen skall ske på: ● Sträcka ○ Tid

Max sökavstånd (meter el. sekunder) 50000

Antal "närmaste": 1

Typ av Målpunkt: (Ex. 1,2,3,7,11) 1

Ansluter Punkter

Generaliserar Vägnät

Beräknar tillgänglighet

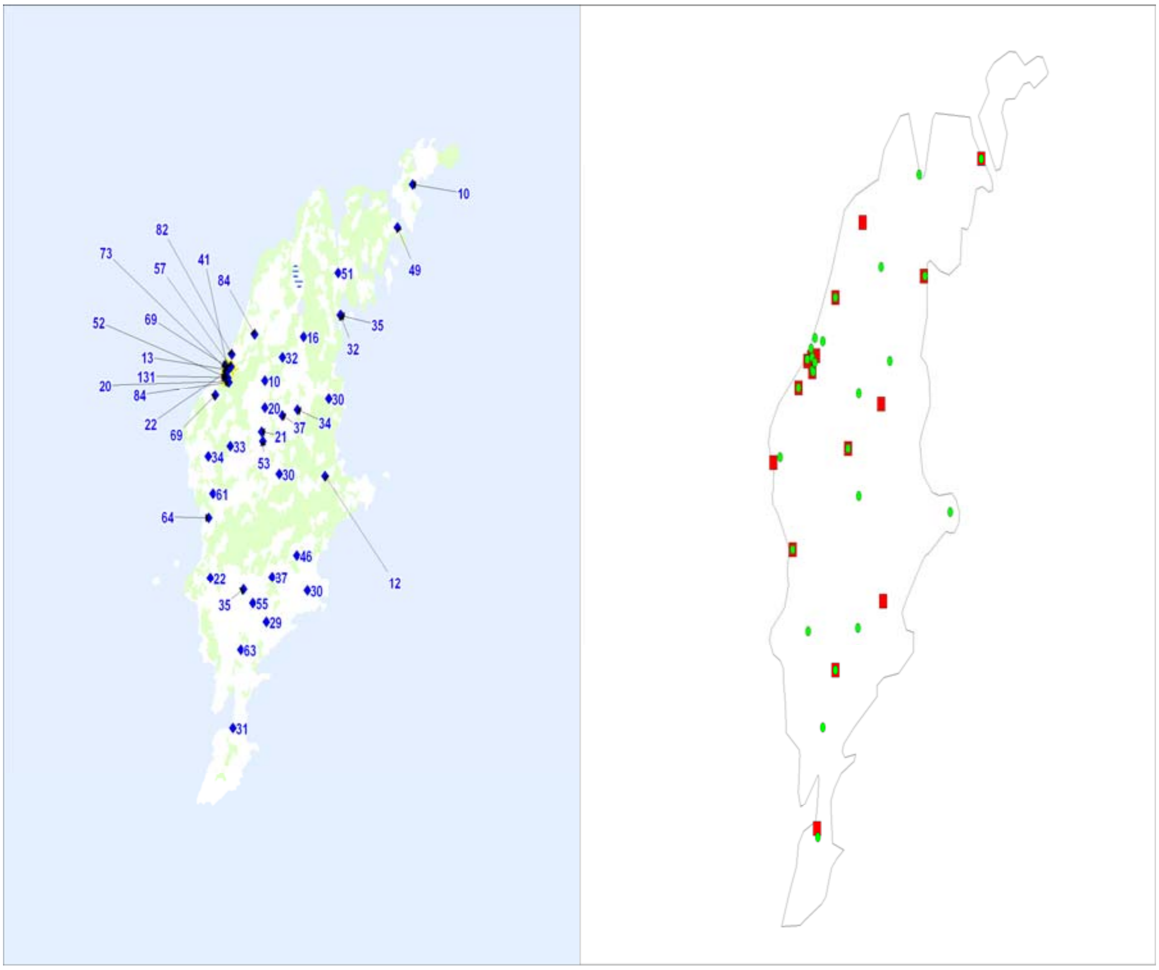
Sparar resultat

Figure 6.2 *User interface for the MapProx application.*

6.3 The Structure application

Sweden has a tax system that redistributes money among municipalities. The municipalities pay a part of their taxes into a common tax pool. The money is distributed from this pool back to the municipalities. The size of the grant is dependent on a number of components. If a municipality has a large number of elderly persons they receive more money from the pool. Another component, called the structure component, is dependent on the geographic distribution of the municipality's population. It is believed that public service in a municipality with a widely distributed population is more expensive than a municipality with a concentrated population. For example, if school-age children are distributed throughout the municipality the municipality will have to build small expensive schools or transport children long distances.

The calculations that decide the amount of money to be distributed to the municipalities as part of the structure component are performed by the Structure application that uses NetRider. The model used to calculate the municipality's structure is independent of political decisions about where public services are actually located. It is the distribution of the population and the road network that decide where the simulated public service should be placed. An example of the output from such a simulation is shown in Figure 6.3b. Figure 6.3a shows the actual distribution of elementary schools (pupils aged 7-15) in the island municipality of Gotland. The calculations are performed in two steps. In the first step a "new" distribution of schools is calculated depending on where the pupils live and independent of where the schools are actually situated. In the second step distances from the pupils to the closest school and the sizes of these new simulated schools are translated into financial measurements that make up the municipalities' share of the tax pool.



(a) *(b)*

Figure 6.3 *The island of Gotland*
a) The distribution of existing elementary schools.
b) The simulated placing of elementary schools according to the tax distribution model. Green dots are schools for pupils aged 7—12. Red squares are schools for pupils aged 13—15.

6.4 The Rescue Unit Planner

The Swedish rescue agency uses the NetRider library in their prototype Rescue Unit Planner (RUP). This is a tool for rescue service planners. In the RUP it is possible test different scenarios for placing rescue units and evaluate them against each other from an accessibility perspective. Paper III describes RUP in more detail.

6.5 Future use

We believed that the NetRider function library could be used in more applications in the future. This is indicated by application X in Figure 6.1. A component that handles geographic accessibility with large source databases could be included in larger computer systems. To help future developers who would like to use NetRider, an SDK (Software Development Kit) should be developed. Apart from the function library this SDK should consist of a thorough description of NetRider's interface and code examples of applications.

7 Performance aspects

7.1 Introduction

The common theme of this dissertation is fairly obvious: methods for improving performance in accessibility calculations. But why is that an issue? In this chapter the advantages of high performance accessibility calculations are discussed.

7.2 Detailed source data

New methods for producing geographic data are continuously improving accessibility calculations as datasets become increasingly detailed. When Statistics Sweden released grid data at a resolution of 250 m it coincided with the release of the matching high resolution Swedish National Road Database. The releases meant that tools for accessibility analysis had to deal with a quadrupling in the size of data.

7.3 More analysis

With faster analysis it is possible to carry out more analysis in the same time. If high performance makes it possible to carry out more analysis it could often raise the quality of the analysis as a whole. An example of this is the accessibility analysis carried out for upper secondary schools.

In middle of the 90s accessibility analysis was carried out for upper secondary schools. Due to the performance limitations of the accessibility tool used at that time, only one analysis was made for the closest upper secondary school. This analysis produced results that showed fairly good accessibility to schools for the pupils. The disadvantage with this analysis was that consideration was taken to the fact that the schools gave different educationprograms.

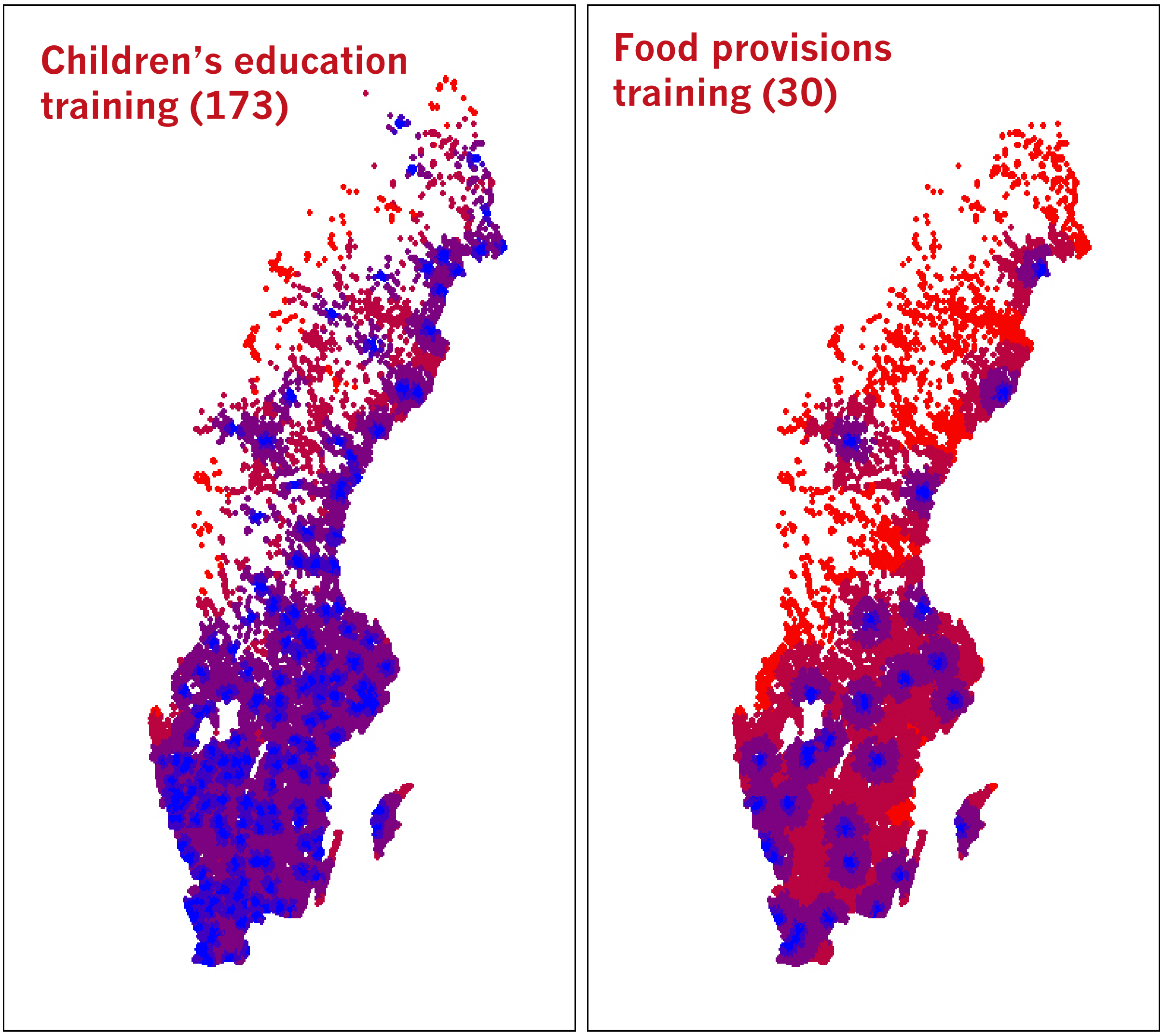
When the tool developed into the second generation it provided the opportunity to perform more analysis, but using the same time as one analysis used to take. This meant that all 20 standard educational programmes at the secondary level could be analysed. The result of two of those analyses is shown Figure 7.1. The new analysis gives a better overview of the accessibility situation. It shows that accessibility, from a national perspective, is satisfactory for some education programmes (e.g. children's education training). However, for some education programmes (e.g. food provision training) accessibility is unsatisfactory.

7.4 Iterated simulations

Chapter 7.3 presented an application for calculating tax distribution. One of the calculation steps in this application is a simulation. In simulations it is common to iterate calculations. A value of accessibility is calculated for different scenarios. Dependent on the value the scenarios can be compared against each other. The scenario with the best value is preferred from an accessibility point of view. If calculations using the accessibility model are effective more scenarios can be calculated and a better result will be obtained.

7.5 Larger geographic areas

Europe now has national geographic database providers that cooperate with international projects or organisations. The results of these cooperation's will be large detailed geographic databases covering the whole of Europe. Examples of such projects/organizations are Eurostat and Euroroads. This will lead to lager detailed data sets that will make the foundation of international accessibility analysis of large geographic areas.



(a) (b)

Figure 7.1 *Accessibility to upper secondary schools*
a) Accessibility to upper secondary schools that provide children's education training
b) Accessibility to upper secondary schools that provide food provision training.

8 Case studies

8.1 Introduction

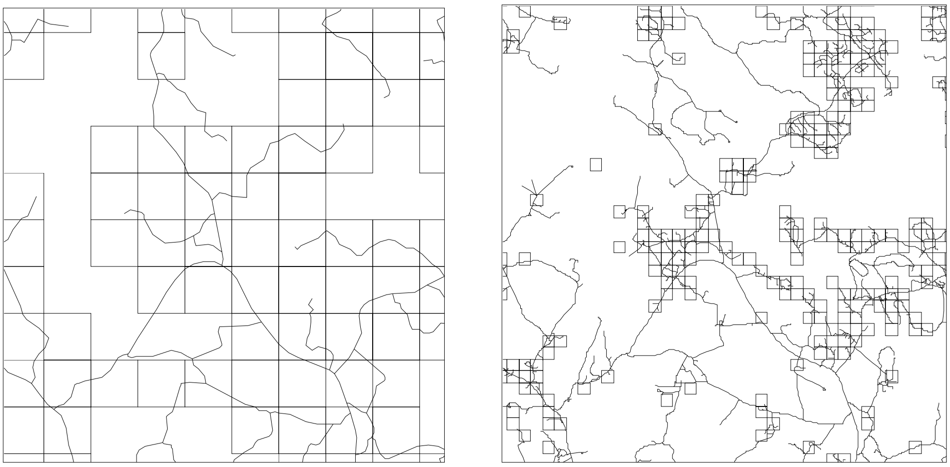
The MapProx application that uses the second generation of the NetRider function library was put into production in 2004 and is the platform for the case studies in this chapter. The aim of the fist case study was to give an indication of what effects different resolutions in source data sets would have on the result of an accessibility analysis.

The following case studies were performed in order to pinpoint the performance bottlenecks in the application. All calculations were performed on a 3 GHz, 2 Gb Ram computer. The result of the case studies are discussed in chapter 9.

8.2 Case study 1

For the first case study a population dataset covered the whole of Sweden with 1km tiles. In the first part of the study a sparse road network containing the large roads were used (Figure 8.1a). The second part of the study used a population dataset with 250m tiles and the road network was the dense Swedish National Road database, which aims to include all the roads that can be travelled by car (Figure 8.1b). A point dataset containing all the cash dispensers in Sweden was used for target points (2940 points).

The resulting file contained the whole of Sweden but two municipalities were analysed, the municipality of Härjedalen and the municipality of Solna. Only populated tiles are used.



(a) *(b)*

Figure 8.1 *Two Figures that show the same area using population grid datasets and road network with two resolutions.*

a) 1km tiles and the National Land Survey's roads.
b) 250-metre tiles and the Swedish national road network.

Härjedalen:

- rural municipality.
- 10,889 inhabitants
- 12,000 square kilometres.
- 524 populated 1km grids.
- 1430 populated 250-metre grids

Solna:

- urban municipality,
- 60,575 inhabitants
- 21 square kilometres
- 30 populated 1 km grids.
- 158 populated 250 metre grids

***Table 8.1** Average distances to cash dispensers for a rural municipality (Härjedalen) and an urban municipality (Solna).*

	Average distance to a cash dispenser for a grid point (metres).	Average distance to a cash dispenser for an individual (metres).
Härjedalen 250m grid dense road network	22,433	13,432
Härjedalen 1km grid sparse road network	26,189	13,914
Solna 250m grid dense road network	978	682
Solna 1km grid sparse road network	1,120	729

8.3 Case study 2

A second test was conducted with large datasets with a variable maximum search distance to calculate the distance to the closest target point. The results are shown in table 8.2. The datasets used were:

- A road network from the National Land Survey.
- 766,894 polylines.
- A point file containing the whole Swedish population tiled into 250 m squares. It contained 400,885 squares (the central points of the squares were used in the calculations).
- A point file of grocery stores. It contained 1,767 points.

The MapProx application has a function in which the maximum search distance can be set. In table 8.2 the maximum search distance is varied in order to study the impact this has on calculation time. If the maximum search distance is set to low not all the starting points reach a target point. In this case no one in the population has more than 200 km to its closest grocery store. Not surprisingly, the time for connecting points and generalizing the network stays stable if source datasets are the same.

Table 8.2 *Calculation times with different maximum search distances.*

Maximum search distance (km)	Connecting points to network.	Generalizing the network	Calculating the shortest distance	Total time for calculation	Gives complete results.
50	55 min	16 min	7 min	1h 18min	no
100	55 min	16 min	21 min	1h 32min	no
150	55 min	16 min	38 min	1h 49min	no
200	55 min	16 min	1h 25min	2h 36min	yes
300	55 min	16 min	3h 17min	4h 28min	yes
500	55 min	16 min	8h 23min	9h 34min	yes

8.4 Case study 3

A second test was done using two different road networks with the same start and target points, calculating the closest target point. The maximum search distance was set to 200 km. The results are shown in table 8.3.
The datasets used were:

- A road network from the National Land Survey with 766,894 polylines. The size in MapInfo format is 141 Mb
- A road network from the Swedish Road Agency (NRDB) with 1,876,472 polylines. The size in MapInfo format is 515 Mb.

- A point file containing the whole Swedish population tiled into 250m squares. It contained 400,885 squares (the central point was used in the calculations).

- A point file with grocery stores, which had 1,767 points.

Table 8.3 *A test with two different road networks and many target points.*

Road network	Connecting points to network.	Generalizing the network	Calculating the shortest distance	Total time for calculation
National Land Survey	55 min	16 min	1h 25min	2h 36min
NRDB	4h 49min	39 min	1h 27min	6h 55min

A variation of the third test was using a single target point and a higher maximum search distance. The results are shown in table 8.4. The changes in the input parameters from the test before were:

- One single target point was used (a central point in Stockholm)
- The maximum search distance was set to 2,000km.

Table 8.4 *A test with two different road networks and a single target point.*

Road network	Connecting points to network.	Generalizing the network	Calculating the shortest distance	Total time for calculation
National Land Survey	55 min	27 min	34 min	1h 56min
NVDB	4h 45min	38 min	50 min	6h 13min

8.5 Case study 4

A study was constructed to test the ability to calculate large distance matrixes.

- A road network from the National Land Survey, containing 766,894 polylines.
- A point file of all Swedish population centres with more than 200 inhabitants, containing 1,936 points.

The test calculated from all the population centres to all the other population centres, ending up with a distance matrix with theoretically 3,748,096 calculated distances (taking account of the zero distance if the start and target points are the same). The actual number of calculated distances was 3,648,400 because the island of Gotland does not have a connection to the mainland in this road network. The calculation took 57 minutes in MapProx. On breaking down the calculation into sub processes we find:

- 10 minutes for connecting points to the road network.
- 7 minutes for generalizing the road network
- 40 minutes for calculating the distances

9 Discussion

Case study 1 (8.2) show that the resolution of source data affects the result of accessibility analysis significantly. In the rural test area the average distance differed by 4% for individuals. However, what is more interesting is that for studies in peripheral rural areas the test showed differences of 17% when distances to the populated tiles were calculated without weighting them according to the number of individuals in each tile. The corresponding result for the urban test area was 7% for individuals and 11% for tiles.

Case studies 2–4 investigate the performance of the second generation of the NetRider. The steps that are timed can are connected to process description given in chapter 5. The results indicate that the step where points are connected to network takes an inexplicit long time. This case study and the study in paper I prioritized the spatial index and the internal data structure to be studied in paper II. This was done by developing a test bench, GIL (Geographic Index Laboratory) for evaluating spatial index methods.

For final research areas where generalization of network and network search a test bench where also developed. The study of this test bench is presented in Harrie (2008).

GIS studies and computer science are closely connected and do overlap in some areas. Even though this dissertation focuses on GIS using models and algorithms it would be wrong not to discuss trends in computer science that will effect this dissertation, but even more so the actual software development that will follow on this dissertation. Computer hardware and development environments affect the performance of algorithms and models. Suggestions like those in the conclusions of paper II need to leave openings for adjustments according to the chosen software platform in order to be as effective as possible.

The open source movement (as described in Raymond 2001) entails a new way of looking at software development. Code, that just a couple years ago was a software company's biggest asset, is now available through public licences. New business models are emerging in which the source code is less important, while knowledge of how to modify and produce the source code is becoming more important. This means that the development of NetRider 3.0 can probably use components that are available under a public licence. This also provides the necessary transparency for the application.

Desktop computers with more than one processor are becoming more and more common. An application that is built with the aim of using all the computer's processors can gain in performance. This means that if subdivisions in calculation processes could be made in order to use parallel processing there could be gains in performance.

A desktop computer's processors and operating system can nowadays use a 64-bit architecture. This means that larger amounts of data can be held in RAM-memory, so minimizing time consuming disk access. NetRider's performance could be improved if it is compiled for a 64-bit platform.

10 Summary of papers

Paper I starts the work of this study. A number of research areas were identified and a number of questions were put forward. In some way, the paper sets out the direction of the work in rest of the study. The study's ultimate aim was to create a solid platform for future development work for the next generation of the accessibility application. This was achieved in this study.

In paper I four proposals for improving the performance of the studied accessibility application were highlighted. The first dealt with *connecting points to a large road networks*. This was studied in paper II and the conclusions of the study suggest that two spatial indexation methods should be implemented in the next generation of the accessibility application. Firstly, the already implemented *kD-tree* indexation should be further developed and, secondly, a *fixed grid* indexation should be implemented. The reasons for this are twofold. The two methods each have different advantages. The fixed grid is very fast at building the index whereas the kD-tree has its performance advantage in the search. The second reason for implementing two spatial indexation methods is to be able to evaluate and search for bottlenecks in performance and errors in where the points are connected in the road network. When dealing with small datasets this task could be performed with brute force methods but when the datasets are large, as in this case, it becomes impossible.

The remaining proposals: generalization of the road network, network search and the internal data structure are studied in Harrie (2008) and not a part of this dissertation.

In paper III a case study of how a computer application for planning rescue services, based on these types of accessibility functions, should work as a prototype. It should be noted that the improvements suggested above were not implemented in the function library used in the study. The study was performed in order to test the concept of such an application. The study and the prototype showed such promising results that a project for implementing a commercial application built on the prototype has started. When this application is ready it will benefit from the improvements implemented in the third generation of the accessibility function library.

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Paper I Dahlgren, A., and Harrie, L., 2006. Development of a tool for proximity applications, *Proceedings of the 10th AGILE International Conference on Geographic Information Science*, Aalborg, Denmark.

Paper II Dahlgren, A., and Harrie, L., 2006. Evaluation of computational methods for connecting points to large networks. *Mapping and Image Science*, Swedish Cartographic Society, 2006:4, pp. 45-54.

Paper III Dahlgren, A., Harrie, L., and Axelsson, A., 2008. Planning rescue services with non-stationary rescue units. *Fire Technology*, In Print, Published online May 1, 2008, The article is published in this licentiate dissertation with the kind permission of Springer Science and Business Media.

Paper I

DEVELOPMENT OF A TOOL FOR ACCESSIBILITY CALCULATIONS

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MAJOR THEME: Applications of GIS
NATURE OF THE ABSTRACT: Strategic

ABSTRACT

Performing detailed proximity analyses in a national perspective implies dealing with large source datasets. In this paper we present an ongoing work of developing a proximity tool specially designed for handling large dataset. The main focus in the paper is methods for improving the performance of the network search.

KEYWORDS: network search, generalization of graphs, proximity analysis

INTRODUCTION

Proximity analyses are of interest within many areas; they make an important foundation in describing accessibility relations. In temporal studies they can be used to monitor the change in accessibility over time. Some of these analyses only becomes of real interest when dealing with large geographic areas and/or high resolution in the analyses. This implies that large datasets are required. A problem is that several (on-the-shelf) proximity tools cannot handle large datasets efficiently.

Proximity analyses are of interest for monitoring the situation for the inhabitants in the rural areas. In Sweden, Glesbygdsverket (the National Rural Development Agency) is responsible to define the rural areas and analyse the living conditions for the people living there. Glesbygdsverket uses proximity analyses, for example, to monitor the population’s accessibility to food stores, train stations and hospitals. Glesbygdsverket has a national responsibility; this means that the analyses are performed for the whole country. Because the analyses require high resolution the datasets inevitable become large. Since Glesbygdsverket did not find a suitable on-the-shelf proximity tool for such large dataset, it has decided to develop its own tool. This paper describes the ongoing work of the development of the proximity tool.

The remaining part of the paper is structured as follows. In section 2, a short description of the current proximity tool is given and section 3 is devoted to requirements of the new tool. In section 4, possible improvements of the new tool are discussed with focus on network search. The paper ends with concluding remarks.

CURRENT TOOL FOR PROXIMITY ANALYSIS

Glesbygdsverket has developed its own proximity tool. The first generation of the tool was developed in the early nineties. When the requirement of the analyses increased, as well as the size of the datasets, the performance of the calculations became a growing problem. In the years 2002–2003, a second generation of the tool was developed. This version is referenced in this paper as *MapProx* (*Map* for the mapping capabilities and *Prox* because it is a proximity tool). An example of the output from *MapProx* is shown in Figure 1.

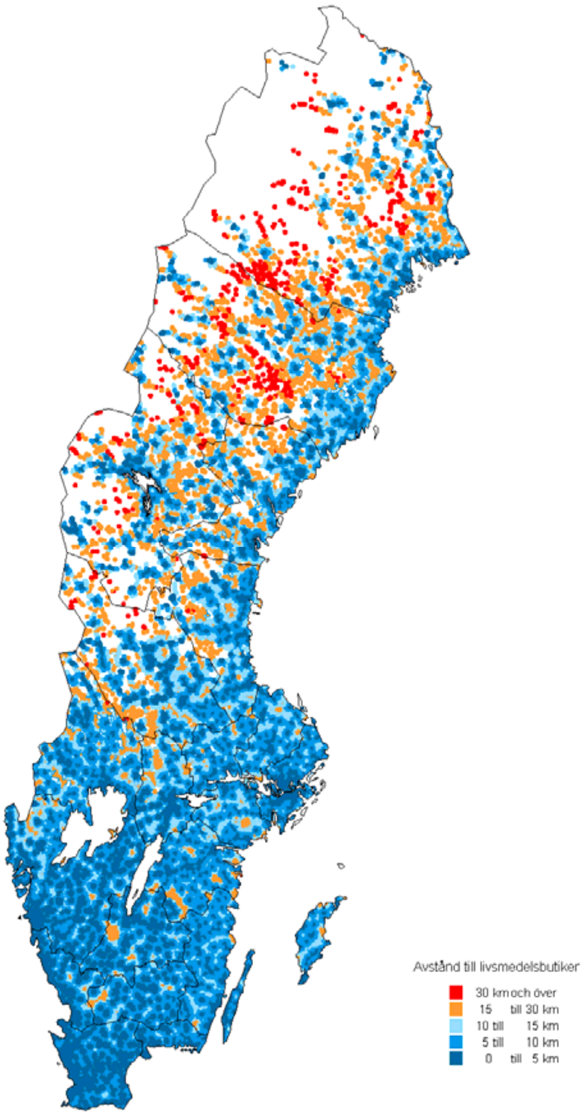

Figure 1 *A thematic map showing an example of the output Glesbygdsverket's proximity application MapProx showing the Swedish populations (2004) accessibility to the closest grocery store. Glesbygdsverket (2007).*

REQUIREMENTS ON THE NEW TOOL FOR PROXIMITY ANALYSIS

The design of the new tool should have a scalable approach. The source datasets used within Glesbygdsverket will certainty become larger, both expanding into new geographic areas (foremost Europe) and using higher resolution. Examples of the latter are:

To use the national road dataset (NVDB) from the Swedish Road Administration instead of the roads from the 100 000 topographic map (*Blå kartan*) from the Swedish National Land Survey. This implies an increase of the number of roads with a factor of two.

To use a population grid of a resolution of 250 m instead of 1 km. There are about 120 000 populated km-squares and about 400 000 populated 250m-squares in Sweden.

At a first glance the process of performing proximity analysis seems to be a fairly static task: *once it's done it's done*. But considering changes in the source datasets and simulation functions dealing with iterations, means that a lot of calculations are required. This makes high performance an important requirement on the application.

The development of the application should be performed in such a way that dependencies to operating systems and GIS-platforms are held to a minimum. This allows the application to evolve into heterogeneous computer environments.

The design of the application shall consider the future trends in the computer hardware development aiming at e.g. computers with multiple processors and 64-bits processors.

A requirement that of course is of interest is the applications usability. When doing time-consuming calculations it is important for the user to get information on the progress. This also has an impact on the performance while updating the user interface uses computer power.

When new source dataset is used in the application, there are often small changes from the datasets used in earlier calculations. In *MapProx* today a total recalculation is made regardless of the size or type of the changes. If some incremental update routines could be implemented they will with all certainty a positive effect on performance.

The application should have the possibility to use a categorization of the target points. This function can then be used to calculate the shortest distance to more than one type of target points in the same calculation.

The *MapProx* tool has two implementations. Firstly it will work as a desktop application for the employees of Glesbygdsverket, doing straightforward proximity analyses. Secondly, it will work as a module in larger, more complex systems that have proximity analyses as a base function. Examples of the latter are program systems for rescue planning and for calculating tax adjustments between municipalities[1]. This means that the interface to the functions in the tool could be accessed of both a human and another computer process.

When a new system is developed or bought by an organization the transparency of the system should be considered. Buying a ready made system in most cases tend to become a "black box" with few or no possibilities changing the system according to the requirements of the organization, whereas a system developed inside the organization becomes a "transparent box". It seems to be a growing requirement from organizations to get access to the source code for the applications they use. This is a point often brought forward in discussions in favor of Open Source concepts (Raymond, 2001). Doing proximity analysis is a core function within the Glesbygdsverket, which makes it important to have a clear insight into the details of the application. Glesbygdsverket wants to have access to the source code to have this insight. Of

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[1] Glesbygdsverket assists the Ministry of Finance to calculate tax adjustments dependent on structural differences between municipalities.

course this discussion of trying to rank, developing a new system with buying an on-the-shelf system, is more complex..

IDENTIFYING RESEARCH AREAS

A performance test was made in Dahlgren (2005) where four candidates for performance improving research areas are selected. Three of the areas can be directly related to the measurable sub processes in the test:
Create a spatial index and connect the points to the road network
Generalize the road network with the connected points.
Calculate the shortest distance between start and target points.
The overall interest area of the internal data structure can be added to this list. This area is affected of all the three above but should because of its importance be handled separately. The points identified above delimit this work. There are of course other areas that could affect the performance of the application and should be treated in the development project but they are not the concern of this paper.

CREATE A SPATIAL INDEX AND CONNECT THE POINTS TO THE ROAD NETWORK

This process has been previously studied in Dahlgren and Harrie (2006) and will not be described here.

GENERALIZATION OF THE ROAD NETWORK WITH THE CONNECTED POINTS.

The *MapProx* tool is a one-purpose tool, namely performing proximity calculations. Tools with similar functions often have a multipurpose approach. They often tend to broaden their field of operation to please a vaste amount of users. However, such designs often lead to compromises in the core function of the application. An example of this is the mixing of proximity analysis and navigation. In a proximity analysis tool you are not interested in a description of the path from start point to target point. You just want to know the travel distance or travel time. This fact has impact on the generalization process where a pure proximity calculation can use a more effective approach. Removing relations between the complete geographic representation of the road network and the generalized road network is no problem.

Start points and target points must be connected to the road network before the generalization process can begin. The goal with the process is to simplify the road network to make the calculations of the distances as smooth as possible without tempering with the correctness of the result.

CALCULATE THE SHORTEST DISTANCES BETWEEN START AND TARGET POINTS IN THE GENERALIZED NETWORK

Finding the shortest way in a network graph is a classic problem in computer science and mathematics. The algorithm used in the tested application is the Dijkstra algorithm (Dijkstra, 1959) later described and discussed in many sources (e.g. de Berg et al, 1997; Ahuja et al., 1993). There have also been a number of suggestions of improvements and modifications of the Dijkstra algorithm; e.g. by using heuristics as in Lauther (2004) and Ertl (1998). Dijkstra's algorithm has been proven to be the fastest exact search algorithm but heuristics could be of interest for the further development of *MapProx*. A test in Dahlgren (2005) showed an increased calculation time with increased search distances. The recommendation is still to prioritize the internal data structure before going into details of the search algorithm.

THE INTERNAL DATA STRUCTURE

Figure 2 shows the internal format in the current application uses in a simplified manner. There is a geographic area tiled into of sub areas. One sub area tile holds the reference to the corresponding links and nodes that lay within the area. The advantage with the approach of tiling the geographic area into sub areas is that the sub areas become "independent" from each other, which make them easier to handle. The Sub areas are serialized into individual files in the internal format. The sub areas can be handled independently in their own calculating threads, suggesting parallel calculations as a possible performance enhancing measure. The disadvantage with the tiling is that a new type of nodes must be introduced on the borderlines between the tiles. These border-nodes will appear in two adjacent sub tiles. The intimate connections between links and nodes (in the implementation realized with pointers) are the core of the internal topology of the internal format. As long as the road network stays intact the same imported network can be reused in forthcoming calculations.

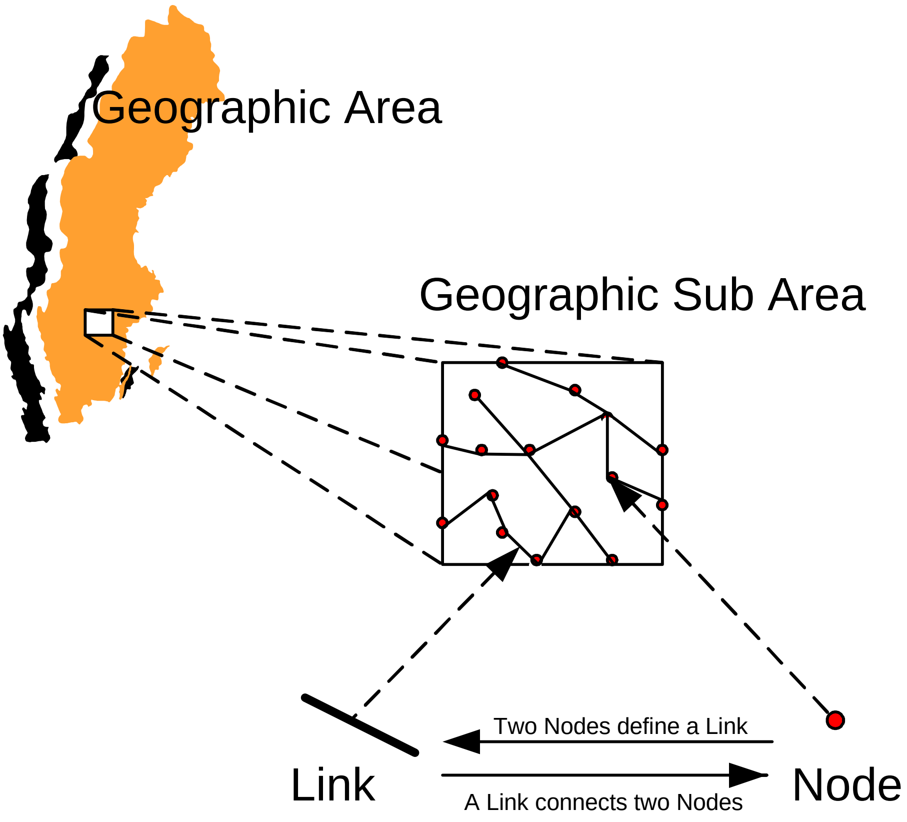

Figure 2 *The Figure describes a simplified schema of the internal format used.*

A suggestion is to let the geographic sub area have a polymorphic behaviour. The area should have three different interfaces, illustrated in Figure 3, used as described below. It remains to be tested if this way of structure of the data has an effect of performance or only works as a structural clarification.

The processes that connect start and target points to the road network use the first interface. In this interface it is important that the right geographic representation of the road network is used. When the start and target points are connected the generalization process can start presenting its result, a simplified road network, through the second interface. This is used for searching within a Geographic sub area. When a sub area only has the function as transportation between two other sub areas, i.e. the area does not have any start or target point of interest for the calculation connected, the third interface is used. This interface shows the sub area as a matrix of distances between the sub areas border nodes. An interesting fact is that the matrix can be calculated before the connection of the start and target nodes in a pre calculation.

In the design of the internal format it should be if there are processes that could use parallel calculations. One overall calculation process can use both a single thread approach in a sub calculation and a multithread approach in another (Figure 5). Examples of this can be the import of a single in-data file that is a single thread procedure. When the dataset is imported and tiled into subsets, a multithread approach can be used to calculate the matrix representation. The tests in Dahlgren 2005 could not directly pinpoint any bottlenecks in the internal data structure because it affects the whole calculation process. When the size of the datasets increases a hierarchical approach (Car and Frank, 1994) and the suggested interface structure should be of interest of study further.

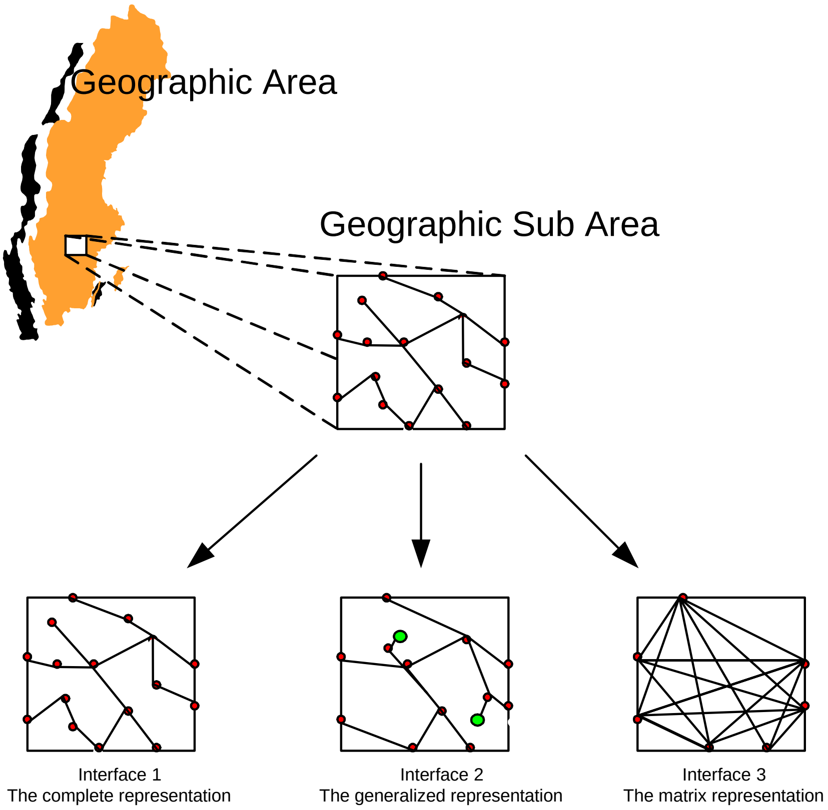

Figure 3 *Three interfaces of the Geographic Sub Area component. The big nodes in Interface 2 represents start or target nodes.*

In Figure 2 & 3 the geographic sub areas are illustrated as squares. In reality this may not be the optimal way of tiling the road network. A method of expanding rural areas with dense road networks into geographic sub areas is suggested (Figure 4). At least two advantages with this method can be seen. Firstly the probability of internal proximity analysis within the sub area increases. It is often the tool is used for finding the closest target point in the form of service within rural areas. Secondly the introduced borders between the geographic sub areas are drawn in rural areas with a sparse road network. Suggesting a low number of border nodes to be applied.

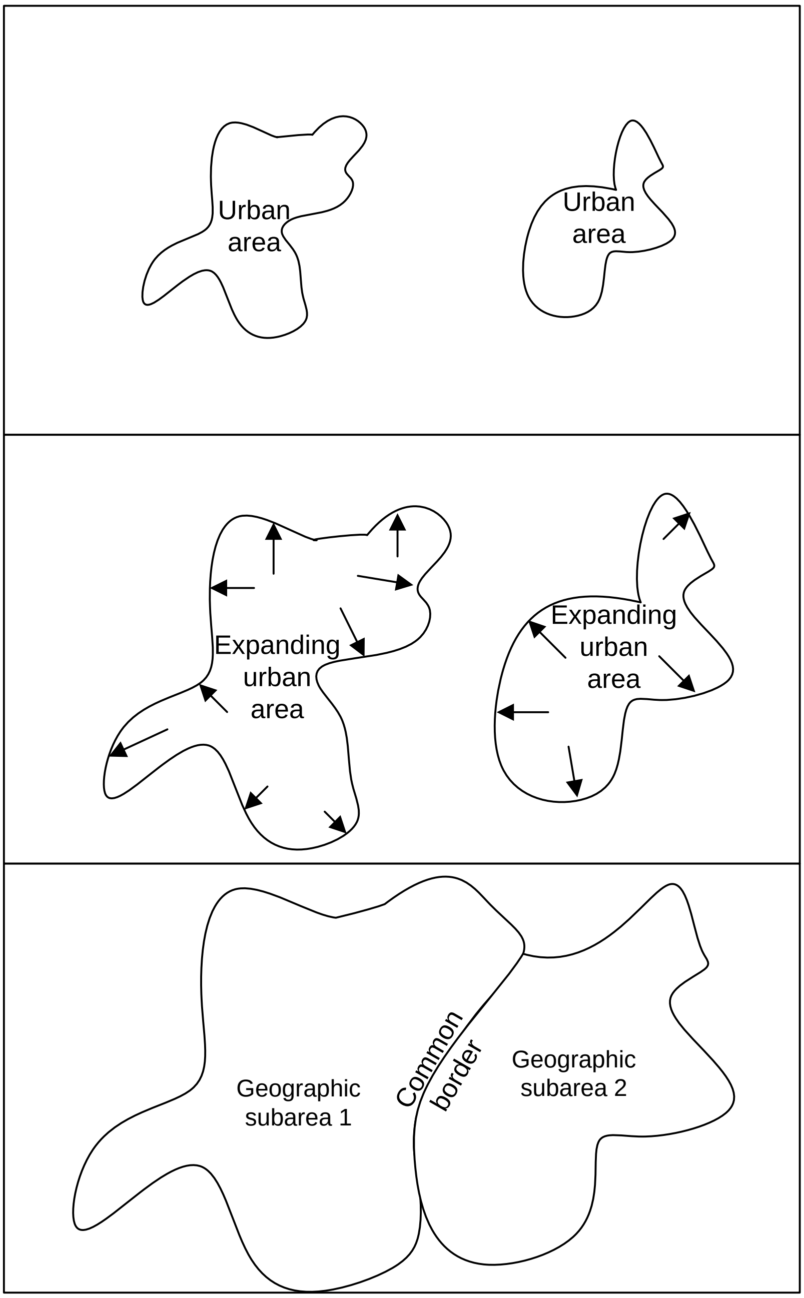

Figure 4 *A method of constructing Geographic subareas by expanding urban areas*

CONCLUDING REMARKS

This study describes an ongoing project of developing a new version of a proximity tool (*MapProx*). The requirements stated above are the guidelines of the development work. The focus in this development project is to improve the performance of the application. This is done by going through the different calculation steps and suggesting improvements. An area that affects all calculation steps is the internal data structure which is the focus of this paper. The internal data structure is the concern of all the calculation steps and can therefore not be looked at as an isolated problem.

ACKNOWLEDGEMENTS

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Paper II

EVALUATION OF COMPUTATIONAL METHODS FOR CONNECTING POINTS TO LARGE NETWORKS

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Abstract

This study deals with performance issues for connecting points to a network, a common operation in e.g. geographic accessibility studies. The problem is analysed by the development of a test bench where the spatial indexation methods kD-tree, Morton code and fixed grid are implemented. Using the test bench scenarios of networks, point datasets, spatial indexation methods, and methods for computing distances between point and line segments are evaluated. A case study indicates that the indexation method fixed grid has the best performance for connecting point to the network. Furthermore, the results show that it is also important to choose an appropriate algorithm to compute the distance between a point and a line; the study recommends an "algebraic method" that does not include any trigonometric functions.

KEYWORDS: *GIS, geographic accessibility, spatial index, fixed grid, kD-tree, Morton code*

INTRODUCTION

Connecting points to a network is a common operation in geographic information handling. The operation is used in for example:

- In car navigation, where a position from e.g. a GPS-receiver is connected to the road network (Horemuz, 2006).
- Establishing neighbourhood relationships between geographic objects. These relationships can be found e.g. by applying a triangulated data structure (see Jones et al., 1995 or Harrie and Sarjakoski, 2002).
- Connecting pollution sources to a river network. The connection here can be performed by utilising the drainage areas.
- Geographic accessibility studies. This is described in Section 2.

In this study we are only interested in methods where we connect point to the closest point in the network.

There are two major types of ways to connect points to the closest link in the network; in a *static* case the point has a fixed position while in the *dynamic* case the point is moving. In the dynamic case, the connection operation can utilise the movement of the point by using e.g. a filtering process (Horemuz, 2006). To connect a *static* point to the closest point in a network is a straight forward process, by computing the distance between the point and all line segments in the network, and connect the point to the closest line segment (Figure 1). However, in many applications the number of line segments is abundant which causes the connection process to be slow. To overcome this performance problem efficient computational methods are required.

The aim of this study is to evaluate computational methods for connecting static points to networks in accessibility studies. The paper is organised as follows. In section 2, a short background of accessibility studies is given. The aim is not to give an exhaustive description of accessibility studies, the sole aim is to give a background of why we are interested in connecting points to a network. Section 3 provides the theoretical background to the study. Especially, spatial indexation methods and formulas for computing the distance between points and lines are described. Section 4 describes a test bench where these indexation methods and distance formulas are implemented. An evaluation of the implemented methods is given in Section 5. The paper concludes with a discussion and conclusions.

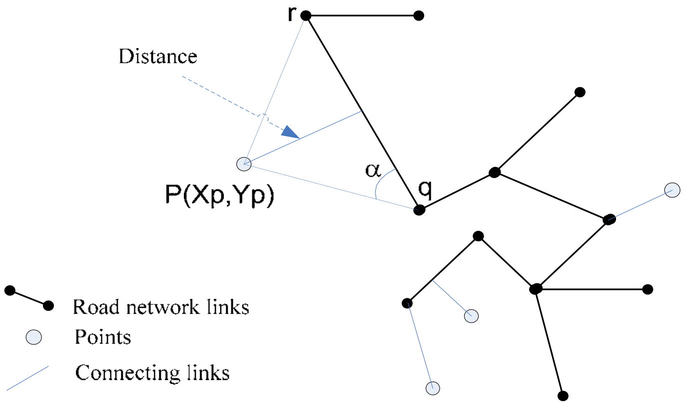


Figure 1 *Connecting points to a network. The points (e.g. P) are connected to its closest line segment (e.g. q->r) in the network. The points are linked to the network through a connecting link.*

GEOGRAPHIC ACCESSIBILITY STUDIES

Geographic accessibility studies are of interest in application areas such as: health geographic (Guagliardo, 2004), transport modelling (Berglund, 2001) and logistics (Bergqvist and Tornberg, 2005). To compute the geographic accessibility three datasets are required: the start points (e.g. census data), the target points (e.g. service location data), and a network (most commonly a road network). In principal, accessibility is computed as follows. Firstly, the starting points and the target points have to be connected to the network. Secondly, the shortest distance, or shortest travelling time, from the starting point to the target point in the network is computed.

The Swedish National Rural Development Agency (SNRDA, 2006) is responsible for monitoring the Swedish population's accessibility to different kinds of service. Examples of services of interest are: airports, hospitals and grocery stores. The SNDRA has developed a tool for these accessibility studies (Figure 2 gives an example of the output). In recent years, the datasets used as input data has become more detailed and therefore larger. [1] identified that two processes that had potential to be improved: (1) connecting points to the road network, and (2) computing the shortest route in the network. This paper is concerned with improving the first the first of these processes.

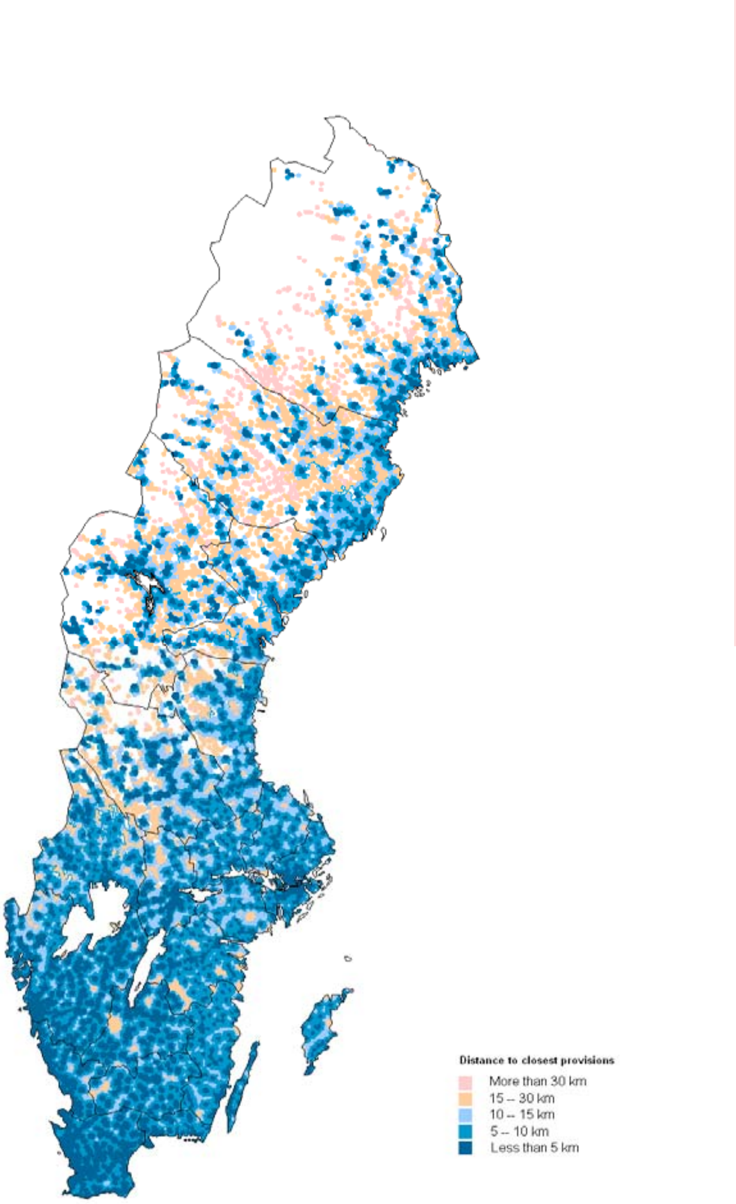


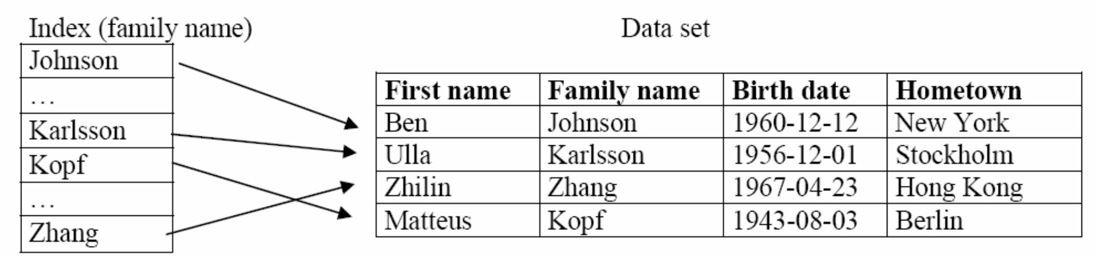
Figure 2 *A thematic map showing an example of the output SNRDA proximity application showing the Swedish populations (2004) accessibility to the closest grocery store. SNDRA (2005, p.41).*

METHODS FOR CONNECTING POINTS TO THE NETWORK

This section contains a theoretical background of the computational methods that are implemented and evaluated in this study.

SPATIAL INDEXATION METHODS

To search in an unordered dataset is a slow process. You have to search through each element in the dataset, i.e. linear search, which has a computational complexity of O(n) where n is the number of elements in the dataset. To enable binary search, which has a computational complexity of O(log n), the dataset must be ordered or must have an index. An index is an auxiliary ordered data structure (Figure 3).



First name	Family name	Birth date	Hometown
Ben	Johnson	1960-12-12	New York
Ulla	Karlsson	1956-12-01	Stockholm
Zhilin	Zhang	1967-04-23	Hong Kong
Matteus	Kopf	1943-08-03	Berlin

Figure 3 *By using an index (here on family name) we can access unordered data rapidly. Start by performing binary search on the index and then follow a data pointer to the correct element in the unordered list.*

To use indexes in the Cartesian plane is difficult since the plane lacks ordering in one dimension. There are a number of methods to circumvent this problem, e.g. by introducing an artificial ordering (by using a space filling curve) or introduce tree structures designed for spatial data (kD-trees, R-trees, etc.) (see overviews in e.g. Rigaux et al., 2002 or Worboys and

Duckham, 2004). The indexation methods can be broadly categorized as either data-driven or space-driven. In space-driven methods each location in space is indexed irrespective of the data distribution. A number of researchers have worked with optimizing the size of the indexation cells (e.g. Ottoson and Hauska, 2002). In data-driven methods the indexes is dependent on data distribution. This is often advantageous if the data is unevenly distributed.

By using an indexation method, the search process is divided into two parts. In the first part, a binary search is performed (by using the index). The result of this part is a *candidate set* (in our application this candidate set consist of a number of links). In the second part, a linear search is performed in the candidate set to identify the best element (in our application the closest link to the point). To be successful an indexation method should create a small candidate set rapidly. Some indexation methods, e.g. the space filling curves, do not guarantee that the best element is part of the candidate set. This implies that for these indexation methods there is a trade off between fast computation (i.e. creating small candidate sets) and the quality of the result.

Even though there is an extensive literature of spatial indexation methods, there are few studies published that concerns design and implementation issues (Hadjieleftheriou et al., 2005). The aim of our study is to implement some well-known indexation methods and evaluate their performance for connecting static points to a network. The following methods are implemented:
no index (only used for reference),
fixed grid ordering (space-driven method),
kD-tree (data-driven method), and
Morton code (a space filling curve; in our implementation we use it as a space-driven method).

A short justification of the choice of methods is as follows. Firstly, *fixed grid ordering* is a conceptually easy method that ought to give good results in our application. Secondly, we would like to evaluate the fixed grid method to two standard methods, one method based on creating a tree structure for spatial data and one method based on space-filling curves. The choice became *kD-tree* and *Morton code* since both of these are well-known, and often used, methods for spatial indexation.

SEARCHES WITH NO INDEX

As a reference, a function for connecting the points in the point dataset to the network without indexation is implemented. This means that the shortest distance from each point in the point dataset is calculated to every link in the road network.

FIXED GRID ORDERING

One method for indexing spatial data is to order it in a fixed grid (Figure 4). Each link is sorted into a bucket if it is located within (or partially overlaps) the corresponding cell. This implies that a link can be placed in more than one bucket.

When a point (e.g. P in Figure 4) is to be connected to the network the following is performed:
Check in which cell P is situated.
Investigate if the corresponding bucket contains any links.
If the bucket does not contain any link the search is done also in the surrounding cells; this implies that totally nine buckets are investigated. This procedure is repeated until at least one link is found in any bucket.
A problem is now that a link that is just outside the searched cells might be closer than a link that is within the cells. There

are two reasons for this; the search is a square rather than a circle and the point can lie close to a border in the cell. To guarantee that the shortest link is found the search is therefore extended to surrounding cells. How many cells that are searched are determined by the number of original cells and a user set criterion.

All the links in the investigated buckets constitute the candidate set.

If it is not essential to find the closest link, but only a sufficient close link, step number 4 can be disregarded.

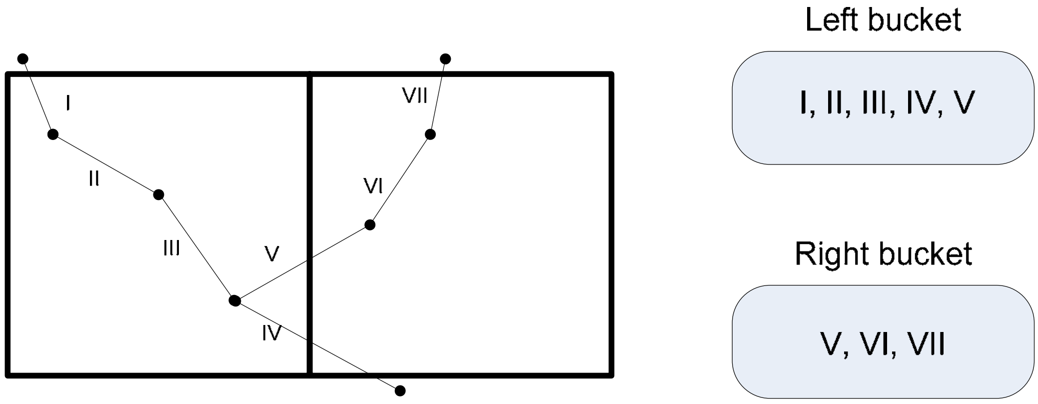


Figure 4 *A map that shows points and links overlaid by fixed grid. All links (named by roman numbers) that lie within or overlap a cell is placed in the corresponding bucket (see examples on the right hand side).*

KD-TREE

The kD-tree indexation method uses a tree structure to index spatial point objects (Bently, 1975; Figure 5). The kD-tree is a variant of a binary search tree that divides the data on the *x*-coordinate on uneven levels of the tree and the *y*-coordinate on the even levels, working its way down to the leaves where the coordinates of the spatial objects are stored. In the search for link candidates for a particular point a search window is constructed around the point. Then all links that has an end point in this search window constitute the candidate set.

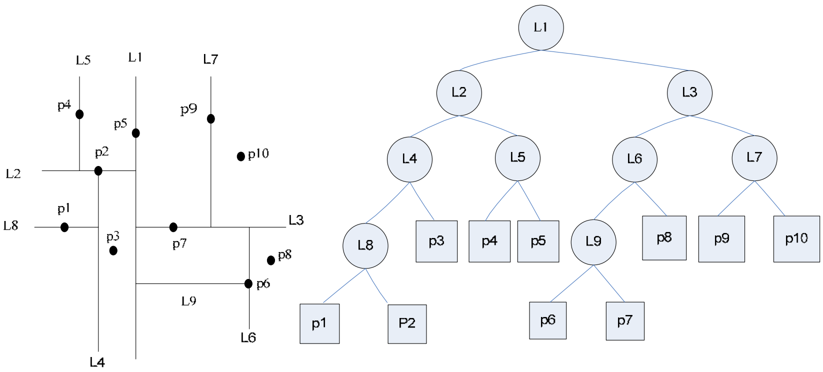


Figure 5 *A kD-tree: in the left Figure the plane is subdivided, and in the right the corresponding binary tree is illustrated. (The Figure is redrawn from de Berg et al., 2000, p. 100).*

MORTON CODE

The ideal space filling curve, in our application, runs through the plane in such a way that areas that are close to each other in the plane also are close to each other along the curve. In mathematical sense, the curve should be a bijective continuous function from a closed subset of $\mathbf{R}^2$ to a closed subset of $\mathbf{R}$. It is theoretically impossible to construct such a curve, but there are rather good approximations. One of these approximations is the Morton code (cf. Sagan, 1994; Chen and Chang, 2005) (Figure 6). Morton code is computed by bit interleaving of binary representations of the (integer) coordinates (see e.g. [1])

Morton code can be used for improving spatial search as follows. First, the coordinates for all elements (in our application endpoints of the links) are converted into integer value. Then Morton values are computed for all the elements. The Morton values are stored in a suitable data structure (e.g. a B-tree; cf. Worboys and Duckham, 2004). When a search is performed (in our application when a point is connected to the network) it starts by computing the Morton value of the search point. Then an interval is decided around this search point in the Morton code domain, and finally all elements with a Morton value in this interval are identified using binary search. These elements constitute the candidate set.

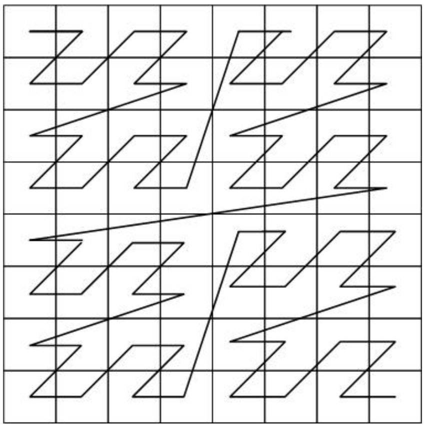


Figure 6 *An illustration of the Morton code.*

COMPUTING THE SHORTEST DISTANCE BETWEEN A POINT AND A LINE SEGMENT

A point is, in our application, connected to a network via the closest point on the network (Figure 1). The shortest distance between a link and a point is either the distance to an endpoint or an interior point of a line segment. The distance to the endpoint is easily computed by the Pythagorean theorem. The distance (*dist*) between point *p* and the interior of a line segment (with the end points *q* and *r*) can be computed by a *trigonometric method* (using the notations in Figure 1):

$$\cos\alpha = \frac{d(q,p)^2 + d(q,r)^2 - d(r,p)^2}{2 * d(q,p) * d(q,r)}$$
$$dist = d(q,p) * \sin\alpha \qquad (1)$$

where *d*(.,.) is the Euclidean metric. Another method, as we denote the *algebraic method*, is given by (see e.g. Worboys and Duckham, 2004; Okabe and Miller, 1996):

$$dist = \frac{\left|(a \cdot x_p + b \cdot y_p + c)\right|}{\sqrt{a^2 + b^2}} \qquad (2)$$

where
x_p and y_p are the coordinates for the point *p*,
|…| denotes absolute value, and
the line segment is represented as part of the infinite long line (*l*):

$$l : \{(x,y) \mid a \cdot x + b \cdot y + c = 0\}\,. \qquad (3)$$

Since we are only interested in the relative size of the distances to order them, we computed the square of the distances to avoid the square root in the denominator in Equation 2. It should be noted that Equation 2 is not valid if the point is closer to an endpoint than to an interior point on the line segment.

A TEST BENCH FOR SPATIAL INDEXATION METHODS

To study the methods in an isolated environment a test bench is established called *Geographic Index Laboratory* (GIL). The two algorithms for computing the distance between a point and a line segment (Equations 1 and 2) as well as the four indexation methods were implemented. Below follows some notes about user aspects and implementation details of GIL.

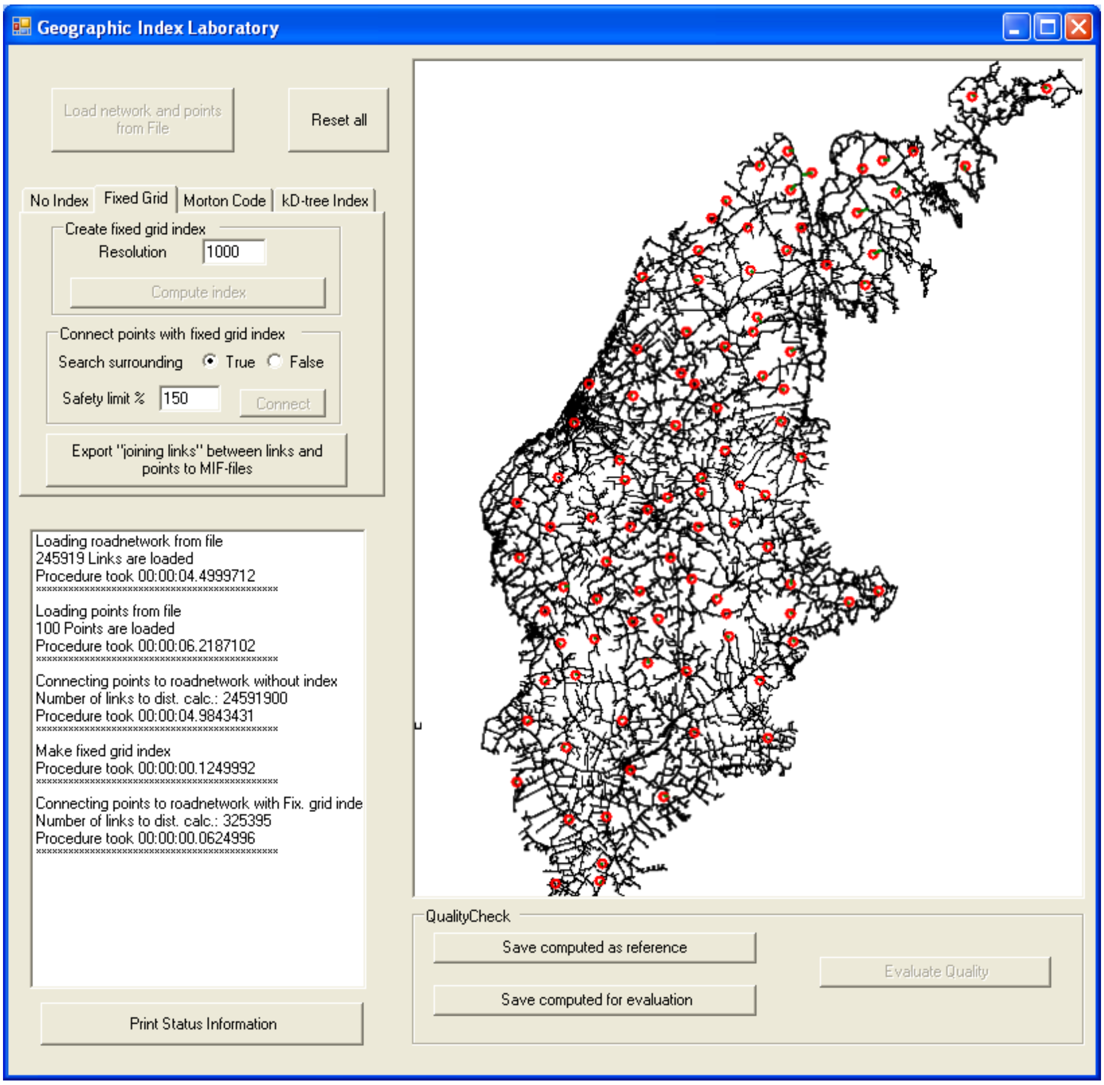
USER ASPECTS OF GEOGRAPHIC INDEX LABORATORY

The user interface of the test bench is shown in Figure 7. The controls of the different indexation methods are placed in the upper left corner. Information of progress and performance is given in the lower left corner. The panel at the right shows a map over the datasets.

The test bench is easy to use. First, the user opens two datasets, a network dataset and a point dataset. Then, the user selects which indexation method to use (no index, fixed grid, Morton code or kD-tree) and sets the parameters that control this indexation method (e.g. the resolution in the fixed grid method or the interval in Morton code index). The connection of the points is performed in two steps. In the first step, GIL creates a spatial index for the line segments in the network; and in the second step, the indexation method is used to connect the points in the point dataset to the network. The result (the connecting links between points and the road network, cf. Figure 1) can be viewed in the map window or exported to MapInfo export files (Mid/Mif) and analysed outside the test bench in a standard GIS environment (i.e. MapInfo Professional). Information about each operation (e.g.

calculation times, number of elements in the candidate sets, etc.) can be read in the lower left panel (see Figure 7).

GIL includes a quality check of the connection process (see bottom right in Figure 7). The quality check requires that two connections of the points to the network is computed. Start by using an indexation method that will provide the correct answer (e.g. using *no index*). Then connect the point once more utilising another indexation method. The quality of the latter indexation method can then be evaluated by comparing the connecting links of the two methods. GIL computes some statistics of this comparison that is shown in the lower left panel.



Resolution 1000

Search surrounding ● True ○ False

Safety limit % 150

```
Loading roadnetwork from file
245919 Links are loaded
Procedure took 00:00:04.4999712
************************************************
Loading points from file
100 Points are loaded
Procedure took 00:00:06.2187102
************************************************
Connecting points to roadnetwork without index
Number of links to dist. calc.: 24591900
Procedure took 00:00:04.9843431
************************************************
Make fixed grid index
Procedure took 00:00:00.1249992
************************************************
Connecting points to roadnetwork with Fix. grid inde
Number of links to dist. calc.: 325395
Procedure took 00:00:00.0624996
************************************************
```

Figure 7 *The user interface of the Geographic Index Laboratory. This example uses the national road database of Sweden, NVDB, covering the area of Gotland.*

SOME IMPLEMENTATION DETAILS OF GEOGRAPHIC INDEX LABORATORY

In this section we only describe details of GIL that are of interest while comparing the performance of the indexation methods. However, anyone that is interested in the details can download the code from [3]. GIL is developed in C# (see e.g. Deitel et al., 2003).

FIXED GRID ORDERING

The links in the fixed grid approach are stored in a matrix of dynamic arrays (the C# class *ArrayList*). The links are, of course, unordered in the array.

MORTON CODE

The Morton values are computed for the mid point of each link and the values are stored in a dynamic array (the C# type *ArrayList*). The array is sorted (after all links are added) using the method *Sort* for the class *ArrayList*. Furthermore, the search is performed using the method *BinarySearch* in the same class. We are aware of that storing indexes, such as Morton values, in an array is not appropriate in a dynamic environment where new index values are introduced (better to use e.g. B-trees). But since we are creating all index values at a single time in our application, we do not come across this problem.

To improve the performance of the Morton index search we divide the coordinate with an integer value before the computation of the Morton code start. This integer is set by the user. Furthermore, we transform the coordinates to a local system to further diminish the size of the coordinate values.

KD-TREE

The search in the kD-tree is done in an iterative way. In the first search iteration a search distance (*sd*) is given by the user (in our tests we have set this value about the same size as the longest link in the network). The length of the quadratic search window is two times the search distance, with the point to connect centered in the middle. This implies that all links that has an endpoint in this window will be added to the list of candidates. If no links are found in the first iteration the search window is expanded with the search distance until a link is found.

EVALUATION

Two cases studies were conducted. The first concerns spatial indexation methods and the second concerns methods to compute distances between point and line segments. All the computations were performed using the Geographic Index Laboratory on a PC with Windows XP, Pentium 4, 3 GHz and 2 GB Ram.

SPATIAL INDEXATION METHODS

In the first case study we performed two tests both with the national road database of Sweden, NVDB, from the Swedish National Road Administration (SNRA) covering the island of Gotland (246352 links). For the point data sets we used:
In the first test (Table 1) - the points are given in a 250 meter grid, but only cells that has at least one inhabitant is used; this implies that all points are rather close to the road network. Totally 5795 points.
In the second test (Table 2) - a regular grid point dataset with a resolution of 250 meters covering the whole road network;

some of the points are far from any link in the road network. Totally 38218 points.

The results of the case study are given in Table 1 and 2. The calculations begin with a pre-process where the indexes are built (for the fixed grid method this pre-process equals sorting the links in the buckets, cf. Section 3.1) which is documented in column three. This process is not time critical since it only has to be run once for a network. The performance results are given in the fourth and fifth columns. In the fourth column the mean number of links selected by the binary search is given (i.e., the number of links in the candidate set). And in the fifth column the total time for the search is given (including both the binary search to find the candidate set and the linear search in the candidate set). The quality of the connecting point operation is given in columns six and seven (number of incorrect connecting links and the maximal difference in length for the connections).

The spatial index methods have parameters that can be tuned balancing exact result on one hand and good performance on the other. When the indexation method fixed grid is used 3 parameters can be set:
Grid size (*gs*)
A Boolean parameter that decides if an extended search is performed. This parameter governs?? if step 4 in the description of fixed index in Section 3.1 will be performed.
Safety limit. If the extended search is performed this parameter governs how much extended the search will be.
In our tests we have used to settings of the parameters 2 and 3:
Safe – 2 = true and 3 = 150%
Unsafe – 2 = false
In the case of the Morton code index two parameters are set:

The resolution of the Morton key value (*res*). This parameter is equal to the integer value that all coordinates are divided with before the Morton code is computed.

Search interval (*si*). This parameter governs the size of the search interval in the Morton code domain.

When the kD-index is used the size of the search distance (*sd*) is varied.

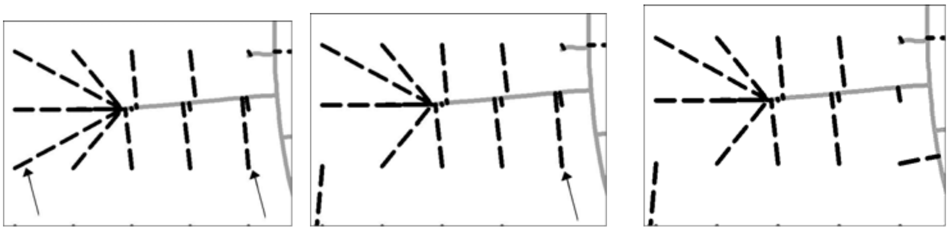
***Table 1** Time for connecting points to the network using the test bench. 5795 points connected.*

Indexation method	Parameter settings	Time for building the index	Mean of links in the candidate set	Time for connecting points	Number of incorrect connect links	The maximal difference in length between a incorrect connect link and a correct link (m)
No index	-	-	246352	5 min	0	-
Fixed grid	*gs* = 1000m safe	0.1 s	3660	4.3 s	0	-
Fixed grid	*gs* = 250m safe	0.2 s	380	0.6 s	0	-
Fixed grid	*gs* =1000m unsafe	0.1 s	135	0.3 s	116	791
Fixed grid	*gs* =250m unsafe	0.2 s	27	0.1 s	69	34
Morton code	*Res* = 10 *si*= 1000	2.5 s	35	0.2 s	1040	4886
Morton code	*Res* = 10 *si*= 10000	2.4 s	216	0.5 s	362	2080
Morton code	*Res* = 50 *si*= 1000	2.3 s	455	0.7 s	233	2367
Morton code	*Res* = 50 *si*= 10000	2.1 s	3170	4.2 s	77	892
Morton code	*res* = 100 *si*= 1000	2.2 s	1464	2.4 s	120	2243
Morton code	*res* = 100 *si*= 10000	1.8 s	10500	13.6 s	27	484
kD-tree	*sd* = 225 m	5.7 s	81	1.3 s	23	84
kD-tree	*sd* = 451 m	6.3 s	238	2.8 s	3	73
kD-tree	*sd* = 902 m	6.1 s	714	7.8 s	0	-
kD-tree	*sd* = 1804 m	5.8 s	2266	19.9	0	-

***Table 2** Time for connecting points to the network using the test bench. 38 218 points are connected.*

Indexation method	Parameter settings	Time for building the index	Number of links in the candidate set	Time for connecting points	Number of incorrect connect links	The maximal difference in length between a incorrect connect link and a correct link (m)
No index	-	-	246352	30 min	0	-
Fixed grid	*gs* = 1000m safe	0.1 s	3299	24.9 s	0	-
Fixed grid	*gs* = 250m safe	0.2 s	267	2.9 s	0	-
Fixed grid	*gs* = 1000m unsafe	0.1 s	193	1.6 s	6357	1007
Fixed grid	*gs* = 250m unsafe	0.2 s	76	0.1 s	488	123
Morton code	*res* = 10 *si*= 10000	2.3 s	131	1.8 s	8455	17896
Morton code	*res* = 10 *si*= 100000	2.0 s	1261	10.9 s	2576	2579
Morton code	*res* = 50 *si*= 10000	1.7 s	3076	23.8 s	1863	2111
Morton code	*res* = 50 *si*= 100000	1.9 s	22747	3 min 14 s	470	1507
Morton code	*Res* = 100 *si*= 10000	1.8 s	10908	1 min 30 s	878	1594
Morton code	*Res* = 100 *si*= 100000	1.7 s	69447	11 min 24 s	268	1507
kD-tree	*sd* = 225 m	5.7 s	38	7.9 s	2886	1204
kD-tree	*sd* = 451 m	5.6 s	118	12.3 s	1149	1204
kD-tree	*sd* = 902 m	5.9 s	432	33.9 s	193	1204
kD-tree	*sd* = 1804 m	5.7 s	1705	1 min 48 s	9	278
kD-tree	*sd* = 2029 m	5.7 s	2156	2 min 24 s	4	392
kD-tree	*sd* = 2706 m	6.5 s	3833	3 min 44 s	0	-

The quality can also be investigated visually by exporting the links that connect the point with the road network to a standard GIS environment (MapInfo professional). This is a good approach to study what type of error the indexation method might introduce. An example of the quality of the result in Morton indexes is illustrated in Figure 8.



(a) (b) (c)

Figure 8 *The connecting links given by Morton code indexation with an increasing search interval in the Morton code domain. (a) shows the best links connecting the road network with the parameters res = 10 and si = 100 000; the two arrows points at incorrect connecting links. In (b) the parameters are changed to res = 10, si = 100 000; here one of the incorrect links still remains. Finally, in (c) the parameters are set to res = 10, si = 1 000 000; the solution is now correct (=identical to the given by the no index method).*

COMPARISON OF METHODS FOR COMPUTING DISTANCE BETWEEN POINTS AND LINE SEGMENTS

The second case study was a performance test of the two algorithms for connecting a point to the closest link. The study was performed using:
* no spatial index,
* a road network consisting of 2 104 384 links, and
* a point dataset of 100 points randomly distributed within the convex hull of the road network. This implied that 2 104 384 links were tested against all the 100 points ending up with 210 438 400 line segments to point calculations. Connecting the points with the implementation of the trigonometric function took 27 seconds (Equation 1). When using the implementation of the algebraic methods (Equation 2) the calculation took 5.6 seconds.

DISCUSSION

The first case study (Tables 1 and 2) reveals that the fixed grid method seems to have best performance in our application. Even if fixed grid is used (with a grid size of 250 m) in *safe mode*, the response time is comparatively low compared to the other indexation methods. If we are satisfied with a “good connection” rather than the closest connection to the network it seems that fixed grid is also the best indexation method (also with a grid size of 250 m).

A problem that accurse when using a quadratic search windows is that when a link is found it may not be the closest link; this affect both the fixed grid method as well as kD-tree. You would have to have a circular search window to assure a correct solution. This means if you want to guarantee an optimal solution with the quadratic search window you should expand it with the square root of 2 after a link is found.

The importance of feeding the right calculation parameters into the different indexation methods became obvious during the tests. It is important to test different parameters to get an optimal solution regarding correctness in result and in performance. The tests also show that different datasets has their own set of optimal calculation parameters. This indicates that if an application deals with different kinds of datasets a pre-process of analysing the dataset could be one way of improving the performance. Such a pre-process could look at e.g. parameters as the longest link in the road net or some measure of the distribution of the point.

An important issue is of course to which degree the result is dependent on our implementation of the indexation methods. The fixed grid method is fairly simple to implement; it is possible to use C# collection classes (array, matrix) leaving the programmer little own code to implement. The kD-tree needs, in our programming environment, more coding and can therefore be subject for, and can gain from, further design work. For the Morton code implementation the programmer has to decide a number of implementation issues. E.g. should the Morton value be linked to the end points (any of them or both) or should it be linked to the midpoint (which was our choice). Furthermore, the binary search in the Morton code domain can be implemented in different ways. To conclude, one should be careful before stating that one indexation method is *better* than another indexation method, our conclusions are built on our implementations of the indexation methods.

GIL is an open source application (Dahlgren, 2006); the application can be used as general testing environment or as an education tool teaching spatial indexation methods. GIS could be used for e.g. studies in tuning the spatial indexation methods, since it enables a user to test different settings of parameters on different datasets.

CONCLUSIONS

The aim of this study is to evaluate methods for connecting points to networks. Based on the evaluation of the case studies using the test bench we make the following recommendations:

The recommendation for the development of accessibility tool is to use *fixed grid ordering* as indexation method. But we also recommend that *kD-tree* is implemented. To have two indexation methods also gives the possibility for relative tests regarding performance and correct results. The setting of the parameters for a given scenario is inherent to the distribution of line segments in the network and points in the point data set; therefore computations using new types of datasets should start by tuning the indexation methods parameters.

It is recommended to use the algebraic method (Equation 2) for computing the shortest distances between the points and the line segments in the network.

ACKNOWLEDGEMENTS

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Paper III

PLANNING RESCUE SERVICES WITH NON-STATIONARY RESCUE UNITS

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ABSTRACT

Geographical accessibility is fundamental when planning rescue services. At present there are several programs for computing the accessibility of stationary rescue units. This study suggests a method for evaluating geographic accessibility in scenarios containing stationary, non-stationary or a mix of both types of units. The method supports the planning process by matching the risk of an incident occurring with rescue units' capabilities and accessibility. The method is implemented in the computer program *Rescue Unit Planner*. The result of the analysis is presented in thematic maps and graphs as *level of coverage*, *mean response time* and *concentration*. The method and the computer program have been evaluated in two case studies: one urban area in southern Sweden and one rural area in northern Sweden. The case studies show that that the method can be useful in the rescue service planning process.

Keywords: rescue service, accessibility, planning, non-stationary units, level of coverage, mean response time, concentration

INTRODUCTION

The study presented in this paper is about rescue service planning. There are several methods that can be used to support the planning process such as cost-benefit analysis [22] , [27]. This study concentrates on the geographic accessibility aspect of risk and on the resources that are equipped to meet these risks. The motivation for this research is the importance of being able to evaluate the geographic accessibility of stationary and non-stationary rescue units of a given type in a given scenario. Later in this article a risk-layer is introduced. This risk layer describes the probability that a risk of a certain type will occur in a geographical place. A rescue-unit as defined in this article is a unit that could in personnel and in equipment responds to this accident type, i.e. the type of rescue-unit is dependent on the risk layer.

In this article we define a non-stationary rescue unit as a unit that is stationed within an area rather than a point. For example a fire-fighter with his equipment in his car when he is doing inspections within a predefined area. Other examples of non-stationary units could be roving units, unit moving in a sector [28] and semi-stationary units located moved to a place with large risk [27]. An important distinction from a static unit is that the non-static unit does not need to return a fire station before responding to an accident. This means that scenarios using the concept of System Status Management [31], [32], [33] could be evaluated with this method.

There are a number of planning methods that support planning for rescue units with a static placement. However, over the last few years some rescue services are started testing non-stationary units. The consequences of using these non-stationary units present a new challenge in the planning process.

The aim of this study is to establish new methods and develop a tool to support rescue service planning that includes non-stationary units. This includes the possibility of testing scenarios using stationary units, non-stationary units or a combination of the two types of units.

The paper is structured as follows. It starts with a background to the project. Section three describes some related studies in order to put the work into context. In the fourth section the methodology of using non-stationary units is described. This methodology is implemented in a tool for rescue planning (section five) that is evaluated in two case studies (section six). The paper ends with discussion and conclusions.

BACKGROUND

In many ways the fire and rescue service in Sweden can be regarded as fairly conservative and traditional. Its organizational structures have not changed since the rescue services used horses and steam-powered water pumps. This traditional approach, which is used commonly all over the world, is to have a fire station from which the rescue resources respond when there is an emergency. In some fire and rescue services in Sweden the effectiveness of this traditional organization is being questioned. This questioning is triggered by both financial reasons and a new law (SFS 2003:778 *Swedish Civil Protection Act*) that has placed tougher requirements on the rescue services provision of an efficient organisation.

In Sweden, as in several other countries, there is an increasing interest in non-stationary units. Some rescue services now have a mixture of stationary and non-stationary units. There are two primary reasons for using non-stationary units. First of all, it makes possible a more effective use of fire service personnel. The most substantial cost in the administration of a fire and rescue service is that of personnel. Traditionally, the fire and rescue service is divided into two distinct branches, one that often exclusively deals with emergency responses and another that primarily focuses on fire prevention and inspections. There is starting to be a realization, in the face of budget cuts, that these two functions need to merge in order to increase efficiency. However, organizational change is necessary in order to achieve this. The most common staffing pattern at Swedish fire stations is one officer and four fire-fighters. They normally perform their daily duties together at the station and travel in the same vehicle to incident scenes. In order for the crew to be able to perform preventive action this structure needs to be revised. It is not efficient resource utilization for example to send the whole crew to do an inspection that would only require one fire-fighter. To be effective the crew has to split up and the stationary unit comprised of five fire-fighters is replaced by smaller non-stationary units that meet at the incident scene and form the full response unit on site. In order to make a change like this you need to determine what the consequences will be for coverage. This could be done in a simulation model that can handle response time calculations for non-stationary, emergency vehicles.

The second reason for introducing non-stationary units is that it decreases response times to initial emergency action at the same or even at a lower cost than for the stationary units. The reason for this is that transferring responses from large stationary units to smaller non-stationary units which are distributed over the covered area will enhance fire service coverage for immediate, often vital, emergency action. The advantage of non-stationary units is of course related to the capabilities of these units. The major advantages are for the type of incidents where the non-stationary units have enough capacity (or where the non-stationary unit could make an important early action at the incident site). For accidents that immediately require more specialized persons and equipment the advantage there are now real advantages with the non-stationary units.

RELATED STUDIES

Geographic accessibility is a much studied field in diverse areas of application, such as health geographics [1], transport modelling [2] and logistics [3]. It is also a main topic in rescue service planning. There are currently several commercial programs that can be used for planning rescue resources. Common programs in Sweden are *Geosecma – Alarmos* [23] and *Effektanalys* [24]. Examples from outside Sweden are *FSEC* (Fire Service Emergency Cover) [29] and *ADAM* (Deccan International) [30]. However, these programs can only process stationary units.

There is substantial research in aspects of geographic accessibility for rescue services. Kolesar and Blum [4] predict the amount of resources required to obtain a certain (average) response time. That is, they predict the number of rescue units required, but not where to place these units. Other researchers have studied problems related where to locate fire stations and other rescue resources. An early study by Hogg [5] presents a method for locating fire stations. The main criterion is that each station must be financially viable, meaning that the optimum number of fire stations and their best position in relation to each other will minimize the total lost from fire. To model this information about incident risks and travel time via the road network a similar approach is proposed by Toregas et al. [6]. In this study an upper limit is placed on the response time, and an optimization problem is solved in order to find the location of fire stations that minimizes costs whilst adhering to the response time. Karasakal and Karasakal [7] use a similar optimization approach where they introduce the concept of *partial coverage*. A partially covered area is the area between the fully covered area (i.e. reached within the predefined response time) and the area without coverage. Anderson and Värbrand [8] studied the problem of dynamic relocation of resources (in their case ambulances, but the concept is also valid for rescue units, see also [9]). Their idea is to build a decision support system that considers the current location of resources and the possible relocation of resources in order to better meet incident risks. A related problem is studied by Swersey [10]. He develops a decision model for the number of units to send to an alarm. This decision model balances the risk of delayed response (by not immediately sending all the available resources) with the risk of lowered capacity for later alarms (if too many resources are sent to the first alarm). Huang and Pan [11] also develop a decision model for dispatching response units. In their model they consider traffic flow to get a better estimation of travel times. Finally, Andersson and Särdqvist [12] optimize the location of rescue service resources. In their model they allow resources (e.g. small rescue units) to be placed outside the fire station, but all resources have a fixed spatial location (i.e. non-stationary units are not allowed). The cost function that is optimized in their model is *equal time*, which is defined as the integral of the rescue resources (here number of persons) as a function of response time.

METHODOLOGY

Smaller non-stationary units (e.g. first response units) do not have the capacity to undertake the required rescue actions at a large incident, due to a lack of people and equipment. That is, in order to take action at an incident it may be necessary to combine one or several non-stationary rescue units with stationary units. The planning process requires that we have a good model for risk and capacity. In this study we have used a model presented by Svensson and Särdqvist [13]. This model concentrates on a number of common types of accidents and the capacities of the rescue units that are sent to respond to the accident (Tables 1-2). The model often has to be extended. For example, a small non-stationary unit could have half capacity, meaning that two units are required to obtain full capacity.

Table 1 *Unit capacities. (From [13], somewhat simplified)*

A	Person release tools for use in vehicle accidents
B	Firefighting
C	Height work in houses lower than 4 floors
D	Height work in houses 4 floors or higher
E	Water supply
F	Water rescue

***Table 2** Incident classification and capacities required (From [13], somewhat simplified).*

Incident type	**Extent**	**Required capacity**
Fire in building	One-family house	B
	Multiple-family house, low	B+C
	Multiple-family house, high	B+D
	Public building	B+C+E
	Work locality	B+C+E
Traffic accident	Single vehicle accident	A+B
	Multiple vehicle accident	A+B
	Heavy vehicle accident	A+B

In a planning situation the risk levels for the different incident types are important. In our study, NCO (the Swedish Centre for Lessons Learned from Incidents & Accidents) produced map layers where the risks of different types of incidents occurring are presented (cf. Table 2). The map layers consist of a raster with a cell size of 250x250 m. The layers, which are hereafter denoted as risk layers, have an estimated risk value for each incident type. NCO estimated the risk values by using regression models. These models fairly well explain reported incidents by statistics of inhabitants (including socio-economical factors), buildings, traffic flow, etc.; and the models can therefore be used to forecast future incidents.

MEASURES OF GEOGRAPHIC ACCESSIBILITY FOR STATIONARY UNITS

For measuring the geographic accessibility we need well defined measures (see a general overview in [14]). In our study these measures are based on the risk layers. That is, to compute geographic accessibility we need a risk layer with the same area as the study area. In this study we used the following measures:

Level of coverage

This is the level of risk covered as a function of *response time*. Here, the response time is defined as the elapsed time from the emergency call until enough capacity (personal and equipment according to Table 2) is available at the incident location. It should be noted that the level of coverage is defined as the level of *risk* covered, and not the level of *inhabitants* or *space*.

Mean response time

This is the mean value of all *response times* (RT). The normalization factor is the risk level; i.e., we have the following definition of *mean response time* (MRT):

$$MRT = \frac{\sum_{j=1}^{n} RT_j * risk_j}{\sum_{j=1}^{n} risk_j}$$

where:

RT_j is response time for cell j in the risk layer,
$risk_j$ is the probability of an incident in cell j, and
n is the number of cells in the risk layer.

Concentration

This measure varies depending on the position in the study area. It is defined as the number of persons that could be present at the incident location as a function of time. The measure of concentration does not consider the persons' capacity.

MEASURES OF GEOGRAPHIC ACCESSIBILITY FOR NON-STATIONARY UNITS

Since the location of non-stationary units is not precisely known, measures of geographic accessibility will be probability measures. In our study we have worked with three cases for non-stationary units (see Figure 1):

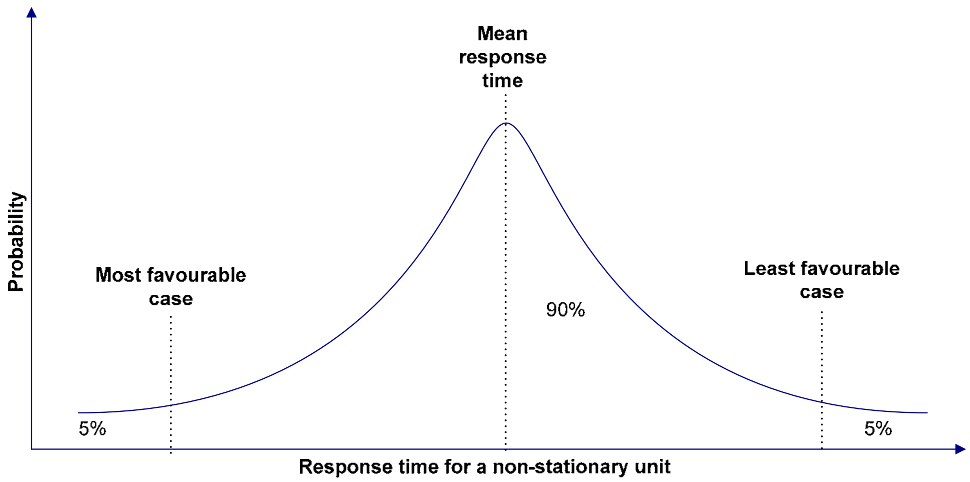


***Figure 1** Definition of the normal, least favourable and most favourable case. For the normal case the mean response time is used. For the least favourable case the response time corresponding to 95% of all cases is used and, finally, for the most favourable case the response time corresponding to 5% of all cases is used. The values for the most (least) favourable case are computed using the mean value and standard deviation of the response time and assume that the response times are normally distributed (i.e., the t-distribution is applied because the standard deviations are estimated).*

The mean and the standard deviation of the response time are estimated by computing the response time for the non-stationary units' different locations. To study the effect of selecting locations a minor test was performed in the municipality of Kävlinge, southern Sweden (Figures 3 and 4). Two non-stationary units were defined, one in the village of Kävlinge and one in the village of Löddeköpinge. Both units could be located anywhere within the village border. Both of the units had capacity for the risk type studied and both had a response time of five minutes. In this study we only used the risk category, fire in buildings one-family house (cf. Table 1) and used a risk layer with a geometric resolution of 250 metres. Three different strategies were used for the computations. Four methods were used to select locations for the non-stationary units for estimating the response times. For the *all points* method one location is computed for each cell in the risk layer within the area for the non-stationary unit. In this case, this equals 80 locations for the unit in Kävlinge and 90 locations for the unit in Löddeköpinge. In the second method, *20 random points*, we selected a random subset of these locations. The reason for this method is to decrease computational load (the program has to compute the network distance from each location to each cell in the risk layer). In the third method we selected 10 random points. In the fourth and final method we used the break points for the polygon as locations. The mean response times for the four different methods are given in Table 3. The most accurate estimation of the response time is the *all points* method (if we assume that the likelihood for the location of the non-stationary units in the area is uniform). We can see that a good estimation is obtained by only using a subset of the locations in the computations (10 and 20 random points). Therefore, this is the method we recommend for practical computations if the area is too large to use all the cells in the risk layer as possible locations. Using the polygons' break points as locations does not provide a good estimation. The main reason is that in this case the rescue unit is never modelled within the area in which a major part of the incidents occur.

Table 3 *Mean response time computed for two non-stationary units in the municipality of Kävlinge (see Figure 4). It should be noted that this study is only used for studying methodology for non-stationary units. In reality the two rescue units are not capable of serving the whole municipality of Kävlinge.*

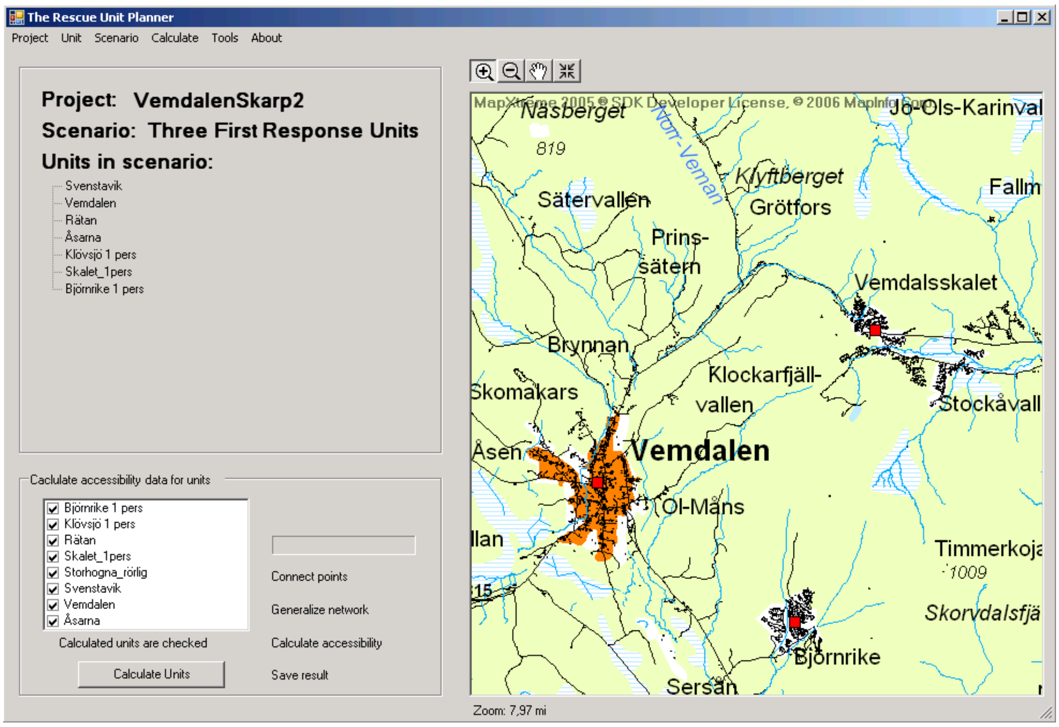
Method for selecting locations	Most favourable case	Normal case	Least favourable case
All points	13 min, 53 sec	18 min, 26 sec	24 min, 40 sec
20 random points	14 min, 4 sec	19 min, 14 sec	24 min, 24 sec
10 random points	13 min, 46 sec	18 min, 50 sec	23 min, 54 sec
Break points	12 min, 9 sec	21 min, 1 sec	29 min, 51 sec

In practice there is often a mixture of stationary and non-stationary units. In those cases we also have to compute the most and least favourable case. For the stationary units the response time for these cases equals the normal response time.

A TOOL FOR PLANNING USING NON-STATIONARY RESCUE UNITS

The *Rescue Unit Planner* (RUP) is a tool that is that is being developed for use in the of rescue services' planning process (Figure 2). The tool targets a user group consisting of planners and evaluators at the county or municipal level. In Sweden the county administrative boards are responsible for evaluating the plans drawn out by the rescue service planners at the municipal level.

In RUP, users can build different scenarios for rescue units, their equipment and their placement. Then the scenarios can be tested against each other. The result is then presented using numerical data, diagrams and thematic maps.



Project: VemdalenSkarp2
Scenario: Three First Response Units
Units in scenario:

- Svenstavik
- Vemdalen
- Rätan
- Åsarna
- Klövsjö 1 pers
- Skalet_1pers
- Björnrike 1 pers

Caclulate accessibility data for units

☑ Björnrike 1 pers
☑ Klövsjö 1 pers
☑ Rätan
☑ Skalet_1pers
☑ Storhogna_rörlig
☑ Svenstavik
☑ Vemdalen
☑ Åsarna

Calculated units are checked

Figure 2 *The Rescue Unit Planner's user interface.*

RUP

RUP is a desktop application developed in C# for the Windows environment. It uses the *MapExtreme* module for its mapping capability [15] and the *NetRider* module for accessibility analysis [16-18].

To start a project in RUP the user has to define the geographic area by choosing a background map, a risk layer and a road network that covers the project area. The risk layer is a tiled GIS-layer that describes the distribution of a particular risk in the region. In the next step the user places different types of units in their geographic positions. Because of the mapping capabilities in the application this is done by digitizing. If it is a stationary unit a point is digitized. In the case of a non-stationary unit an area within the unit is allowed to move and is digitized (cf. Figure 10). Accessibility data is calculated for each of the units.

In the third step, scenarios that are evaluated in the analysis are constructed by choosing different combinations of the digitized units. In the last step, the joint accessibility for a scenario is calculated and the result is presented in diagrams as *level of coverage*, *mean response time* and *concentration*. It is then possible for the user to compare different scenarios and see how the joint capability of the scenario covers the risks in the risk layer.

CASE STUDIES

Two case studies were performed. The first region is an urban region in southern Sweden and the second a rural area further north in Sweden (Figure 3). The point of the regional case study is to look at different scenarios for locating and equipping rescue units. The major aim of the studies is to evaluate RUP's capabilities in handling non-stationary rescue units in the planning process. This article focuses on the methods used in the case studies. Details and results of the case studies are presented in [19] and [25] for the southern study area and in [26] for the northern study area.

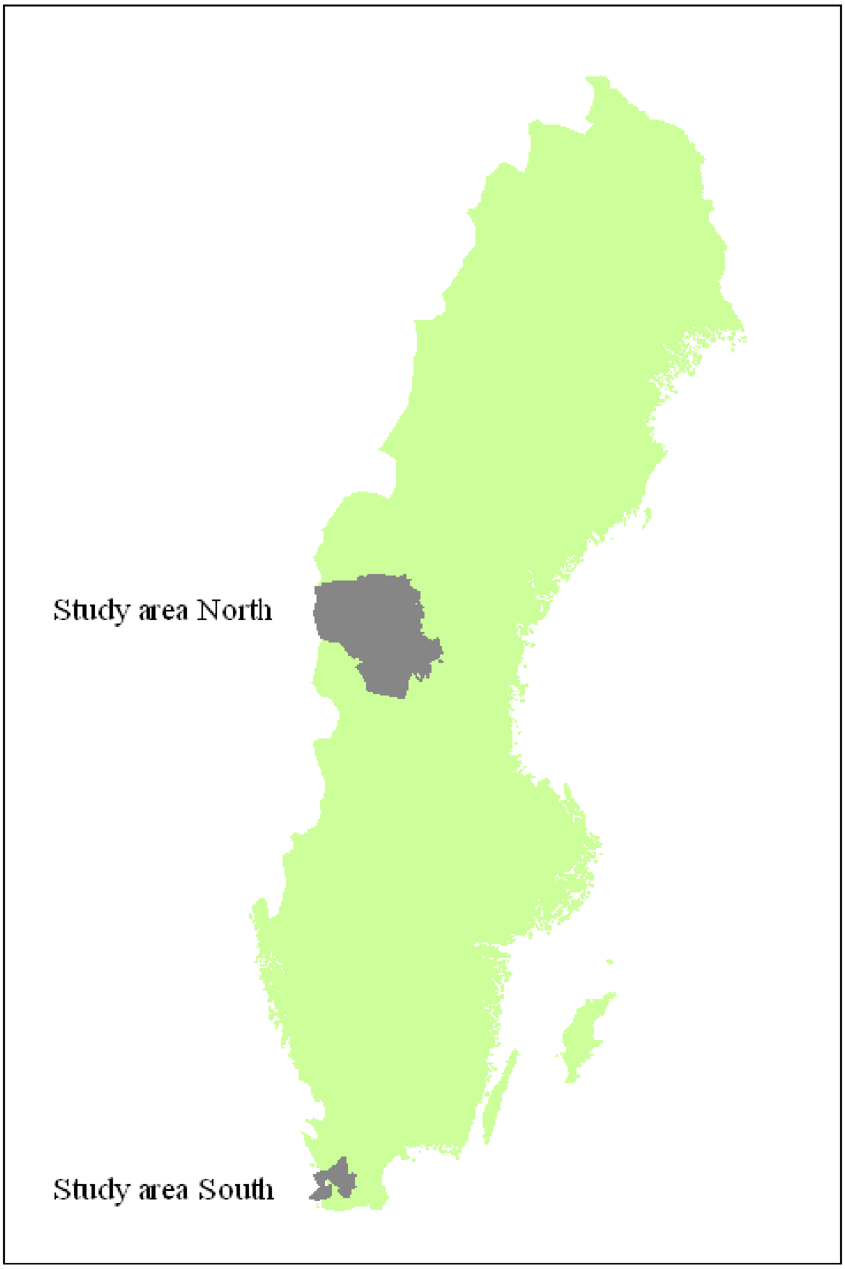


Figure 3 *The study areas' location in Sweden.*

Figure 4 *The study area for the first case study.*

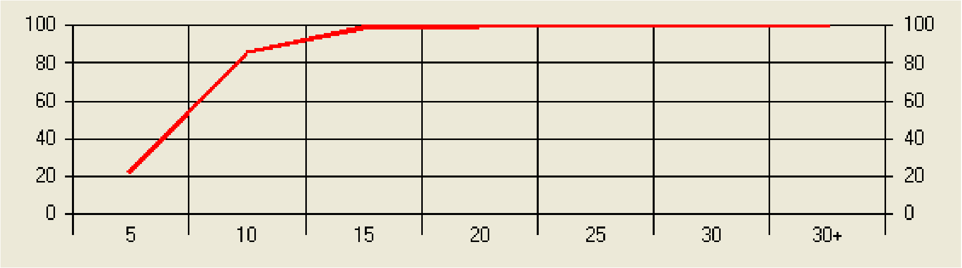
URBAN REGION IN SOUTHERN SWEDEN

The study area for the first case study comprises the municipalities of Malmö, Lund, Burlöv, Kävlinge and Eslöv (which have a co-operation for rescue services, see Figure 4).

About 15 different scenarios were evaluated using RUP [19] in a study for evaluating the future organisation of the rescue services. We will only show the results of two of these scenarios. The first scenario is the current system (daytime) that only uses stationary units at the fire stations. The second scenario also primarily includes stationary units, but there are also two non-stationary units that are placed somewhere within the city of Malmö. The location of each of these units is modelled with 20 random points within the area.

The degree of coverage for the current organisation and the scenario with non-stationary units is presented in Figure 5. We will not make a judgement about which organisation that is preferable (this discussion falls outside the scope of this article). However, we did notice one thing about the non-stationary units; a non-stationary unit could sometimes be close to the incident location and therefore the level of coverage is good for the most favourable case. In the case when stationary and non-stationary units are mixed, as in this case, the least favourable case could be equal to the normal case. The reason is that both of these cases could include only stationary units (this is actually the case in the bottom graph in Figure 5).

For certain locations where there is a risk of larger incidents (e.g. major traffic junctions), being able to compute the concentration helps the planning process. Figure 6 shows the result for such a computation in the scenario with mixed stationary and non-stationary rescue units.



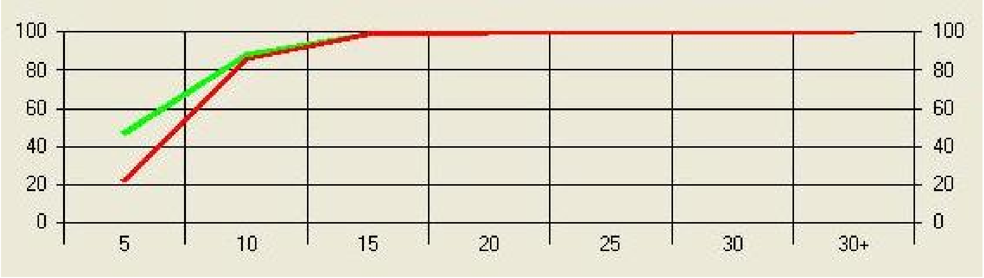


Figure 5 *The level of coverage (in percent) for the risk category of single car accident shown as a function of response time (minutes). The top graph shows the situation for the current organisation (daytime) with only stationary units. The bottom graph shows the level of coverage for a scenario using mixed stationary and non-stationary units. The red line shows the normal case and the green line the most favourable case.*

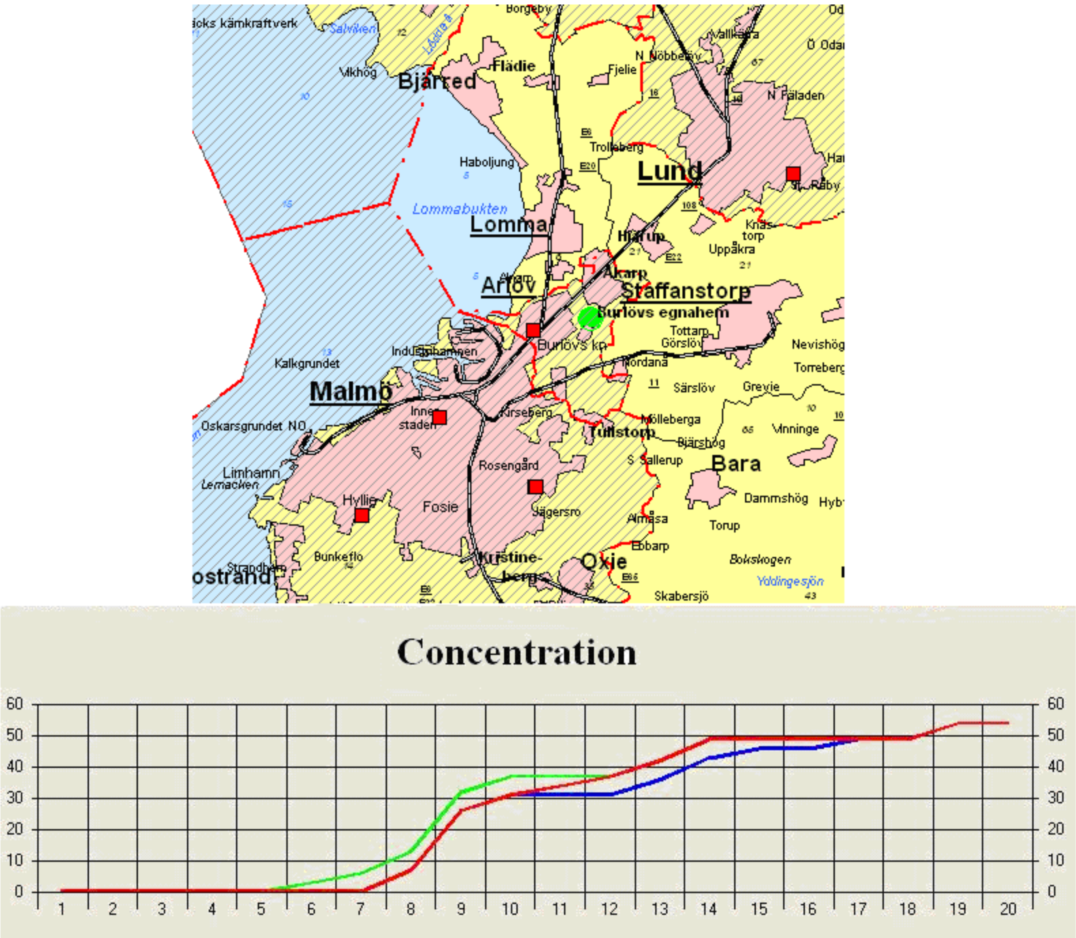


Figure 6 *The concentration for a roundabout north-east of the city of Malmö (marked with a green circle) for a scenario using a mix of stationary and non-stationary units. The stationary units are placed at the fire stations (red squares) and the non-stationary units are placed somewhere within the city of Malmö. The graph shows the number of persons (y-axis) that could be present at this location as function of time (minutes, x-axis). The green line shows the most favourable case, the red the normal case, and the blue line shows the least favourable case.*

RURAL REGION IN NORTHERN SWEDEN

The area where the second case study was performed contains two municipalities, Härjedalen and Berg (Figure 7). The two municipalities cooperate in their efforts to use their rescue services as effectively as possible. The region covers 17,000 sq km and has 18,328 residents, according to the 2006 Figures from Statistics Sweden. This means that the region is a sparsely populated rural region with long distances as part of normal life. The rescue services in the region are categorized by small static rescue stations manned by retained fire fighters. Responses to rescue calls often mean long distances to the incidents. The tourism industry is the largest contributor to the regional economy, but it is also a problem when the tourists load the area's public services. For the rescue services, one way of managing these special conditions is to evaluate the possibility of using temporary non-stationary vehicles or static units during the holiday season.

A large ski-resort has been built in one geographically small area on the border between the two municipalities(see Figures 7 and 8). The resort is now planning on expanding from ~13,000 to ~32,000 tourist beds in the area [20-21]. This entails new challenges for the rescue services in the two municipalities.

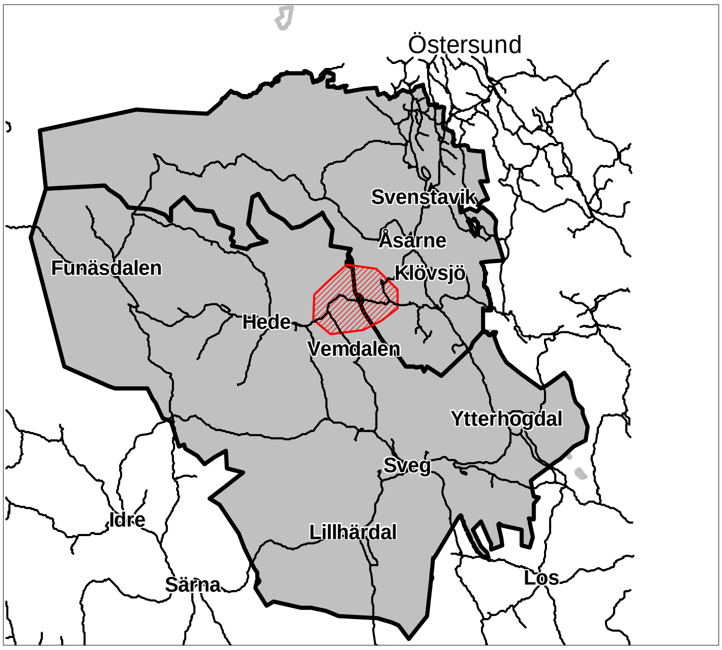
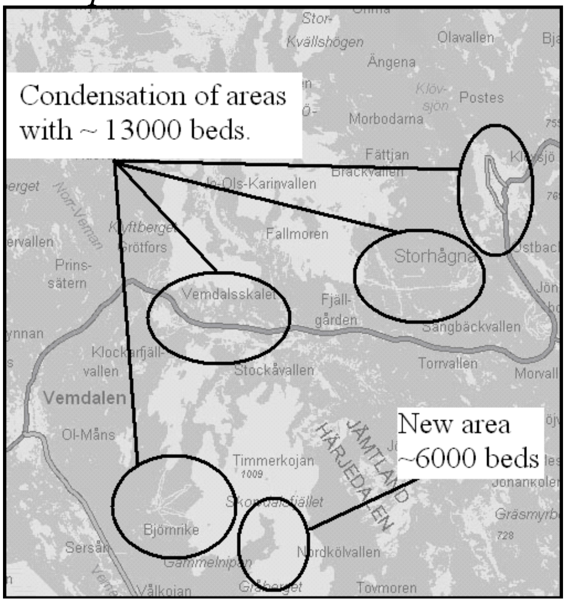


Figure 7 *The Vemdalen study area, on the border of Berg and Härjedalen municipalities.*


Condensation of areas with ~ 13000 beds.

New area ~6000 beds

Figure 8 *Expansion plans for new tourist beds in the Vemdalen study area.*

Two scenarios were evaluated in a test . Firstly, a scenario like the current situation in the test area (Figure 9) with three static rescue units placed in Vemdalen, Åsarne and Rätan. The result of the coverage level calculation is shown in Figure 11 (top graph). In one of the possible scenarios, three first response units where added to the current scenario, Figure 10. Two static units in Björnrike and Vemdalsskalet and one non-stationary in Storhogna (modelled with random points). The bottom graph in Figure 11 shows the level of coverage for that possible scenario.

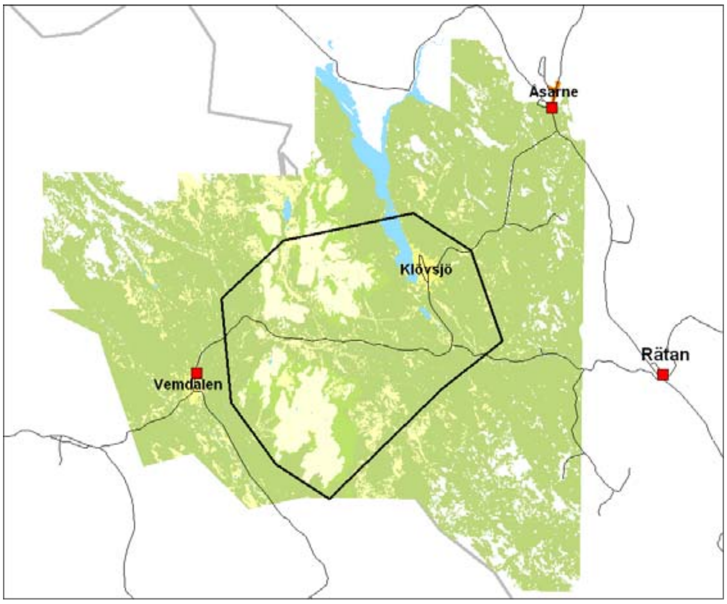


***Figure 9** The current scenario for rescue units in the Vemdalen area.*

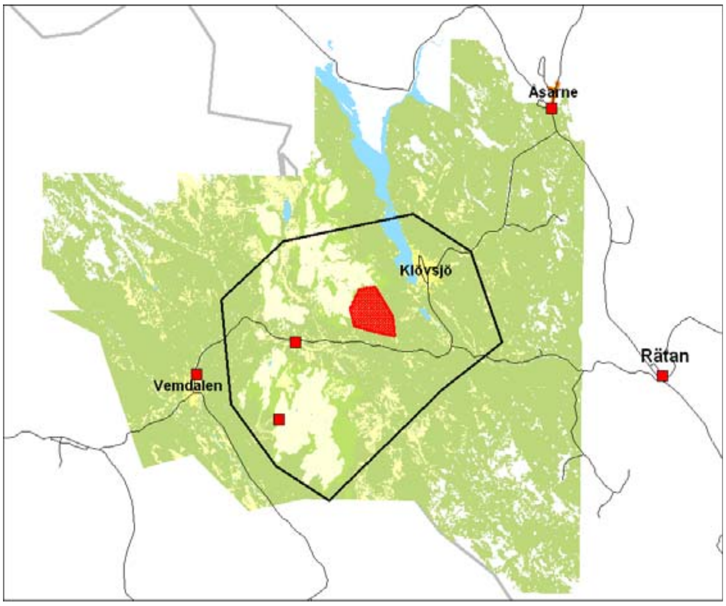


***Figure 10** A possible scenario adding three first response units to the current scenario (one non-stationary unit).*

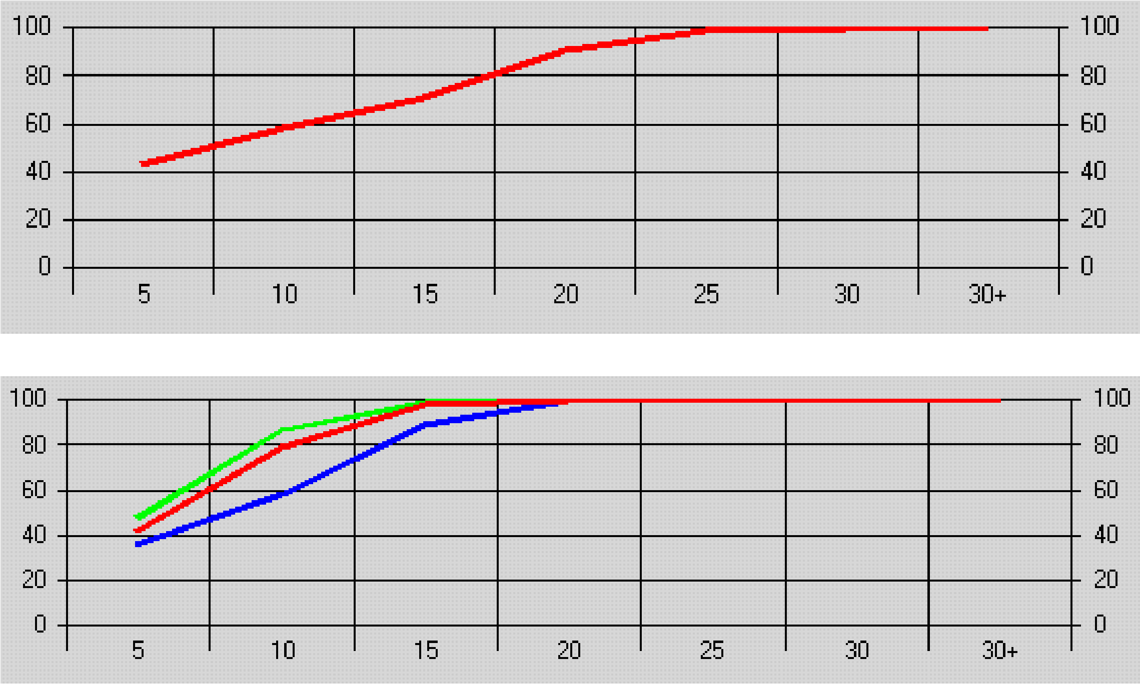


Figure 11 *The level of coverage (in percent, y-axis) for the risk category of a one-family house fire as a function of response time (minutes, x-axis) in the Vemdalen study area. The top graph shows the current situation and the bottom graph shows a scenario using non-stationary units. The red line shows the normal case, the green line the most favourable case and the blue line the least favourable case.*

DISCUSSION

When two scenarios are compared with each other we use three types of measures that are commonly used in the rescue services: *level of coverage*, *mean response time* and *concentration*. There is one drawback to these measures, they are only capable of modelling zero or full capacity for a given risk category. There are many circumstances in which it would be interesting to model partial capacity (e.g. the capacity of a small unit that could arrive early at the incident) (see [11]). The new tool can provide opportunities for calculating other parameters, or present the results using new types of diagrams or thematic maps.

The concept of using two case studies in the project highlighted important aspects in the differences in the planning process for urban and rural areas. This is important to consider if an application is to be developed that will support the planning process in different types of areas. One example of this is that in rural areas the rescue services comprise retained fire-fighters and how recruitment problems can influence the location of the rescue services. The same problem is not found in urban areas which have full-time fire-fighters. Another example is that response times that are considered unacceptable in urban areas are considered acceptable in rural areas. This results in different demands on a planning tool, which a developer must take into account when developing a program that works both in urban and rural areas.

RUP is a good tool for evaluating a proposed rescue organisation. With just a couple of hours introduction the users of the prototype was self going in their analysis, indicating high usability. When working with the prototype in a group, the prototype acted as a catalyst for interesting discussions. The relative high resolution of source data worked well in the application. Calculation times where reasonable and will probably improve further in a real application. The next step is to integrate it with a tool for optimising the location of stationary rescue units (described in [11]). We anticipate that this will be the major tool for planning rescue services in Sweden in a few years.

One important issue that became obvious when working on the case studies was the correspondence between risk and a unit's capabilities, from discussions in the reference groups among people with knowledge of rescue service planning. This is a key problem area that must have a good solution in order to render a tool like RUP trustworthy.

CONCLUSIONS

In this paper we have proposed a methodology for planning rescue services that includes non-stationary units. This methodology includes both computational methods and measures of geographic accessibility. We have used traditional measures of geographic accessibility (*level of coverage*, *mean response time* and *concentration*) but instead of using single values (used for stationary units) we use probabilistic measures.

The methodology was implemented in a tool for rescues planning (RUP) and two case studies have been used to evaluate it. The results show that RUP, and other tools based on similar theories, could be used as support when planning rescue services using non-stationary units.

ACKNOWLEDGEMENTS

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