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Prompt Pediatric Care

Pediatric patients’ estimated travel times to surgically-equipped hospitals in Sweden’s Scania County

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Disclaimer

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Bachelor thesis, 15 credits, in *Physical Geography and Ecosystem Analysis*

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Foreword

This bachelor thesis (15 credits) concludes my Bachelor of Science Degree with a major in physical geography and ecosystem analysis from the Department of Physical Geography and Ecosystem Analysis at Lund University in Sweden. This thesis has been carried out as part of a joint project between the Centre for Geographical Information Systems and the Department of Medicine at Lund University. I would especially like to thank my supervisor Andreas Persson for his helpful advice, guidance and feedback during the planning and writing of this thesis. I would also like to thank Karin Larsson at the GIS Centre in Lund for her assistance in data processing. Furthermore, I would like to thank Erik Omling and Lars Hagander at the Department of Medicine for communicating clear objectives and providing medical information and data.

Lastly, I would like to thank my mother Regina Näslund for providing endless support and patience by proofreading and offering invaluable discussions.

Abstract

Health and emergency services aim to provide patients with urgent care according to an accessibility policy that is characterized by “proper service at the proper time and place” (Jordan et al. 2004; Murad 2007). Network analysis using geographical information system (GIS) applications has frequently been used in healthcare planning to investigate a population's accessibility to professional care, e.g. how easy or difficult is it for members of the population to reach a hospital. This network analysis has been conducted to investigate the distribution of possible pediatric patients (children age 0-18) per surgical hospital and these patients’ estimated travel times to the nearest hospital within the county of Scania, Sweden by utilizing data that has been collected per *Small Area for Market Statistics* (SAMS) in Scania, Sweden. A methodology for the implementation of data from Sweden’s national road database (*Nationell vägdatabas, NVDB*) is presented as well as a statistical analysis of each surgical hospital’s *catchment* (i.e. the total area served by each surgical hospital).

The results show that only a relatively small number of children (10,537 or 4%) reside in *underserved* SAMS associated with travel times of 30 minutes or more to the nearest surgical hospital. In addition, there were large differences in the number of children potentially served by each hospital. Adult residents residing within the catchments of the different surgical hospitals did not differ from each other significantly on attributes such as level of education, purchasing power or median income, as the variability among residents within each catchment was very large.

This study revealed some interesting information, but also had several important limitations due to the assumptions made when modeling. The travel time estimated from SAMS with a smaller area to the nearest hospital was generally representative for all patients residing in that particular SAMS. However, the locational sensitivity analysis showed that the travel time estimate was less generally reliable for all residents within larger, rural SAMS, where the population-weighted centroid was less reliable since dwellings were more sparse and further apart. Nevertheless, the results herein may prove helpful in planning and improving healthcare in Scania. This study may also prove helpful as part of a more thorough investigation of socioeconomic factors that may affect where, when, why and how various pediatric patients in Scania seek medical care.

Keywords; network analysis, accessibility, pediatric surgery, GIS, shortest route, hospitals, health planning, healthcare, travel time, Scania

Sammanfattning

Nätverksanalys med hjälp av GIS applikationer har ofta använts inom sjukvården för att planera och undersöka en populations tillgång till professionell vård. I detta kandidatarbete har en nätverksanalys genomförts för att beräkna dem kortaste färdvägarna från varje demografisk avgränsat område (”Small Area for Market Statistics” eller SAMS) inom Skåne län till det närmaste kirurgiska sjukhuset för att undersöka fördelningen av barn (i åldern 0-18) per kirurgisk sjukhus upptagningsområde. En nätverksanalysmetod, med användning av data från Sveriges nationella vägdatabas (NVDB), presenteras liksom en statistisk analys per upptagningsområde för varje kirurgisk sjukhus. Resultaten visar att endast ett relativt lågt antal barn (10.537 eller 4%) bor i SAMS med restider på 30 minuter eller längre till närmaste kirurgiska sjukhus. Det finns också stora skillnader i antalet barn potentiellt försedda av varje sjukhus. Universitetssjukhuset i Malmö omfattar det största antalet potentiella pediatriska patienter (81,750 barn eller 28% av alla skånska barn i åldern 0-18) medan Trelleborg sjukhus täcker det minsta antalet barn (14.075), vilket motsvarar endast 5% av befolkningen 0 -18 år i Skåne. De olika sjukhus upptagningsområden skiljer sig inte från varandra väsentligt på egenskaper såsom vuxen utbildningsnivå, köpkraft eller medianinkomsten eftersom variabiliteten i varje upptagningsområde var mycket stor. Denna studie pekade på vissa intressanta resultat, men hade också flera viktiga begränsningar på grund av de antaganden som görs vid modellering. Restiden beräknad från en viss SAMS till närmaste sjukhus var generellt representativt för alla patienter som bor i till arean mindre SAMS. Lokaliseringskänslighetsanalyen visade dock att den uppskattade restiden var mindre generellt tillförlitlig för alla invånare inom större, rurala SAMS, där befolknings vägda mittpunkten var mindre tillförlitlig eftersom befolkning bor glesare och längre ifrån varandra. Ändå kan resultaten härifrån vara till hjälp i planeringen och att förbättra sjukvården i Skåne. Denna studie kan också vara till hjälp som en del av en mer grundlig undersökning av socioekonomiska faktorer som kan påverka var, när, varför och hur olika pediatriska patienter i Skåne söker vård.

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Abbreviations and Acronyms

GET – Geodata Extraction Tool

GIS - Geographic Information System

SAMS – Small Area Market Statistics

SCB - Statistiska centralbyrå, Statistics Sweden

NVDB - Nationell vägdatabas , National road database

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1. Introduction

Health and emergency services in Sweden aim to provide patients with care according to a “fair access policy” that is characterized by “proper service at the proper time and place” (Jordan et al. 2004; Murad 2007). An important consideration in healthcare planning is patient travel time to the nearest health service location. Travel time by automotive vehicle to a health service location can be estimated by taking into account factors such as driving distance as well as the speed limit and conditions along the roads most likely to be in the route selected. Healthcare accessibility and emergency response times can be critical, especially when patients require immediate treatment for the best possible health outcomes. Poor physical geographical accessibility may reduce the use of service, which may lead to poorer health outcomes (Maheswaran and Craglia 2004). Nevertheless, physical geographical accessibility and travel times to emergency healthcare services vary in different areas of Sweden and even within individual counties.

Network analysis using geographical information system (GIS) applications has frequently been used in healthcare planning to investigate a population's physical geographical accessibility to professional care. Network analysis is a method used to model the way objects can travel within networks to investigate questions related to accessibility, which is defined as “the measure of the capacity of a location to be reached by, or to reach, different locations” (Rodrigue et al. 2013). The route from one location to another that is assumed to result in the least *friction* relative to other paths is often the most accessible. In most cases, friction is expressed in terms of distance, travel time or travel cost.

Network analysis has been conducted to calculate the shortest routes from patients’ locations to alternative locations where health services and emergency care services are provided. For example, Nicoară and Haidu (2014) modelled the shortest route to road injuries from emergency care units and ambulance stations in order to create a centralized system for navigation in Cluj-Napoca, Romania. A “Shortest route” analysis does not necessarily only relate to geographic distance, but may also include the route with the shortest travel time or the most cost-effective one.

Network analysis is also frequently used in conjunction with the statistical analysis of socioeconomic data to investigate disparities in spatial accessibility to vital public services as well as to desirable public amenities. For example, Tansley et al. (2015) investigated the spatial access to emergency healthcare services in low vs. middle-income countries and concluded that there was a significant disparity in lower-income countries compared to higher-income countries. Higher-income countries were found to have greater access to healthcare services in general.

Emergency service coverage areas have previously been studied to calculate the percentage of the population that lies outside of areas associated with response times defined as acceptable or “proper”. For example, Amram et al. (2016) studied injured Canadian children’s geographic access to pediatric trauma centers and the impact of “the golden hour” on the length of those children’s hospital stays. The researchers found differences in health outcomes as a result of access to emergency care. The effect of distance and travel time on health outcome in children who require immediate treatment and/or surgery is in need of further investigation in many countries and areas throughout the world, including areas of advanced healthcare nations such as Sweden. In cooperation with researchers in the Faculty of Medicine at Lund University, this study has been performed to investigate the distribution of potential pediatric patients per surgical hospital in the Swedish county of Scania.

Using GIS analysis techniques, I have herein attempted to calculate and map estimated travel times for potential pediatric patients who reside in different defined areas to the nearest well-equipped surgical hospital in Sweden's southernmost county, Scania (*Skåne*). Data regarding population size and age distribution were supplied by Statistics Sweden (*Statistiska Centralbyrån or SCB*) and are based on the *small areas for market statistics* (SAMS) currently defined by SCB for demographic data collection. SCB has divided the county of Scania into 1,283 such SAMS.

There are hospitals at ten different locations in Scania County. These include major university hospitals with emergency departments as well as local hospitals that focus on providing different types of specialist care by appointment. This analysis takes only the eight hospitals listed below into account, since according to the medical faculty who requested this analysis; all of these eight hospitals are well equipped to surgically treat two common childhood ailments: acute appendicitis and cryptorchidism (an undescended testicle):

1. **Helsingborg** General Hospital (*Helsingborgs lasarett*)
2. **Kristianstad** Central Hospital (*Centralsjukhuset Kristianstad, CSK*)
3. **Landskrona** Hospital (*Landskrona lasarett*)
4. Skåne University Hospital in **Lund** [*Skånes universitetssjukhus (SUS) i Lund*]
5. Skåne University Hospital in **Malmo** [*Skånes universitetssjukhus, Malmö ällmänna sjukhus (UMAS)*]
6. **Trelleborg** Hospital (*Trelleborg lasarett*)
7. **Ystad** Hospital (*Ystads lasarett*)
8. **Angelholm** Hospital (*Ängelholms sjukhus*)

Appendicitis is one of the most common childhood illnesses. It occurs in 7-9% of all children and is most common in teenagers. Appendicitis normally requires immediate surgery: an appendectomy. Delayed treatment can result in perforation of the appendix, serious internal infection and life-threatening complications. Before surgery, healthcare personnel witness that approximately 40% of all inflamed appendices have already burst. Although most surgeons can perform an appendectomy, the youngest patients with suspected appendicitis should be referred to a university hospital or a pediatric surgical unit for an operation.

Cryptorchidism in boys, characterized by at least one undescended testicle (*retentio testis*), is a common congenital deformity exhibited by approximately 1% of all male newborns. This condition is surgically treated to prevent an increased risk of testicular atrophy, infertility and cancer later in life. The Swedish national guidelines, which were revised most recently in 2007, state that the optimal age for surgery to treat cryptorchidism is 6-12 months of age. Furthermore, operations on children under 12 months should be performed in a pediatric surgical unit to increase surgical and anesthesiological safety, thereby preventing errors and complications. Healthcare personnel in Sweden have recognized a geographic concentration of males suffering from cryptorchidism later in life.

1.1 Aims

Healthcare personnel suspect that there may be a correlation between a pediatric patient's health outcome and the family's distance to the nearest hospital. Different hospitals have different specialities, and distance to the nearest surgical hospital may affect accessibility to the right level of care when certain medical problems arise. It is assumed that the greater the driving distance to the nearest hospital, the lesser the hospital's accessibility and the greater the reluctance of a family to seek treatment for their child there. Delays in hospital treatment may in turn affect children's health outcomes.

Healthcare personnel thus wish to study how geographic distance, or more precisely, travel time to the nearest surgically-equipped hospital, and other socioeconomic variables may relate to families' likelihood of seeking medical care and children's health outcomes in emergency and non-emergency medical cases that require surgery. After consultation with medical faculty, cases of appendicitis were used to represent the need for emergency healthcare, while cases of cryptorchidism were used to represent the need for non-emergency, planned healthcare. Unfortunately, no data on patients' actual health outcomes were available at the time of the study. The purpose of this study was instead to do preliminary work by mapping the locations of surgical hopsitals relative to population centers within Scania County and then to calculate patients' estimated travel times to the nearest surgical hospital from different areas of Scania as a measure of the various hospitals' accessibilities and the relative resistance of residents to seek treatment. In addition, certain socioeconomic variables among residents were considered as possibly relating to hospital distance and accessibility. The aims of the study in this thesis were thus to accomplish the following:

- Perform a vector-based GIS road network analysis of Scania County using data from the Swedish Transport Administration's national road database (*Trafikverkets nationell vägdagabas, NVDB*). The network analysis was then used to calculate the estimated travel time from each demographically-defined area (SAMS) to the nearest surgically-equipped hospital.
- Calculate and show the distribution of children per SAMS according to their places of residence and their travel times to the nearest of the eight selected hospitals based on the network road analysis.
- Evaluate the model's applicability through a locational sensitivity analysis.
- Investigate the socioeconomic background of the residents who reside within the different surgical hospitals' catchments.

The results of this research analysis may have implications for future healthcare planning and lead to further research on pediatric health risks associated with longer travel distances and healthcare delays on a national scale.

1.2 Geographic Area for Study

The geographic area for study in this analysis is the whole of Scania County, also known in Swedish as *Skåne län*. Scania is the southernmost of Sweden's 21 counties. Figure 1 shows an overview map of the county, indicating the locations of roads, major towns and cities and the most heavily developed urban and suburban areas.

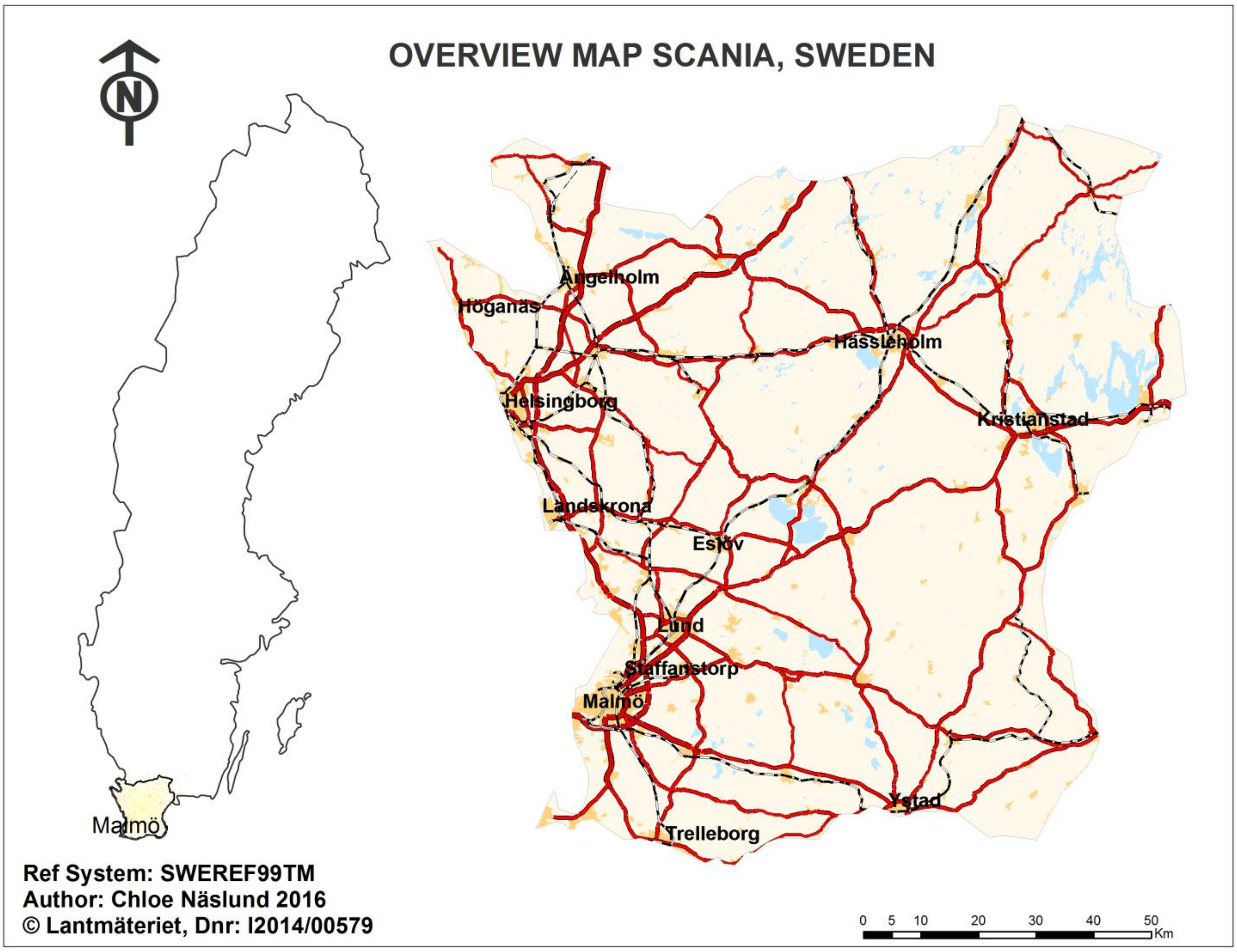

Figure 1 Map of Scania County with European and state highways illustrated in red, heavily developed urban and suburban areas in yellow, and bodies of water in blue. Several of the largest cities and towns are labeled.

There were approximately 1,303,627 inhabitants in Scania County in 2015 (Statistiska centralbyrån [SCB] 2015). Some of the largest cities in Scania - including Malmo, Helsingborg, Lund and Kristianstad - are indicated on the map. Most residents of Scania live in coastal cities such as Malmö and Helsingborg, but many other smaller inland towns have grown up over time. Scania covers an area of approximately 11,027 km^2. Its road network has a total length of approximately 40,700 km. The road network is more extensive near the coast since sea transport has been popular throughout the ages. The 16-kilometer long Oresund Bridge (*Öresundsbron*) serves as a road and rail link between Malmö, Sweden and Copenhagen, Denmark. Some of the most important transportation routes in Scania are the five European motorways (Route E22, E6, E4, E20 & E65). One of these routes leads from the West Coast to the East Coast, while the other four lead northward towards Gothenburg and Sweden's capital city, Stockholm. Scania (*Region Skåne*) is one of the districts in Sweden that has gone furthest in terms of using GIS to examine relationships and plan development projects, especially in the areas of public health and healthcare. For example, the county has geographically coordinated patient records (Schaerström 2002) to allow for spatial analysis.

2. Background

2.1 Network Analysis

Network analysis is founded on the mathematical subdisciplines of graph theory and topology (Curtin 2007). A network is a set of interconnected linear features that define routes along which materials, goods and people can be transported or along which information can be communicated (Heywood et al. 2011). A network is made up of a set of interconnected lines whose attributes share some common theme primarily related to transport or flow. According to Curtin (2007), "network analysis remains one of the most significant and persistent research areas in geographic information science". An example of a road network is shown in the figure below (Fig. 2):

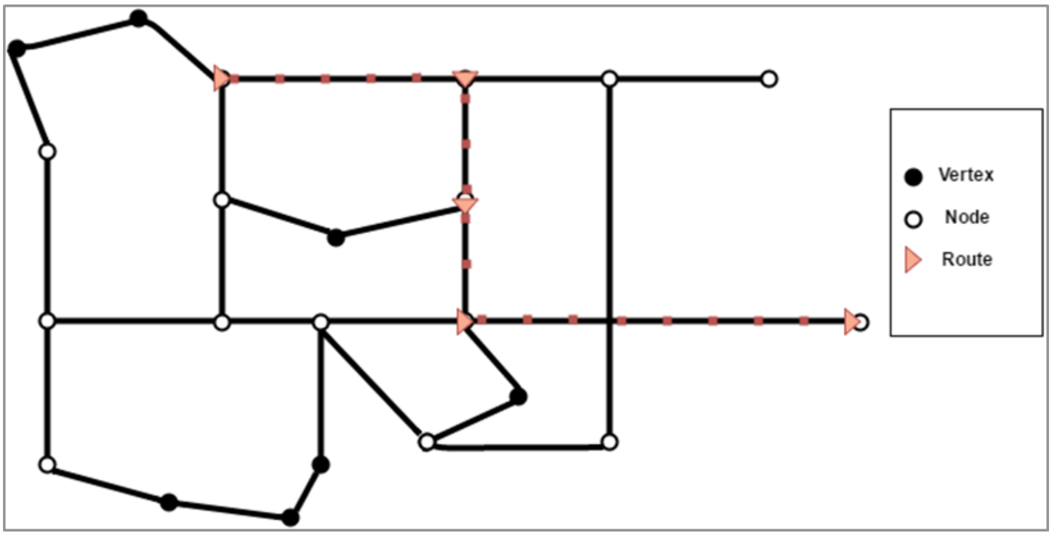

Figure 2 An example of a road network representation with vertices (black circles), nodes (white circles) and routes (lines with red arrows pointing in the direction of travel).

Any network consists of various *routes*. Every route is defined by two *nodes*, a start node and an end node that both have permanently-defined point coordinates, regardless of the desired direction of travel. A *link* is a node shared by two or more routes. Network topology is the arrangement of nodes and links (Rodrigue et al. 2013). A non-linear route can also contain points between the nodes, so-called *vertices*. The difference between vertices and nodes is that nodes contain topological information pertaining to the network while vertices act as inflection points to refine the shape of a route.

The representation of connectivity is of primary focus to evaluate alternative routes in a network. The connectivity of a network can be modelled, analyzed and used in logistical problem-solving. The routes in a network model can be analyzed in terms of certain attributes to better compare the model to real-world conditions. There are four common types of attributes that can be used to describe a route and how objects move or flow along it through the network: costs, descriptors, restrictions and hierarchies (Esri 2016b).

Costs

The cost of a particular route reflects its *friction*, or the level of impedance associated with using it for transport. Cost can be expressed in terms of travel time, monetary expenditure or other resource expenditure as a result of distance. Cost can be affected by many different variables, some that cannot be adequately modelled. These include traffic volume at a particular time, topography and travel direction. Multiple costs can be added to better model the network. For example, costs can be added at road crosses or at stop signs to better model driving behaviour.

Descriptors

Descriptors are attributes that cannot be used directly to estimate the cost of using a particular route, such as the names of the roads along a route or the number of lanes on a particular road.

Restrictions

Restrictions are attributes of certain routes used to describe their availability for use in travelling from one node to another. For example, a one-way road can be used to travel in a single direction, but not in the opposite direction, and some roads may not permit a necessary left turn. Restrictions are expressed as Boolean conditions. Restrictions can further be parameterized so that the restriction attribute prohibits, avoids, or prefers the route it is associated with.

Hierarchies

A road that can be used along routes between two nodes can be assigned a certain hierarchical rank (for example, from 1-3) within a large network to decrease route computation time by giving priority to roads designated by a higher rank. A road’s rank reflects how often or seldom the average driver would choose to use the road under normal conditions. In this network analysis, roads have been designated as primary (rank 1 = most used), secondary (rank 2 = less used), and tertiary (rank 3 = least used).

Together, these attributes can be used to create a network data set that can be used to evaluate route accessibility and solve logistic problems related to, for example, access to health care. Accessibility is defined as “the measure of the capacity of a location to be reached by, or to reach, different locations” (Rodrigue et al. 2013). Walsh et al. (1997) describe network analysis, as employed for modelling healthcare accessibility, as "...an approach of routing and allocating resource flows through a system connected by a set of linear features (e.g., roads and trails), where distance optimization decisions within the network are made dependent on (a) the nature of the travel conduits; (b) links between conduits; (c) location and characteristics of barriers to movement; (d) directionality of resource flows, position, and conditions of centers having specific resource capacities; and (e) node locations, where resources are deposited or collected along paths throughout the network."

2.2 GIS

Geographic information systems (GIS) can be defined as “a system designed to store, manipulate, analyze, and output map-based, or spatial, information” (Steinberg 2006). GIS and network analysis are two emerging applications used more and more frequently in many different disciplines. Interactive map images generated via GIS can be viewed on monitors, and any desired modifications can be made directly.

GIS technology can be used to model a complex network of travel routes. *Geographic Information Systems for Transportation* (GIS-T) is a specific branch of GIS that deals especially with transportation issues. GIS-T is interdisciplinary in nature and represents one of the primary uses of GIS technology with many possible applications. ESRI’s GIS software, ArcGIS with the Network Analyst extension, is commonly used to model transportation routes and road accessibility.

Distance can be represented in many different ways. It can be a simple Euclidean distance calculation or a complex estimation of travel time that considers all the tasks necessary for realization of movement from point A to point B. The use of the Euclidean distance metric to calculate proximity underestimates the true distance traveled because it fails to take into account the underlying transportation infrastructure (i.e. the actual roads used) between two locations. In recent accessibility studies, the traditional distance measure (Euclidean) has been replaced with more plausible measures such as travel distance or time along actual roads.

Network Analyst relies on Djikstra’s algorithm to calculate the route of shortest distance between various nodes in a network. This algorithm identifies the shortest route within an undirected, non-negative weighted graph and is the most widely used algorithm used for network analysis (Dijkstra 1959). Nevertheless, the algorithm must be modified to create a model that can be used in real-world applications by taking into account route cost constraints and restrictions such as one-way roads, turn impedances, junction impedances and other barriers.

2.3 GIS Applications in Healthcare Service Evaluation and Planning

GIS-T is one of the leading GIS application fields. In public healthcare planning, questions of accessibility are important since spatial access to healthcare services can have a great effect on patients’ health outcomes.

In Sweden, the national law regarding health and medical services [*Hälso och sjukvårdslagen (1982:763), HsL,* §2a (Socialdepartementet 1982)] states that besides good health (*“en god hälsa”*), the goal of Sweden’s healthcare system is to provide medical services on equal terms to the entire population (*“en vård på lika villkor till hela befolkningen”*). The law also states that health care is to be readily available (*“lätt tillgänglig”*). These may be difficult objectives to achieve since “health services are inevitably concentrated in particular places, and are therefore more accessible to people nearby than to people who live further away” (Lovett et al. 2002).

Therefore, actual accessibility to health care must be assessed in order to evaluate Sweden's progress in relation to the objectives of the national healthcare system. GIS-T can therefore prove to be valuable.

According to Davenhall (2003), more than 80% of all healthcare transactions are believed to have significant geographic relevance, and likewise 80% of the information needed for decision making in health care has a local or spatial component (Skinner 2010). Locational analysis through GIS-T helps healthcare organizations to improve service accessibility and delivery by conducting smarter planning and making more effective choices regarding the distribution and deployment of resources.

GIS-T applications can either be field based (to produce a raster model of the data) or object based (to produce a vector model of the data). The vector data model can also be extended to incorporate network or graph features and is then referred to as a network data model of spatial representation. Delamater et al. (2012) investigated the conceptual and practical differences between raster models and network data models of accessibility. Because of differences in the underlying conceptual models, the data models' outputs vary. In a raster model, connectivity is defined by cell proximity (a grid) while vector-based models enforce topological rules as movement can only occur along links and nodes. The different models also vary in how sensitive they are to different inputs. Vector-based models are often more affected by location in an accessibility analysis. Small differences in the location of populations may result in different routings when conducting a network analysis. Therefore, when conducting a network analysis, the populations' locations must be accurately located to counteract the sensitivity.

Both large-scale and small-scale applications of GIS-T have been used to assess spatial variation in accessibility. Branas et al. (2005) estimated the proportion of U.S. residents with access to trauma centers within 45-minute and 60-minute travel times. (Researchers explained that the 60-minute pre-hospital time period is considered "the golden hour". If an injured patient is denied hospital care within "the golden hour", the patient suffers an increased risk of death. A 45-minute travel time was also chosen for comparative purposes.) Travel time from population-weighted centroid points to trauma centers was calculated using the *Trauma Resource Allocation Model for Ambulances and Hospitals* (TRAMAH). At the time of the study, researchers found that 46.7 million Americans - most living in rural areas - did not have access to level I or II trauma centers (trauma centers that are the most specialized) within one hour's travel time. At the same time, nearly just as many Americans, 42.8 million, had access to 20 or more level I or II trauma centers within an hour. This study exemplifies how access to health care can vary spatially.

Adeoye et al. (2014) investigated Americans' geographic access to acute stroke care by estimating ambulance response times using ArcGIS Network Analyst. Key intervals were used to model ambulance response time in rural vs. urban areas, taking into account ambulance dispatch and driving times. They discovered that approximately half of the U.S. population had access to hospitals that delivered acute stroke care.

Accessibility may also be affected by socioeconomic differences. Tansley et al. (2015) investigated spatial access to emergency services in low-income vs. middle-income countries. The percentages of a country's population with road travel distances of 5, 10 vs. 50 kilometers to emergency healthcare units were calculated. In the low-income country of Haiti, only 51% of the population had a travel distance of 50 kilometers or less to an emergency care unit. In Namibia, this percentage was only 28%. By comparison, 78% of Canadians and 84% of Americans had access to trauma care within one hour's driving time (Hameed et al. 2010; Branas et al. 2005).

Similarly, Jordan et al. (2004) studied geographical accessibility of health amenities in urban and rural areas in England and observed differences in deprivation and demography in the studied areas. It was found that deprivation and the rates of long-term illness were elevated in areas farthest from hospitals. Access to cars was also investigated, and it was found that close to a quarter of the households most distant from hospitals did not own a car. This demonstrates how there can be other barriers to accessibility other than simply distance or travel time.

Smaller-scale GIS-T applications are often used by those interested in local healthcare planning to explore the possibilities of implementing GIS-based solutions. For example, Murad (2007) created a GIS application related to healthcare services in the city of Jeddah, Saudi Arabia. The application covered common hospital issues like the location of health demand, the types of patients, and the extent of the hospital service area. Using overlay analysis, specific districts in the city were identified as producing a remarkable demand on a selected hospital for certain health issues. Overlay analysis is often used in combination with service area calculations to estimate the number of people residing within different travel time intervals. Likewise, Nicoarâ & Haidu (2014) modelled the shortest route from the sites of road accidents and injuries to emergency care units and ambulance stations to create a centralized system for navigation in Cluj-Napoca, Romania.

In Sweden, GIS applications have been implemented to improve rescue services in several cities and municipalities (Eresund 2000). A system in use in Falun, Sweden allows the user to enter the address where a fire or an accident has occurred. On the computer screen in responding emergency vehicles, this brings up the municipality's map of the surrounding area that includes emergency roads, fire hydrants, water mains, traffic barriers, etc. Emergency response planning efforts can thus already begin on the way to the site of an accident.

Researchers in East Anglia, UK have also investigated accessibility to primary care by public transport using patient data and GIS (Lovett et al. 2002). Patient registers kept by general practitioners were used to model the spatial distribution of the population that used primary healthcare services. By creating walking distance buffer zones around bus stops, the proportion of the population able to travel by public transport was estimated through overlay analysis. To travel to a primary healthcare center, most patients (82%) could potentially use the daytime bus, which offered at least four return trips per day. This study shows how public transport can be important in health accessibility, as not everyone has other transportation alternatives.

GIS-T can also be used to ascertain healthcare accessibility by a certain demographic - for example, people with special healthcare needs (REFS). Delmelle et al. (2013) modelled the geographic barriers to healthcare access in Florida by children with the birth defect spina bifida. Distance and one-way travel time from the maternal residence of infants born with spina bifida to their hospitalization location were calculated. Delmelle et al. (2013) found that infants with spina bifida living in rural areas in Florida experienced travel times almost twice as high compared to those living in urban areas. This is important because infants with spina bifida or children with other birth defects may require more frequent and specialized care. Therefore, geographic distance becomes a barrier to seeking medical attention.

All members of a population do not have the same healthcare needs, so such studies are important because they deal with the concept of realized access to healthcare (Khan and Bhardwaj 1994). Realized access to healthcare is measured in terms of whether those with actual healthcare needs are able to benefit from the medical system (Delmelle et al. 2013). Because children have unique characteristics, sick or injured children may require specialized care. Amram et al. (2016) investigated the relationship between injury outcome and access to pediatric trauma centres in Canada. The length of hospital stay after an injury was significantly lower ($P \leq 0.05$) when pediatric patients resided within a 60-minute driving time to the trauma center.

3. Material

3.1 Network Data

The data used in this analysis were acquired from the Swedish Transport Administration's national road database (*Trafikverkets nationell vägdatabas, NVDB*). Various Swedish authorities are required to submit information concerning the Swedish road system to comprise this database, including the Swedish Transport Administration (*Trafikverket*), the Swedish National Land Survey (*Lantmäteriet*), the Swedish Transport Industry (*Transportstyrelsen*), and forest management agencies (*skogsnäring*). The geodata acquired from Trafikverket is part of the EU directive INSPIRE (Infrastructure for Spatial Information in Europe), which aims to provide better access to public geodata services via the Internet and establish an infrastructure for spatial information in Europe to support Community policies that may have an impact on the environment (Patroumpas et al. 2015). All data used for the creation of the network dataset were open data, readily available through the Transport Administration's extraction application, *Lastkajen*, where data are updated on a monthly basis. The data for the network dataset was given as vector, projected in SWEREF 99TM (EPSG: 3006), and downloaded as a file geodatabase file (.gdb). The layers used in the network dataset are outlined below:

Table 1: Description of the types of data supplied by NVDB with their respective use in this network analysis

Name	Description	Use
The Swedish Road Network	This is a comprehensive database that includes all Swedish roads, streets and other paths of travel for motor vehicles.	Geometry
Road Category	This is the hierarchical classification used by the Swedish Transport Administration to designate road importance in relation to national transportation needs. A road can be designated as either a European highway (highest importance), a national highway, or a primary, secondary or tertiary county road.	Hierarchy
Speed Limit	This is designated by traffic regulations pertaining to the maximum speed permitted by law on each stretch of road.	Cost
Permitted Direction of Travel	This is designated by traffic regulations pertaining to direction of travel permitted by law on each stretch of road.	Restriction
Permitted Type of Traffic	This is designated by traffic regulations pertaining to the types of vehicles permitted by law on each stretch of road.	Restriction

(Trafikverket 2015)

The data concerning the number of orchiopexy operations and appendectomies in hospitals in Scania were acquired from researchers in the Faculty of Medicine in Lund. Addresses used for the geocoding of the hospitals' locations where supplied by the *Region Skåne* website (Skåne 2016, see http://vard.skane.se/).

The data is outlined below:

Table 2: The no. of orchiopexy operations and appendectomies between 2001 – 2013 at various surgical hospitals in Scania

Hospital Name (in Swedish)	No. of Orchiopexy Operations to Treat Cryptorchidism (2001 - 2013)	No. of Appendectomies (2001 - 2013)
Helsingborgs lasarett	239	981
Centralsjukhuset Kristianstad (CSK)	282	633
Landskrona lasarett	26	3
Universitetssjukhuset i Lund (SUS)	1332	1305
Universitetssjukhuset i Malmö (UMAS)	147	1038
Trelleborg lasarett	10	79
Ystads lasarett	5	412
Ängelholms sjukhus	26	93

3.2 Demographic Data

Demographic data were collected by Statistics Sweden (*Statistiska Centralbyrån, SCB*) and retrieved as spatial data using the GeoData Extraction Tool (GET) run by the Swedish University of Agricultural Sciences (SLU). The service is financed by a consortium of universities that includes Lund University. Spatial data from agencies with which the universities have a cooperation agreement is stored in GET. The data can be used for educational purposes and research. The demographic data was organized by cells of 250 x 250 meters in urban areas and 1000 x 1000 meters in more rural or undeveloped areas. The GET data, which are updated yearly, were from the year 2015. Demographic data per defined area (SAMS) was also used and given as geodatabase vector files. Of special interest were the demographic data regarding the number of children from age 0-18 (i.e. children up to, but not including, 19 years of age) in each demographically-defined area.

Table 3: Demographic data from SCB

Name	Coordinate System	File Name	File Type	Geometric Representation
Population per age group	SWEREF 99TM (EPSG: 3006)	B1_sw_region.shp	Shapefile	Vector

(SCB 2016)

3.3 Socioeconomic Data

Data regarding income and education per SAMS were retrieved using the GeoData Extraction Tool. The data were originally supplied by SCB, but the data were spatially visualized through GET. The yearly median income of residents per SAMS and the purchasing power of families with at least one child between the ages of 0-18 were of interest. Statistics Sweden (SCB) defined purchasing power as the “disposable income per consumption unit”. This variable makes it possible to compare families based on their purchasing power by taking into account different family compositions (SCB 2016). Data on educational level refers the highest level of education completed by each adult (age 25-65) residing within each SAMS. Levels of education correspond to Swedish educational standards. The data were retrieved as shape files from the service and projected in the reference system, SWEREF99TM.

3.4 Software

The GIS software used in this analysis was ArcGis® 10.2 from Environmental Systems Research Institute (ESRI) of Redlands, California. ArcGIS is comprised of different GIS components used to analyze and treat spatial data. ArcCatalog was used for data harmonization and organization of the network dataset, while ArcMAP and the extension Network Analyst were used for the network analysis. Maps throughout this thesis were created using ArcGIS. Microsoft Excel was used for the statistical analysis of demographic and socioeconomic data.

4. Method

The points below show the objectives that were set to meet the goals of this analysis:

- Collection of network, demographic and socioeconomic data via Lastkajen and GET
- Definition of the data set to be used in the network analysis
- Calculation of travel time from each defined SAMS to the nearest surgical hospital unit based on Dijkstra's algorithm
- Depiction of the distribution of children’s accessibility to emergency care units
- Evaluation of travel time estimates by locational sensitivity analysis
- Analysis of certain socioeconomic variables related to the various hospital catchments

4.1 Assumptions

A number of assumptions have been made prior to spatial representation and modeling. The initial assumption was that travel time between locations can be sufficiently characterized and estimated using spatial data and models, although actual travel times reflect countless different variables in the real-world. For example, the models assume that each person in the population has comparable vehicles and similar driving behaviors. Another assumption is that each person experiences the same constant travel conditions, although in the real world, travel conditions vary on the same stretches of road based on factors such as time of year, weather, time of day and local traffic patterns.

The models also apply the concept of *homo economicus*, i.e. that humans are consistently rational and act optimally and economically in all situations to reap the greatest end results based on their efforts (Brennan 2008). The models herein assume that all people possess knowledge of hospital locations and alternative route attributes and choose to travel to the nearest hospital along the route that takes less time between their residence and the nearest hospital.

Finally, due to limitations in data availability and data-processing capabilities, the location of a population is assigned to a single point location within each SAMS: the calculated population-weighted centroid. Travel time estimates for all members of the population within a SAMS are based on starting from this single-point location. Hence, GIS-based travel time estimates capture only the average travel situation encountered by members of each SAMS.

4.1 Data Processing

Three main types of information are typically required to conduct an accessibility assessment (Maheswaran and Craglia 2004):

1. The locations of relevant service points (i.e. hospitals)

2. The distribution of the resident population in the surrounding area

3. Details about the road network

A detailed description of the data used in this thesis can be seen in section 3. The layers chosen to define the network data set were the Swedish road network, road category, speed limit, permitted direction of travel and permitted type of traffic. Data collected from NVDB were downloaded as a file geodatabase (.gdb) and stored for easy access and management. The steps undertaken in data processing can be seen in Fig. 3.

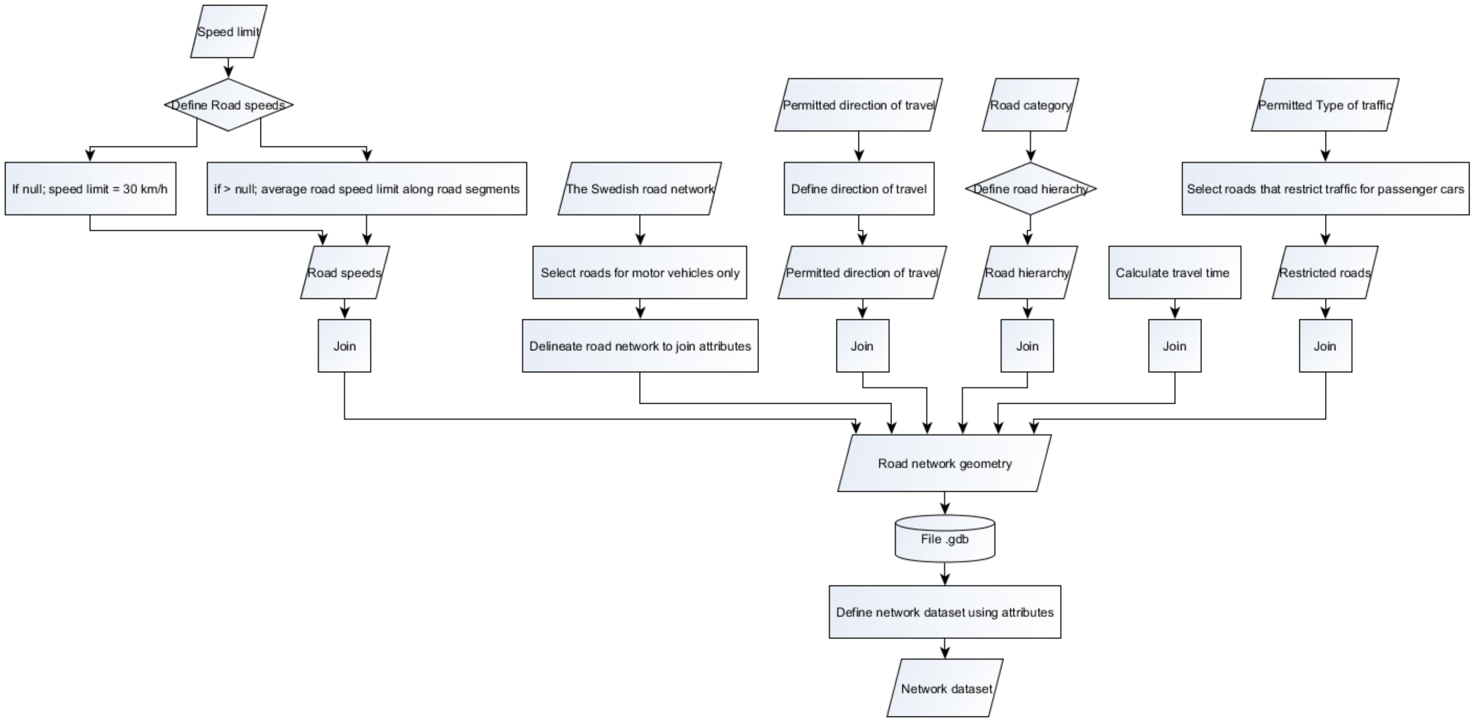

Figure 3: Flowchart showing the steps involved in data processing

The Swedish road network was selected to represent the geometry and topology of the network. Because of the immense amount of data gathered from the NVDB, attributes not pertaining to the problem at hand were excluded. For example, roads not accessible by motor vehicles were removed and limited dates/times when roads were not accessible were not taken into account. Route segments with the same route ID were joined and assumed to share the same attributes, and speed limit was averaged, based on road segments with the same route ID. All road segments with an undefined speed limit were assumed to have a speed limit of 30 km/h. This was decided through manual investigation of the undefined areas of the road network. Almost exclusively, undefined road segments were situated in residential areas where the speed limit is 30-50 km/h.

The use of one-way roads was restricted using the “permitted direction of travel” layer. In the table of attributes, certain one-way road segments were defined as either “S-E”, permitting traffic in the direction moving from the segment’s defined start node to the segment’s end node, or “E-S”, permitting traffic in the opposite direction: from the segment’s defined end node to the segment’s defined start node. Roads that were not specially designated as one-way were assumed to be two-way and transversible, and no attribute changes were made to these. They were assumed to be transversible since they were described as such in the data from NVDB. This layer was joined to the network geometry. Restricted roads that allowed no travel on them whatsoever were also joined to the network geometry and designated as restricted.

The road category layer was added to model road choice hierarchy and limit computation time, modelling the way the average driver would choose to navigate through the road network. Each road was designated as either a European highway (with the highest rank) or a national highway, or as a primary, secondary or tertiary county road. This layer was also joined to the network geometry, and any undefined roads in terms of category were designated as quaternary county roads, with the lowest road category rank. Quaternary county roads are not used as a real road category; however since they were not specified in the data they should receive a lower rank relative to the defined roads. The travel time (by automobile) associated with each road segment was estimated in minutes given the length of each road segment (in km) and the speed limit associated with the road segment (in km/hr) using the following formula:

$$travel\ time\ (\mathrm{min}) = \left[\frac{length\ of\ road\ segment\ (km)}{speed\ limit\ \left(\frac{km}{h}\right)}\right] \times 60$$

(Maheswaran 2004)

The travel time for each stretch of road was then calculated as the sum of the travel times associated with all segments comprising that stretch of road. Travel time was used as an impedance (cost) measure in the analysis. Travel time to the nearest hospital, rather than driving distance, was used since it was theorized that travel time would provide a more accurate estimate of hospital accessibility.

The population layer was constructed using population data from Statistics Sweden (SCB) as organized in a cell grid superimposed on the map of Scania County and its various defined SAMS. Population data (i.e. the number of residents age 0-18) from cells within the same SAMS were averaged to determine a population-weighted centroid within each SAMS. Delamater et al. (2012) described how vector-based models are more sensitive to population location, so the population weighted centroid was calculated and used as the initial starting point for each potential pediatric patient’s hospital journey.

The layer indicating the locations of the eight selected city hospitals was added by geocoding the addresses of the hospitals. Geocoding was done using ArcMaps World Geocode Service.

4.2 Network Analysis

After preparation, the files were exported to a file geodatabase as feature classes, which allow roads and attributes to be grouped together. A feature dataset was created to store the files used for the creation of a network dataset according to ArcMap's software manual (Esri 2010).
The topology of the road network was corrected to ensure that hospitals could be accessed by all 1,283 SAMS. The method is illustrated in the figures below. Similarly, road segments that had invalid geometry due to data errors were identified and excluded from the data set. The probable point of intersection for two or more roads was double-checked. The connectivity of the network was defined so that roads were connected at all intersections and not only at linear end points. (See Fig. 4a). In other words, the line features were split into multiple connections at intersecting vertices. (See Fig. 4b.)

The z coordinates (elevation values) needed to be taken into account so as not to record false intersections in a plane. The z coordinates of the point of intersection on the various roads were compared. If those values were the same, the point of intersection could be deemed as a link where the roads intersected at an end node within the same plane of elevation. (See Fig. 4c & 4b.)

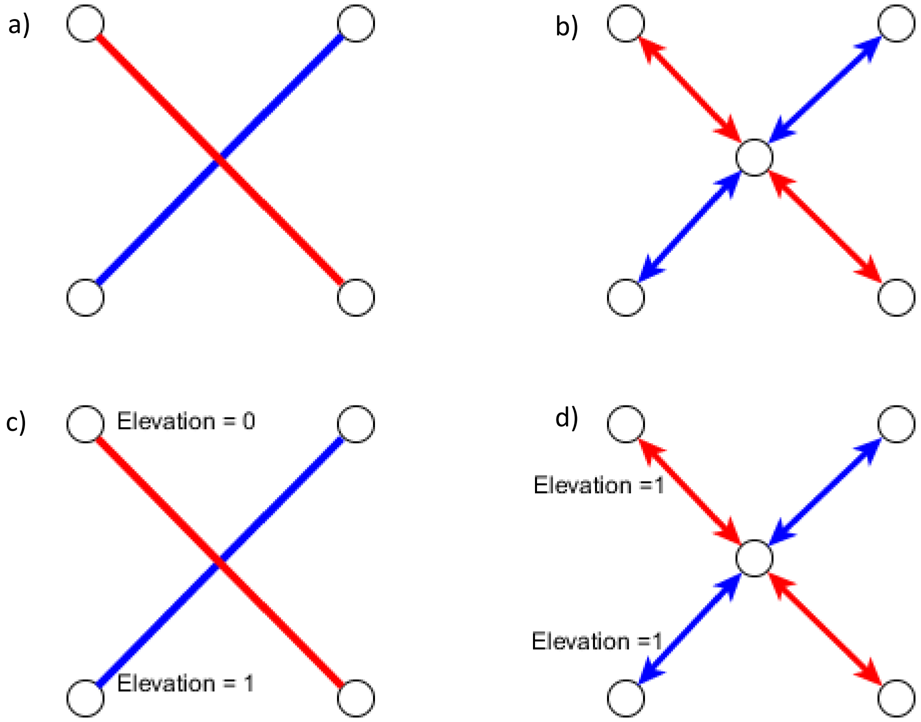

Figure 4: Diagram demonstrating network connectivity. Figures are numbered from a – d starting from the top left corner. Based on (Esri 2016)

Attributes used are defined in Table 1. Route calculations were performed by starting at the centroid in a given SAMS and moving along the most optimal roads to the location of the closest hospital using the "find closest facility" tool. U-turns were permitted only at dead ends because of insufficient data pertaining to where u-turns are allowed in the real world. Use of hierarchy was included to limit the processing time and better model assumed driving patterns. Based on Djikstras algorithm, the network analyst tool performed a shortest-route analysis from each SAMS to the closest hospital as travel time in minutes. The resulting travel time estimates were compared to results obtained from Google Maps, since the collection of sufficient actual travel time data to allow for formal statistical testing was not feasible. The results from Google Maps were not considered as true travel times due to the lack of methodological documentation available. Travel time estimates from Google Maps were derived from independent source data, and the comparison only permitted a general assessment of whether or not travel times within the created networks provided reasonable estimates of travel time. However, in Haynes et al. (2006), GIS estimates of car travel times were reasonably close approximations to 475 reported times and may be superior than the travel times reported by actual patients.

A sensitivity analysis was performed to evaluate whether or not using the population-weighted centroid within each SAMS as the starting point for a hospital journey was generally reasonable for all the potential patients within each SAMS. Each SAMS is divided into cells within a grid. Each cell is 250 x 250 m in urban areas and 1000 x 1000 m in more rural areas. There are 19,588 cells in Scania County.

Shortest-route calculations for travel time and distance from the centroid of each cell within a SAMS to the nearest hospital was calculated for all cells in Scania. The maximum distance and travel time as well as the minimum distance and travel time was then calculated for each SAMS given the data for all the cells that comprised the SAMS. The average distance and time for all cells within a SAMS was also calculated.

4.3 Statistical Analysis

The line layer containing the resulting travel times were joined spatially with socioeconomic and demographic data of each SAMS. In ArcMap, frequency distributions of demographic and socioeconomic data pertaining to different hospital catchments and travel times were investigated to test for normality but were not included in the results. Data such as closest hospital, travel time, population and socioeconomic data was exported to Microsoft Excel for statistical analysis. Socioeconomic and demographic statistics were analyzed descriptively since much of the data did not follow a normal distribution.

5. Results

This section presents the results of the previously described analysis. First, the calculated routes from the network analysis are presented and discussed. Secondly, the hospital *catchments*, i.e. the area covered by each hospital, are presented with area calculations. Thirdly, the hospital *coverage*, i.e. the distribution of children per surgical hospital, is shown with associated statistics. Fourthly, the travel times per SAMS and the distribution of children between different time intervals is shown followed by the distribution of children per hospital and time interval. Fifthly, the locational sensitivity analysis is presented and discussed. Lastly, the socioeconomic analysis is displayed with associated statistics.

5.1 Hospital Routes

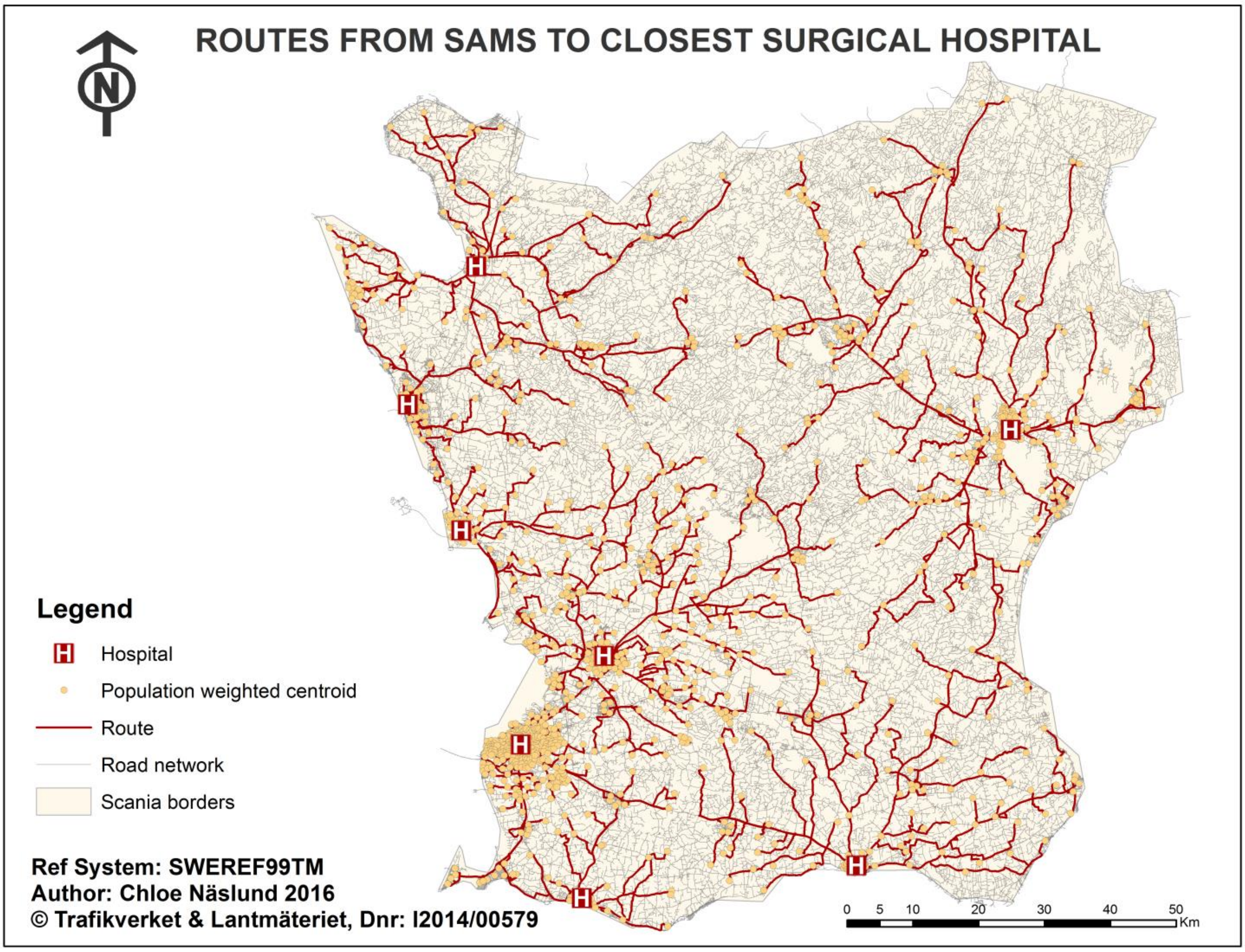

Figure 5: Each of the eight well-equipped surgical hospitals in Scania is represented by a red "H". The population-weighted centroid within each SAMS is indicated by a yellow dot. The route connecting each centroid to the nearest hospital is represented by a red line, while the total road network included in this analysis is shown in grey.

The map above (Fig. 4) shows routes from the population-weighted centroid within each SAMS (1,283 separate SAMS within Scania) to the closest hospital (8 surgical hospitals). The resulting network data set is also demonstrated. The resulting network data set was 153,273 separate line features and a total road length of 40,698 km. The method allowed for the calculation of routes to the population-weighted centroid within each SAMS. It is apparent that many of the routes make use of European highways and state highways, at least in part.

In the middle of Scania, where the area is rural, SAMS are larger and population-weighted centroids were not as concentrated as the centroids in more urban areas closer to the coasts. Population-weighted centroids were rarely situated far from the nearest road, but in several inland SAMS, there was a larger difference of up to hundreds of meters in some instances between the calculated centroid within the SAMS and the road that began the travel route to the nearest hospital.

5.2 Hospital Catchment

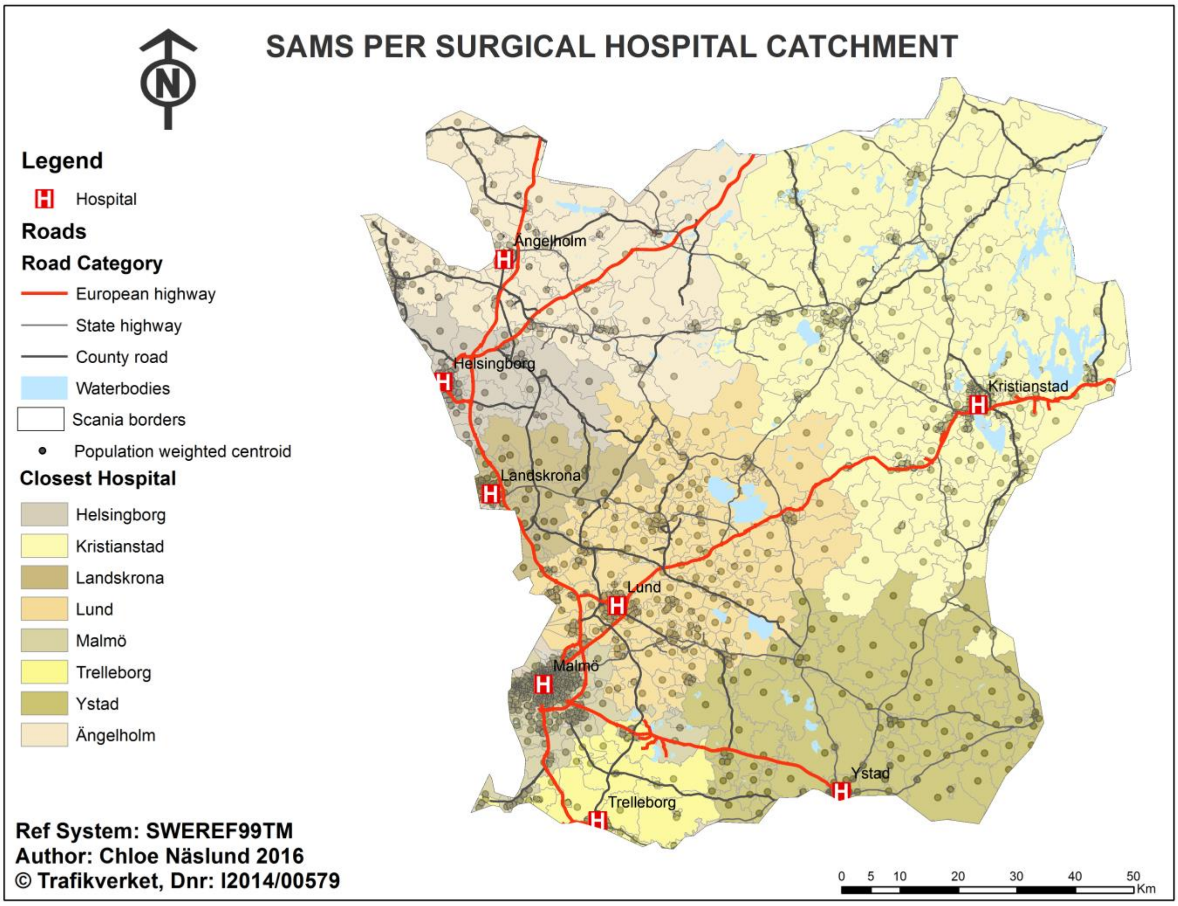

Figure 6: The catchments or SAMS areas served by each of the eight surgical hospitals in Scania are shown here in different colors, where each hospital is represented by a red "H" and the population-weighted centroid within each SAMS is represented by a grey dot.

Fig 6. shows the Hospital *catchments*, the extent of area covered by each hospital or the number of SAMS allocated to each hospital. There are large discrepancies in catchment area and SAMS allocation between hospitals. (See Table 4.) For example, the hospital in Kristianstad caters to a catchment of 4,096 km^2, and the university hospital in Lund also caters to an extensive catchment of 1,948 km^2, but the hospital in Malmo caters to a catchment of only 386 km^2. Similarly, the hospitals in Landskrona, Trelleborg and Helsingborg also cover fairly small areas of 407, 441 and 490 km^2 respectively.

Table 4 lists the total area (catchment) associated with each surgical hospital.

Hospital Name (in Swedish)	**Total Area of Catchment (in km^2)**
Helsingborgs lasarett	490
Centralsjukhuset Kristianstad (CSK)	4096
Landskrona lasarett	407
Universitetssjukhuset i Lund (SUS)	1948
Universitetssjukhuset i Malmö (UMAS)	386
Trelleborg lasarett	441
Ystads lasarett	1751
Ängelholms sjukhus	1771

5.3 Hospital Coverage

The number of children potentially served per surgical hospital in Scania, or the hospital *coverage*. is shown in Fig. 7, while percentages are shown in Fig. 8. Even though the hospital in Malmö has a relatively limited catchment (386 km^2, see table 4) in comparison to other hospitals in Scania, it actually covers the largest number of potential pediatric patients (81,750 children or 28% of all Scanian children age 0-18). Next is the hospital in Lund, which is designed to cover 61,860 children or 21%. Then the hospital in Kristianstad is designed to cover 39,410 children or 13 %. Trelleborg covers the smallest number of children (14,075), representing only 5 % of the population age 0-18 years in Scania. The hospital in Landskrona has a slightly smaller catchment than the hospital in Trelleborg (407 km^2), but covers a comparable number of children in the county (14,200). The hospitals in Ystad and Ängelholm have similar catchments (1,751 km^2 and 1,771 km^2 respectively), but they differ in the number of children covered. Ystad Hospital covers 18,719 children (approximately 6 % of the total number of Scanian children), while Ängelholm Hospital covers 26,736 children (approximately 9 % of the total number of Scanian children).

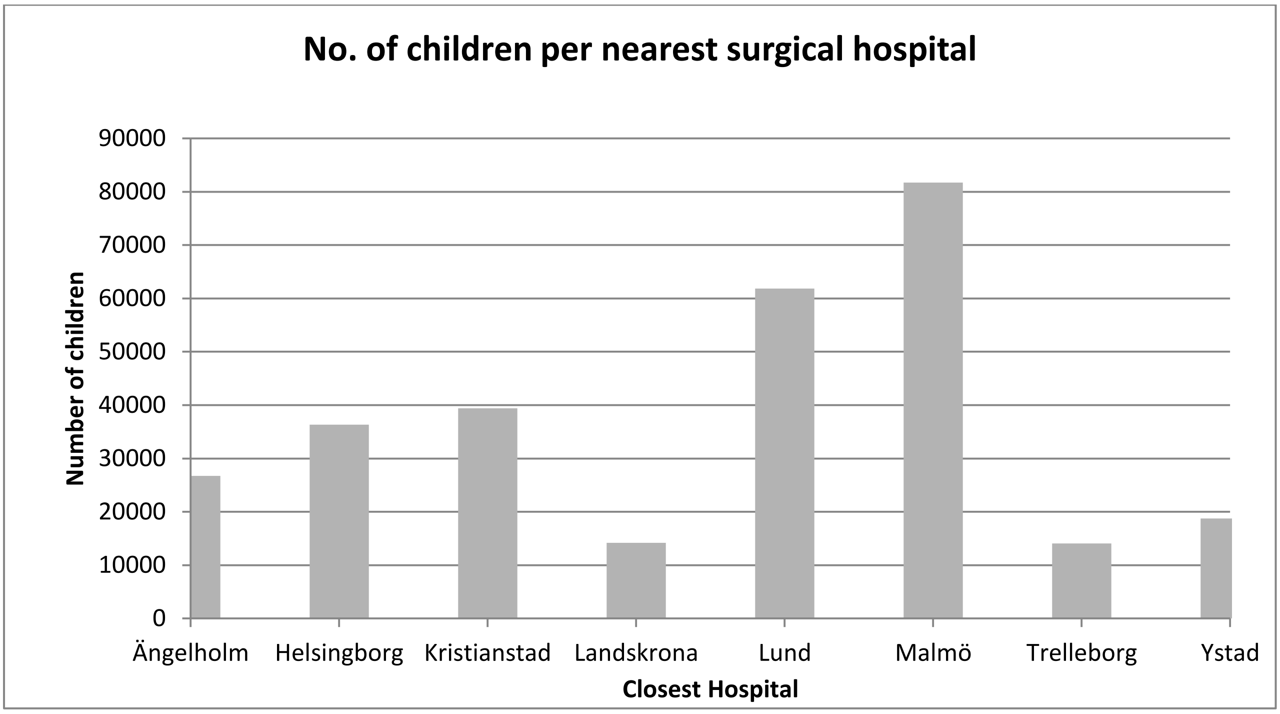

Figure 7: Hospital coverage as the number of children in each hospital catchment

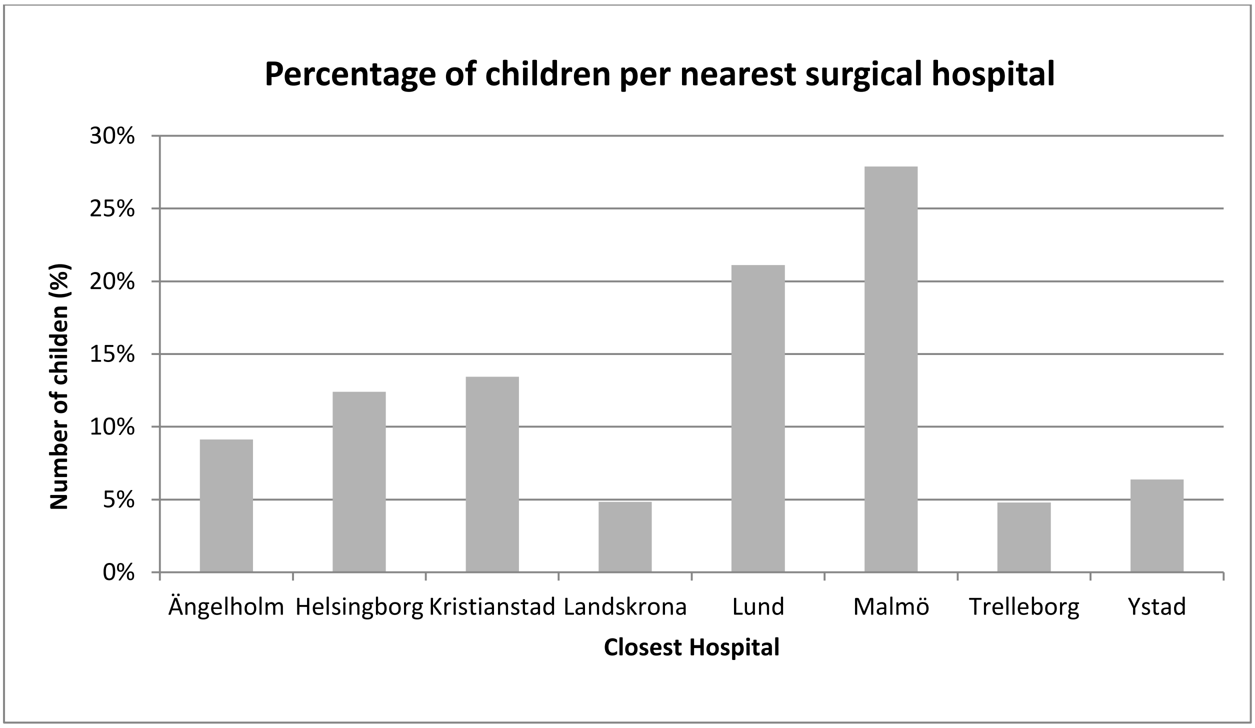

Figure 8: Hospital coverage as the percentage of Scanian children potentially served by each surgical hospital

5.3 Travel Time to the Closest Surgical Hospital

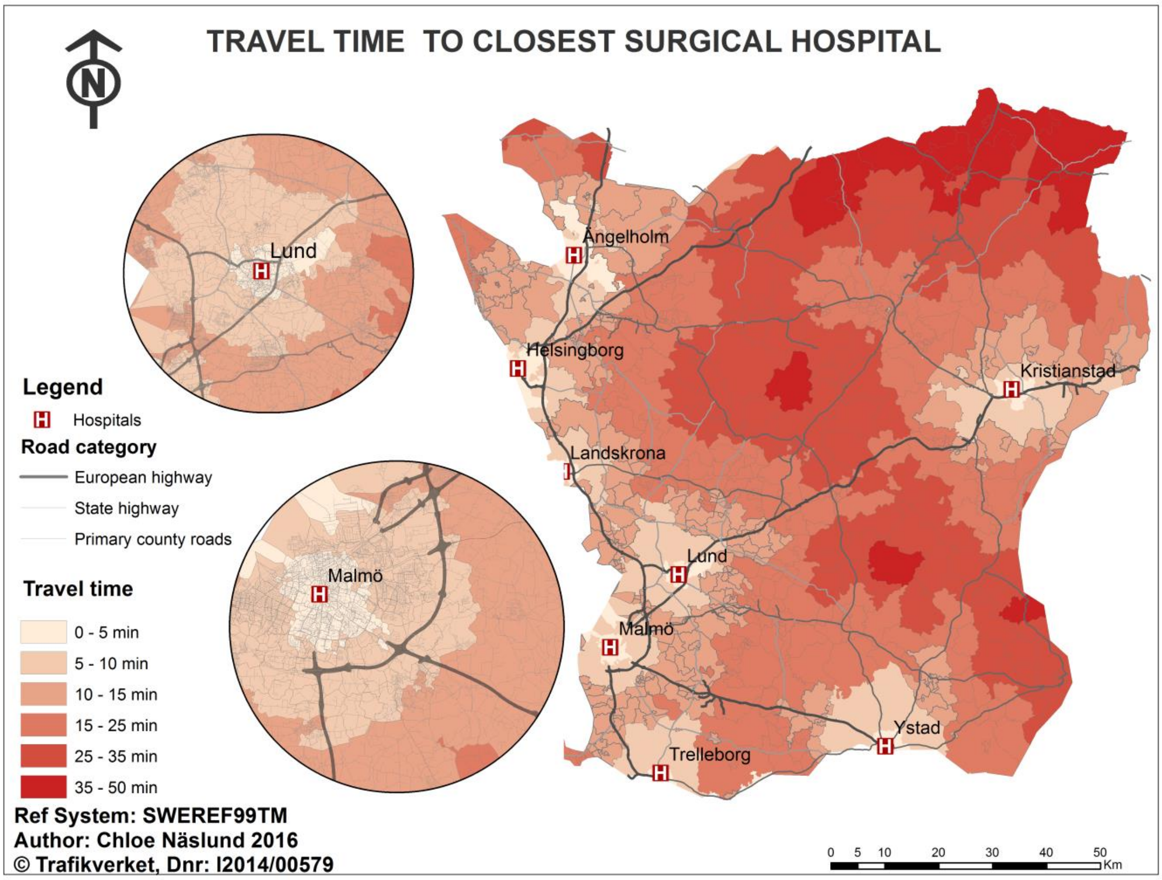

Figure 9: Map showing estimated travel times from areas in Scania County, Sweden to the closest surgical hospital within the county. The road networks associated with the hospitals in Lund and Malmö are shown within the circular figures.

The map above (Fig. 9) illustrates estimated travel time intervals to the closest surgical hospital:

- less than 5 minutes (<5)
- 5 minutes to less than 10 minutes (5 - <10)
- 10 minutes to less than 15 minutes (10 - <15)
- 15 minutes to less than 25 minutes (15 - <25)
- 25 minutes to less than 35 minutes (25 - <35)
- 35 minutes to less than 50 minutes (35 - <50)

Approximate estimated travel times are shown in Fig. 10 to show variations in travel times between the intervals above. A darker red color on the map is used to denote areas with longer travel times to the closest surgical hospital, while lighter red colors denote areas with shorter travel times. According to this study, no potential pediatric patient residing in Scania would be required to endure a travel time of more than 48 minutes to the closest surgical hospital. (See Fig. 10.)

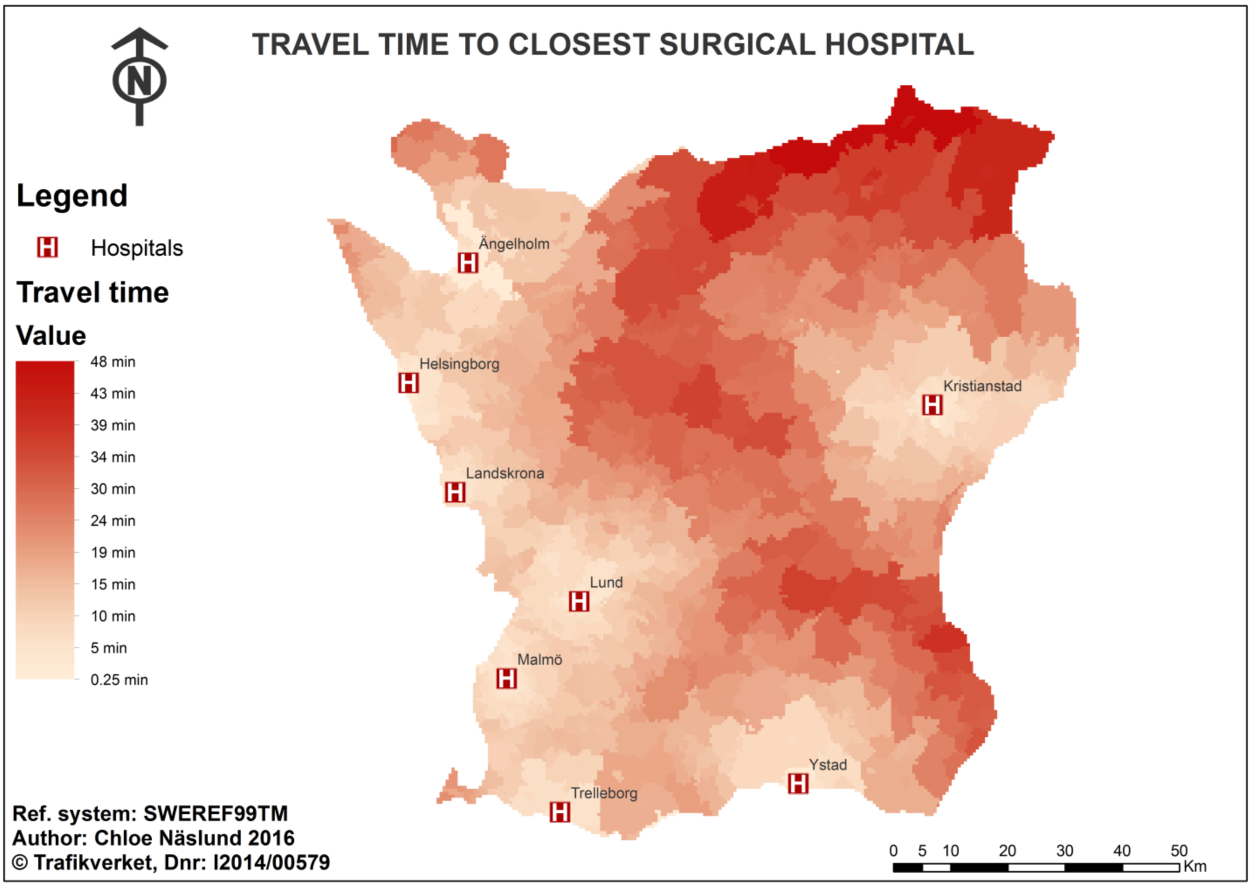

Figure 10: Map showing estimated travel times from SAMS in Scania County, Sweden to the closest surgical hospital within the county.

Table 5 indicates the total area (in km^2) of Scania associated with a certain maximum travel time to the nearest surgical hospital.

Travel Time to Hospital	Total Area of Scania (km^2)
Within <5 minutes	284
Within <10 minutes	1539
Within <15 minutes	3610
Within <20 minutes	5637
Within <25 minutes	7368
Within <35 minutes	10456
Within < 50 min (Total area)	11345

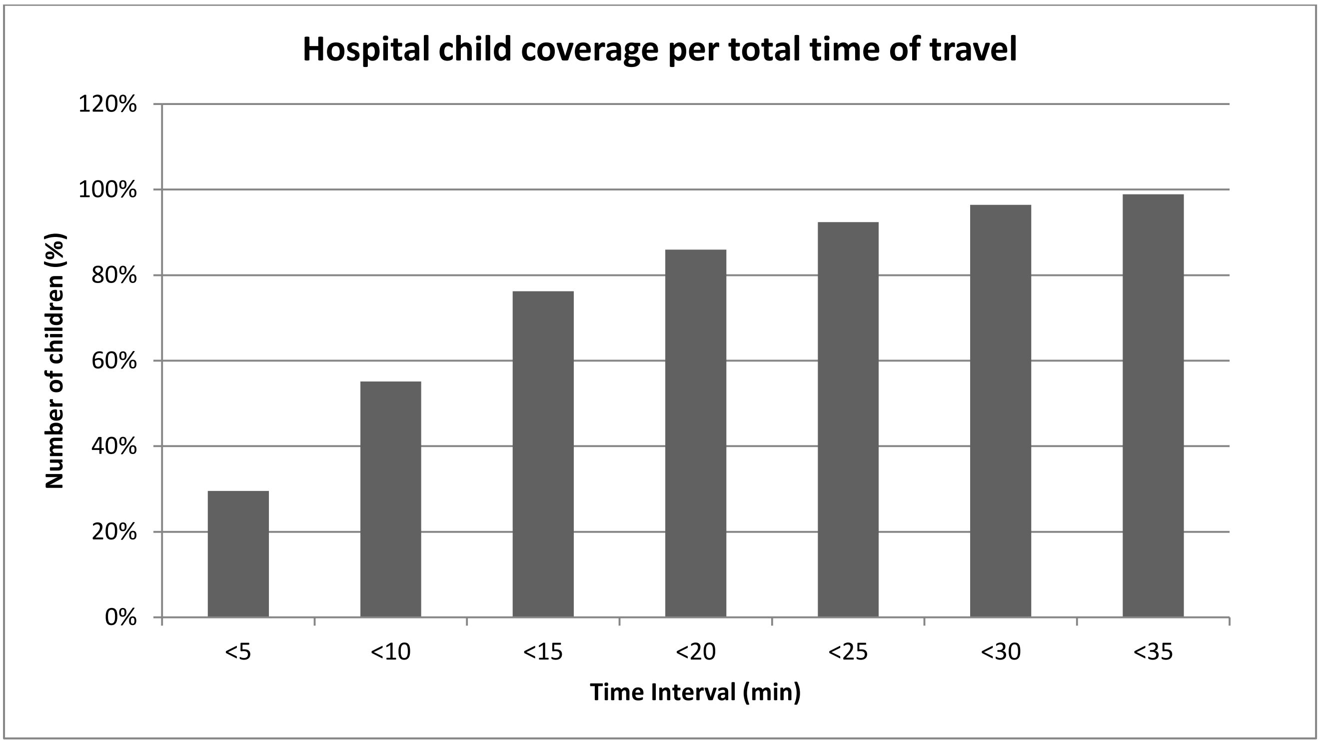

Figure 11: The total percentage of Scanian children who could potentially reach the nearest surgical hospital within a certain maximum travel time (in minutes).

Table 5 shows the area covered in terms of square kilometers per estimated travel time to the hospital while Figure 11 depicts the percentage of children who could potentially reach their respective nearest surgical hospital within a certain time frame. In general, patients residing in most areas of Scania can potentially reach the hospital in less than 15 minutes (76 %). More than half of the children residing in Scania (55%) can potentially reach the nearest hospital in less than 10 minutes and 96% of all children in Scania (282,571) have a travel time of less than 30 minutes. This means that only approximately 4% or 10,537 children in Scania have a travel time of more than 30 minutes to the closest surgical hospital.

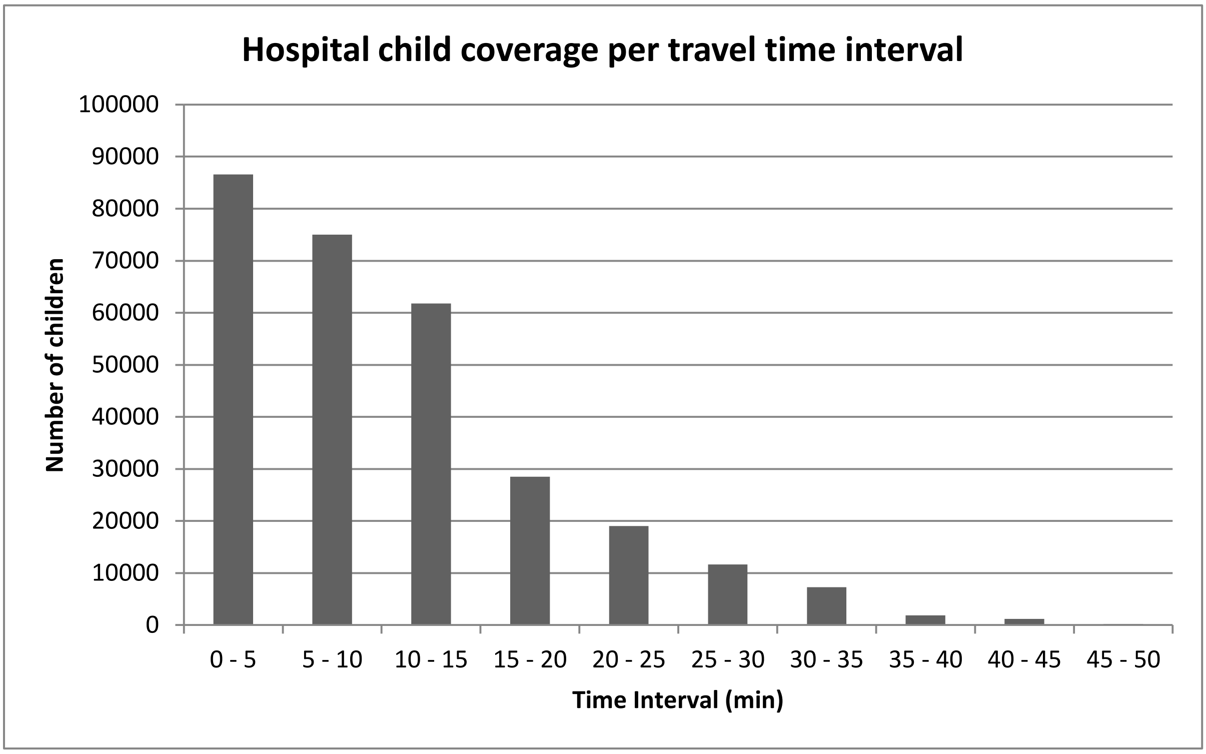

Figure 12: The total number of Scanian children who could potentially reach the closest surgical hospital within a specific time frame

Figure 12 shows the coverage for each travel time interval. 30% of all children in Scania (86,557) have a travel time to the nearest surgical hospital of less than 5 minutes, even though the total catchment within 5 minutes of all surgical hospitals is relatively small, 284 km^2 (See Table 6.)

92% of all children residing in Scania have a travel time to the nearest surgical hospital of less than 25 minutes, while the total catchment within 25 minutes of surgical hospitals is 7,368 km^2 (see Table 5), which represents 65 % of Scania's total area.

5. 4 Travel Times in Different Hospital Catchments

Table 6 lists each hospital and relates the total percentage of Scanian children residing within the hospital's catchment to a certain maximum travel time to the nearest surgical hospital.

Hospital	< 5	< 10	< 15	< 20	< 25	< 30	< 35	< 40	< 45	< 50
Ängelholm	37%	56%	90%	100%	100%	100%	100%	100%	100%	100%
Helsingborg	49%	76%	89%	100%	100%	100%	100%	100%	100%	100%
Kristianstad	10%	30%	43%	58%	77%	85%	92%	97%	100%	100%
Landskrona	41%	54%	88%	99%	100%	100%	100%	100%	100%	100%
Lund	19%	44%	77%	86%	93%	99%	100%	100%	100%	100%
Malmö	42%	83%	97%	99%	100%	100%	100%	100%	100%	100%
Trelleborg	37%	56%	90%	100%	100%	100%	100%	100%	100%	100%
Ystad	17%	26%	43%	64%	81%	90%	100%	100%	100%	100%

Table 6 indicates the spatial differences in the coverage (no. of children covered) provided by the different surgical hospitals catchments per travel time interval. 99% of the children who reside in areas closest to the hospital in Malmö can potentially reach it in less than 20 minutes, and 83% can reach the hospital in less than 10 minutes. By comparison, only 30% of people who live closer to the hospital in Kristianstad can reach it less than 10 minutes. 58% can reach Kristianstad Hospital in less than 20 minutes, and 97% of children can potentially reach it in less than 40 minutes.

In general, a very large percentage of children in Scania can potentially reach the nearest hospital within 30 minutes, as seen in Figure 11. Seven of the eight chosen surgical hospitals cover children in nearby SAMS in less than 35 minutes' travel time. The hospitals situated along the West Coast of Sweden (in Malmö, Helsingborg, Ängelholm and Trelleborg) show high percentages of population coverage (83%, 76%, 56% & 56% respectively) within 10 minutes' travel time. Populations of children residing in areas further inland in Scani, such as the Lund and Kristianstad catchments (44 % and 30 % respectively under a 10 minute time frame), are not as fully covered in the same travel time range as children residing near the hospitals closer to the coast.

5.5 Locational Sensitivity Analysis

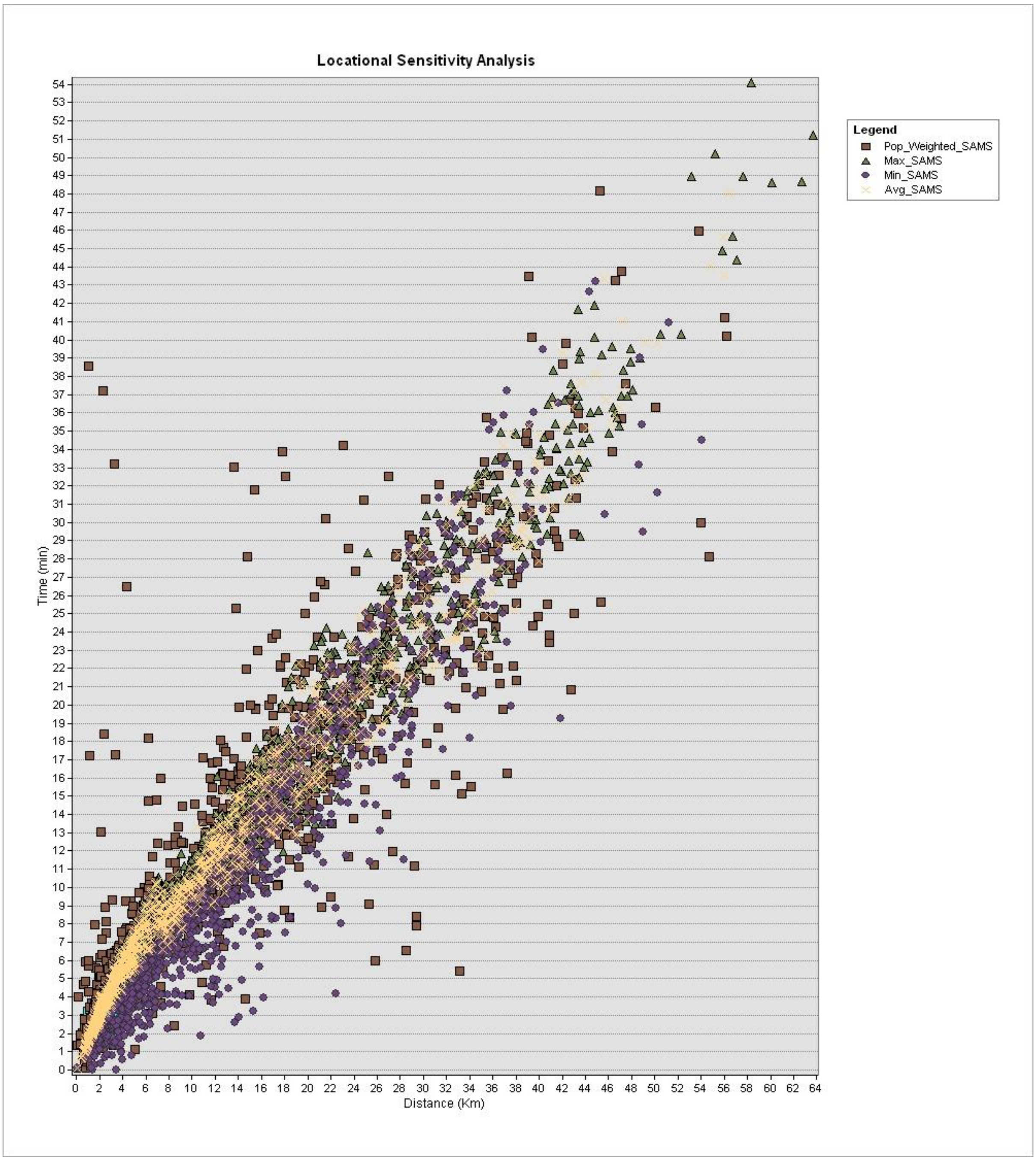

Figure 13: Relative to distance to the nearest hospital within the county, the locational sensitivity analysis graph plots the maximum travel time (Max_SAMS) to the nearest hospital from the cell in each SAMS farthest from the nearest hospital (triangles); the mimimun travel time (Min_SAMS) to the nearest hospital from the cell in each SAMS closest to the nearest hospital (dots); the travel time from each population-weighted centroid within each SAMS (Pop_Weighted_SAMS) to the nearest hospital (squares); and the average travel time (Avg_SAMS) from each SAMS to the nearest hospital (x's).

The locational sensitivity analysis (Fig.13) illustrates the reliability of using the population-weighted centroid within each SAMS as the starting point for each patient's hospital journey when calculating the estimated travel time for all residents of the SAMS. Each SAMS is divided into cells. There are a total of 19,588 cells within the 1,283 SAMS throughout Scania. Relative to distance to the nearest county hospital, the graph in Fig. 13 plots the maximum travel time (Max_SAMS) to the nearest hospital from the cell in each SAMS farthest from the nearest hospital (triangles); the minimum travel time (Min_SAMS) to the nearest hospital from the cell in each SAMS closest to the nearest hospital (dots): and the travel time from each population-weighted centroid within each SAMS (Pop_Weighted_SAMS) to the nearest hospital (squares). The graph also shows the average travel time (Avg_SAMS) from each SAMS to the nearest hospital (x's), where the average is calculated by averaging travel times from all cells within each SAMS.

As demonstrated by the graph, travel times associated with the population-weighted centroids in SAMS (represented by the squares) are more dispersed and show less of a linear correlation relative to distance than travel times calculated using the centroid within the farthest cell, the centroid within the nearest cell or the average travel time calculated using the centroids of all cells within a SAMS. There are more outliers calculated using the population-weighted centroids when distance to the nearest surgical hospital is within the interval from 10 to 30 kilometers. Points calculated using population-weighted centroids are more linear when the distance to the hospital is less than 10 km or greater than 30 km.

Travel times calculated by using the centroid within the cell farthest from the hospital along the shortest route to the nearest hospital per SAMS are represented by the triangles. 54 minutes was the longest estimated travel time to the nearest hospital calculated using the centroid within the SAMS cell farthest from the nearest hospital. 48 minutes was the longest estimated travel time to the nearest hospital calculated using a population-weighted centroid.

Travel times calculated using the centroid within the SAMS cell closest to the nearest hospital along the shortest route are represented by the purple dots. The minimum travel time associated with each SAMS is overrepresented in the interval between 0 to 15 km. Many travel times associated with centroids in cells closest to the hospital are shorter with respect to distance than travel times calculated using population-weighted centroids.

Lastly, average travel times to the nearest hospital are shown in the graph by the yellow x's. The minimum and maximum travel time calculations per SAMS are closer to the average travel time calculation per SAMS than to the travel time calculated using the population-weighted centroid in a SAM. Average travel times show less dispersion than travel times calculated using population-weighted centroids.

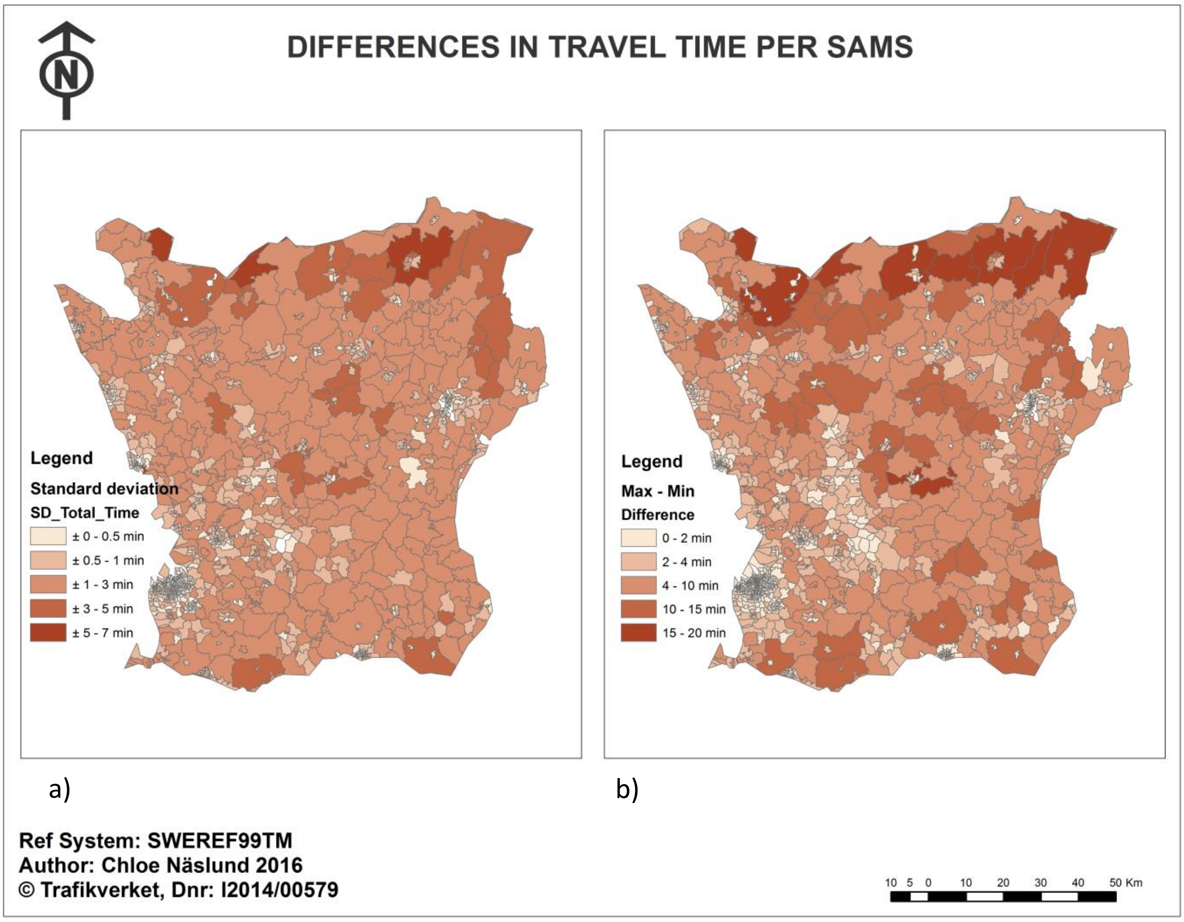

Figure 14: Maps showing travel time relative to the the standard deviation (a) and to the difference between the maximum and minimum shortest route calculations from each SAMS (b)

The map above on the left (Fig. 14) shows the standard deviation per SAMS than has been calculated from all centroids within their respective SAMS. The other map to the right shows the difference (in minutes) between the maximum travel time and the minimum travel time calculated using the farthest and the closest cell centroids within each SAMS. This map indicates SAMS where there may be large differences in travel times associated with different residential locations. There are only three SAMS in Scania that show large standard deviations of ± 5-7 minutes with respect to travel time. In the northern part of Scania, there seems to be a large discrepancy in travel time within the SAMS, as the difference between the minimum travel time and the maximum travel time may differ between 15 to 20 minutes. In smaller SAMS in urban areas, there is a smaller standard deviation and there is little difference between maximum and minimum travel times.

5.5 Socioeconomic Analysis

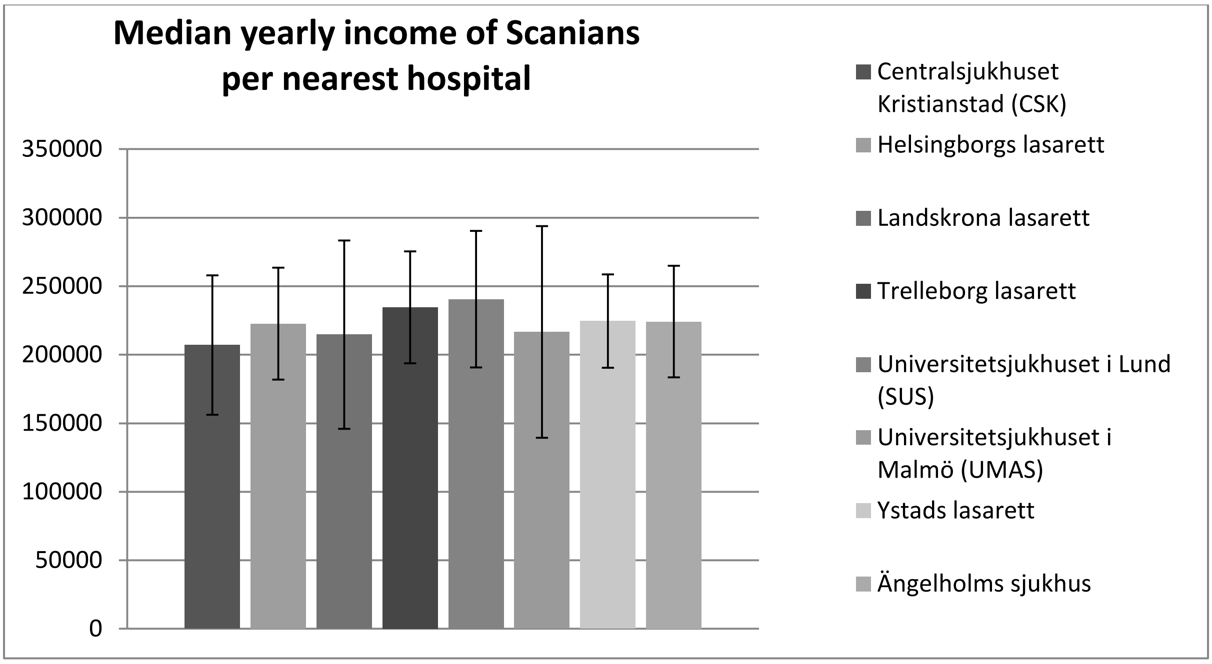

Figure 15: Graph showing the average percentage of all adult Scanians with no more than a high school education per nearest hospital (with standard deviation bars)

The graphs above (Fig. 15) display socioeconomic data in the form of median yearly income of households in Scania per hospital. In this graph, there is no significant difference in median income across the various hospital catchments, as they differ only minimally. The largest difference in median yearly income (a difference of 33,460 SEK/year) is between the residents covered by the hospital in Lund (240,458 SEK/year) and the residents covered by the hospital in Kristianstad (206,996 SEK/year)

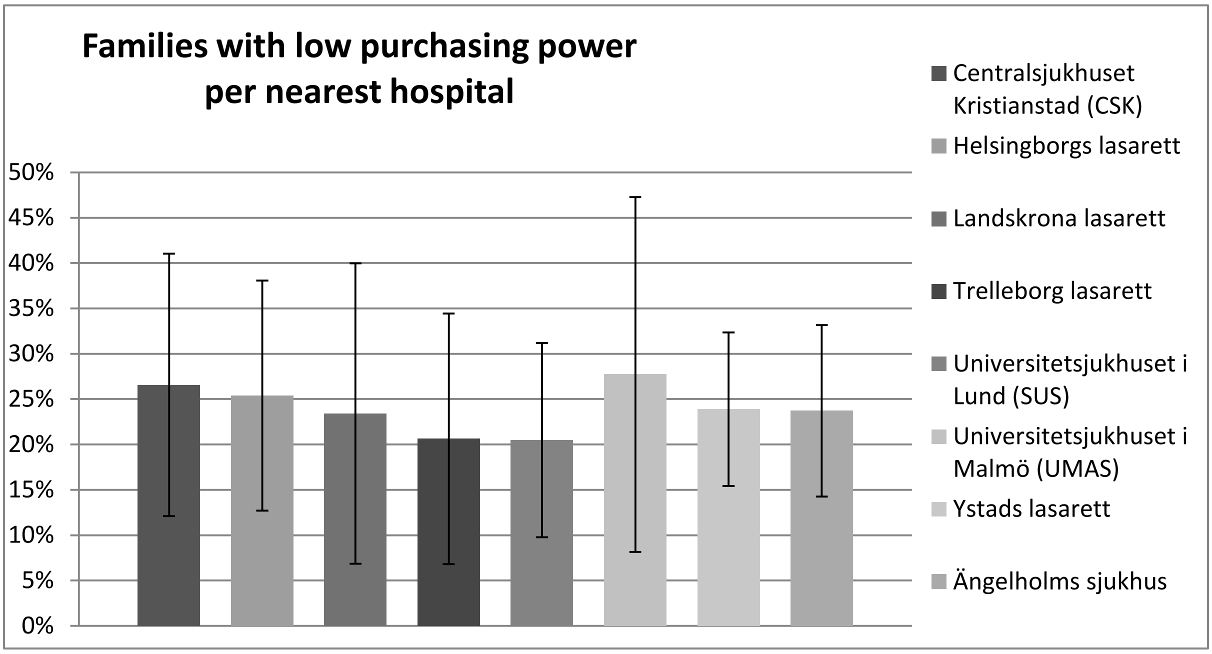

Figure 16: Graph showing the average percentage of families with children with low purchasing power per nearest hospital (with standard deviation bars)

The percentage of families living within each SAMS who have low purchasing power is indicated in Figure16. The hospital catchments in this study do not vary significantly in this regard. The largest difference is seen between the catchments for the university hospitals in Lund (20%) and Malmö (28%). Furthermore, the standard deviation is large for most of the catchments, especially Malmö with a standard deviation of ± 20%.

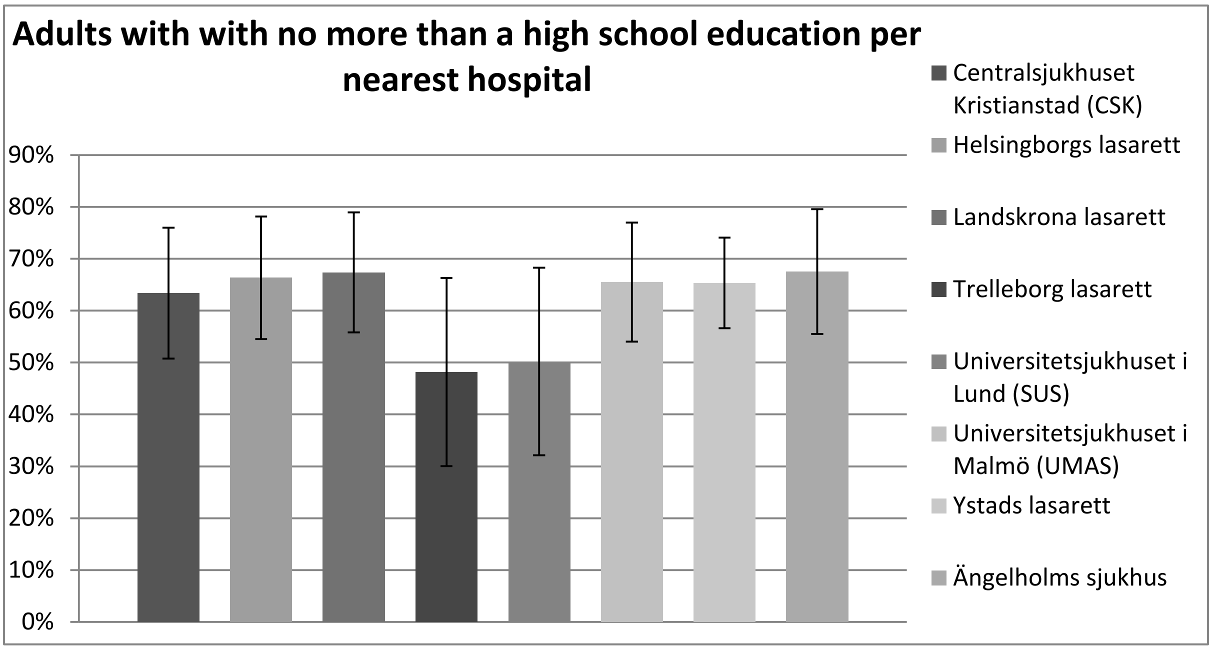

Figure 17: Graph showing the average percentage of all adult Scanians (age 25-65) with no more than a high school education per nearest hospital (with standard deviation bars)

The percentage of adults age 25 to 65 in Scania with no more than a high school education per hospital is shown in Figure 17. One can see that the average percentage of people who have not had any university-level education is fairly uniform except in the university towns of Malmö and Lund. However, Lund and Malmö hospital catchments also exhibit high standard deviations regarding residents' levels of education.

6. Discussion

6.1 Method Discussion

Data from the Swedish Transport Administration's national road database (*Trafikverkets nationell vägdagabas, NVDB*) were used to perform the road network analysis of Scania County. One advantage of utilizing NVDB is that data in the database are relatively current, as the database is updated continually every month. However, one major disadvantage is that the data are not yet complete in terms of all road attributes that would have been interesting to include in this analysis. Although there is no exact method for determining the cost of all possible variables that affect travel time (Schuurman et al. 2006), it is possible to arrive at a more accurate estimation of travel time by examining as many variables as possible.

For example, road speed limit is a key variable because travel time depends not only on distance of travel, but also on speed of travel. Unfortunately, all variables that affect actual speed of travel along the various roads in the network (speed limit, road category, time of day, traffic volume, etc.) could not be taken into account. Rather, the lawful speed limits along different stretches of road were averaged to arrive at the average speed limit per road, and the 30 km/hr speed limit on certain stretches of roads without indicated speed limits was merely an educated guess. It could also be suggested that parent's with a acutely sick child, such as in the case of appendicites, may breach the speed limit in order to reach the hospital quicker. This behaviour was not implemented in the model because of limited information concerning driving patterns.

Furthermore, this model did not take into account the additional time required to stop for turns onto new roads at stop signs, yield signs or traffic signals. Neither did the model take into account the potential time difference in making a left vs. a right turn nor restricted or illegal turns in the road network. No such turn data were available, and it was surmised that, in general, the added time necessary to make some turns would not greatly have affected travel time or relative hospital accessibility.

In one study, Schuurman et al. (2006) assigned a 30-second penalty cost to stop signs and a one-minute penalty cost to traffic lights. In urban areas, this would have increased travel time considerably as urban areas contain many turning points, but this analysis focused solely on the effect of distance to the hospital on travel time. Unfortunately, time constraints did not allow for the real-world evaluation of roads. If time and other resources had allowed, empirical data gathered by randomly driving certain routes could have been compared with the modelled data. In this study, modelled routes and travel times from SAMS were roughly compared to the driving time estimates in Google Maps. A sensitivity analysis could also have been performed to evaluate the reliability and sensitivity of the model to inputs. For example, by making small alterations to known speed limits, it would be possible to see if the new resultant travel times would have been affected in predictable, rather than improbable, ways (Branas et al. 2005; Delamater et al. 2012).

Since Scania is comprised of both rural and urban areas, travel time could have been better estimated by taking into account the estimated additional costs for travel in heavily trafficked urban areas vs. rural areas. For example, Mullen et al. (2015) found that the time period between the time of ambulance dispatch and the time of ambulance arrival at an emergency scene could be more accurately modeled by multiplying drive time in normal conditions by a factor of 1.6 for urban areas; 1.5 for suburban areas and 1.4 for rural areas. Although these factors are more representative for urban, suburban and rural areas of the U.S., the factors could have been altered to better apply to Swedish conditions.

In this study, the only method of transport taken into account was transportation by private automotive vehicle. The study did not consider travel to the hospital using public transportation, i.e. busses and trains. Public transportation is highly effective in Scania, where Skånetrafiken carries approximately 69,646,907 customers each year by city bus (Kollektivtrafiknämnden 2014). This study also neglected to consider people who live in larger urban areas near their local hospitals who may even choose to walk or bike to the hospital. It is entirely possible that many people choose to walk to the hospital in, for example, Malmö and Lund. In larger cities many families may not have access to cars which may prove to be a large barrier to assecibility to proper care, even though the *distance* is relatively small. Investigating families' access to cars in different neighborhoods in larger urban areas may be an important consideration when upscaling this study.

Only eight of the ten hospitals within Scania county were considered in this study. If families with pediatric patients were to travel to a smaller, closer county medical center or to hospitals in different counties - which is permitted by law in Sweden - this may have affected travel time and distance. Thus, the results probably underestimate or overestimate "true" travel distance and travel time to access medical care.

It would perhaps have been beneficial to investigate access and travel time from each SAMS to multiple surgical hospitals within Scania and even out-of-county hospitals. Delmelle et al. (2013) found that families in the state of Florida in the U.S., where healthcare laws and routines differ from those in Sweden, did not always take their sick or injured children to the closest hospital for a variety of different reasons, including the availability of hospital beds, the types of services provided, insurance coverage, referrals, the preference of their primary care physicians and/or specialists, parental occupation or employment status, and maternal age and education. Some of these factors, such as referrals and preferences, may also affect hospital choices made by Swedish parents. Parents may also prefer to travel to hospitals that have a reputation for providing better care or to use travel routes that they are more familiar with or that they currently find more preferable as a result of suspected current traffic conditions due to weather, road construction impediments, rush-hour congestion and so forth. Such preferences may obviously affect actual time of travel to healthcare services.

The residence of every potential pediatric patient within a SAMS was represented in the model by a single population-weighted point, the centroid. Because SAMS are not homogenous in size and are smaller in urban areas than more inland rural areas, the population-weighted centroids are not as representative for larger SAMS. This may underrepresent the travel times of rural populations since they are distributed across larger areas. In the locational sensitivity analysis, the maximum travel time associated with the farthest cell within each SAMS was plotted. It was shown that several populations potentially had longer travel times than were previously estimated using the population-weighted centroids. Moreover, the difference between the maximum and minimum travel time estimations were observable in several larger SAMS. Since rural areas are often of special concern when it comes to spatial accessibility, it is a limitation that the larger SAMS may underestimate travel times to the hospital. However, focusing only on rural areas may underestimate barriers to accessing health care that may exist in urban areas (Jordan et al. 2004). The number of children affected by underrepresentation or overrepresentation in accessibility due to different locational methods has not been studied. As previously mentioned, the method of using the population-weighted method to estimate travel time showed a higher degree of dispersion. Perhaps it would have been more accurate to instead calculate travel time from the weighted center of *every population cell within a particular SAMS* and then use these travel times to calculate the average travel time per SAMS as suggested by the locational sensitivity analysis. However, this method was more time consuming and required large data processing capabilities which would be difficult to upscale when studying an area larger than Scania.

6.2 Results Discussion

Several hospital accessibility studies (Bosanac et al. 1976; Schuurman et al. 2006; Delamater et al. 2012; Eklund and Martensson 2012; Delmelle et al. 2013) have designated a hospital travel time of less than 30 minutes as the limit to denote *served* versus *underserved* areas. The results of this analysis show that the great majority of children (96%) in Scania reside in SAMS with good geographic accessibility and have travel times of less than 30 minutes to the nearest surgical hospital. Only a relative small number of children (10,537 or 4%) reside in underserved SAMS associated with travel times of 30 minutes or more to the nearest surgical hospital.

Nevertheless, it has not been determined if a travel time of 30 minutes or less is indeed an adequate limit. As previously stated, pediatric patients in particular may have more urgent or more frequent healthcare needs than the population at large and may fare better healthwise in the short term and long term when their travel times to the nearest hospital are shorter than 30 minutes. In other words, the *realized* accessibility of a population (in this case, the pediatric population) must be considered to estimate what is considered an adequate travel time in terms of the pediatric population’s need and urgency for care.

It is interesting to consider the mean hospital travel time in Scania and a normal distribution method to indicate possible underserved areas in the county. Dahlgren (2008) used such a distribution method in his study on rescue service planning and accessibility in the Swedish municipality of Kävlinge. According to the study herein that encompasses the whole of Scania, the average travel time of Scanian residents to the nearest hospital in Scania is 11.8 minutes, and 95% of all children residing in Scania have a hospital travel time of 3.02 to 20.56 minutes (the range for the *normal case*). 5% of children live in areas with a travel time of 20.56 minutes or more and could thus be said to live in underserved areas (or the *least favorable case*), while 5% of children with travel times of less than 3.02 minutes can be said to reside in the most well-served areas (or the *most favorable case*).

Scanian children who resided closest to the hospital in Malmö, which had the smallest catchment of the eight different surgical hospitals, were more likely to have shorter travel times compared to the children who resided closest to the hospital in Kristianstad, which had, by far, the largest catchment. For example, people living in the municipality of Hässleholm, with a population of 51,048 and its own hospital, were nevertheless compelled to travel to the hospital in Kristianstad for surgical care.

Furthermore, members of the population living in urban areas with access to state highways along the western coast of Scania enjoy greater geographic accessibility than their rural counterparts. This is because the European and state highways offer relatively fast, straightforward routes of travel, and this decreases overall travel time. Scania contains several European and state highways, and this increases connectivity and thus accessibility on the whole.

There were also large differences in the number of children potentially served by each hospital. The hospital in Malmö served the largest number of children, followed by the hospitals in Lund and Kristianstad. The hospitals in Landskrona, Trelleborg and Ystad served the smallest number of children in Scania, even though their catchments were relatively large. As Pong and JR (2001) have pointed out, in rural and remote regions, residences are typically more spread out over a larger area. Catchment data may not actually correspond to the number of residents catered to by a particular hospital. In other words, one cannot assume that a larger catchment (in terms of area) always results in a larger coverage in terms of the number of potential patients. It is therefore important to actually measure the number of children who reside within different hospital catchments and estimate their various travel times to the closest surgical hospital.

Healthcare planners focused on possible cases of acute appendicities and cryptorchidism to serve as case studies for pediatric surgery and healthcare planning. While acute appendicitis representes a true medical emergency for children of both genders, where travel time to the nearest surgical hospital may be critical for the patient’s health outcome, cases of cryptorchidism in male infants are not normally treated as medical emergencies. Instead they are treated as part of the planned healthcare. Cryptorchidism is not usually surgically treated until the affected infant is six to twelve months old, which gives parents or guardians ample time to plan their travel means and routes to the most preferred hospital. Therefore to accurately model the assecibility for surgeries treating *retentio testis* only male children under a certain age should be investigated.

6.3 Socioeconomic Analysis

Socioeconomic data related to the different surgical hospital catchments are illustrated in Figures 15, 16 and 17. The different hospital catchments did not differ from each other significantly on attributes such as adult level of education, purchasing power or median income. Many of the hospitals are situated in cities where there may be large social and economic differences between particular neighborhoods, but this could not be inferred from the catchment data. According to a study by Salonen (2015), the variation exhibited between different neighborhoods within the same major city was larger than the variation exhibited between different municipalities in Sweden. For example, child poverty in the neighborhood of Rosengård in Malmö was 62.3% in 2010, a percentage that is five times greater than the national percentage. Nevertheless, child poverty in Rosengård decreased by two percentage points in the year from 2009 to 2010, indicating a positive trend for the area. The area in Malmö where child poverty was least was Husie, where child poverty was 11.4 % in 2010, indicating a decrease of 0.1 of a percentage point since 2009.

This suggests the importance of investigating socioeconomic differences on an appropriate spatial scale. If the scale is too large, no conclusive results can be deduced because of the large variation between municipalities, cities or even neighborhoods. On the other hand, minimizing the scale might lead to a lack of sufficient data and biased results. A large variation might be seen without being able to make any correlations. In this study, the largest socioeconomic variations were found when comparing the catchments for the hospitals in Lund, Malmö and Kristianstad. However, these socioeconomic differences were not large enough to raise concern over differences in the residents' hospital needs.

Instead of investigating socioeconomic differences between hospital catchments, an overlay analysis was performed to investigate the SAMS that demonstrated the greatest potential resistance to seeking medical attention based on travel time, income and level of education. However, there was insufficient time to allow for parameterization and the creation of requisite sub-models to justly represent areas of disadvantage.

Scania has an extensive, well-established road network with several European and state highways that aid connectivity and decrease overall travel time. Furthermore, many of the cities in Scania have a greater percentage of residents from age 0 - 19 per SAMS, which inflates the percentage of children in the county who are covered by surgical hospitals within relatively short travel times. The question is if Scania is representative of other counties in Sweden, such as the rural counties in Northern Sweden, which are less densely populated and have a less extensive network of roads and highways. Therefore, the results obtained in this study can thus only be said to apply to Scania.

Children were defined as being from age 0 up to, but not including, age 19. This may be an adequate definition for pediatric patients in general, but to study the correlation of surgical procedures associated with, for example, cryptorchidism, it may have been more beneficial to narrow the age range further. Operations to treat cryptorchidism are normally performed on children from 6 to 12 months of age. In this case, it may have been better to include only male infants from 6 to 12 months old as potential pediatric patients. Unfortunately, no data on the percentages of male vs. female children in each SAMS were available, and no data regarding a pediatric patient's place of residence versus the chosen hospital for surgery to treat cryptorchidism were available.

These results may prove important in aiding better healthcare planning in Scania. For example, since a large percentage of Scanian children reside in Malmö, more pediatric resources may need to be allocated to the hospital in Malmö to better correspond to patients' needs. Furthermore, Scania's population is expected to increase by approximately 13% in less than ten years to 1,455,500. This demographic change will further affect the distribution of children in Scania and the relative coverages of its surgical hospitals, but it is difficult to say with any certainty whether people will move to Scania's urban areas or rural areas. In any case, this study illustrates the value of GIS methods in providing a better understanding of spatial accessibility to medical care for children.

7. Conclusion

This study identified geographic variations in potential pediatric patients' spatial accessibility to the nearest surgical hospital in the county of Scania, Sweden using network analysis. There were large differences between the eight hospitals chosen for the study in terms of their catchments, i.e. the number of children covered by the hospital. The greater percentage of Scanian children reside in areas associated with a travel time of less than 30 minutes to the nearest surgical hospital within the county. Given the prior assumptions, no child in Scania would have a travel time of more than 48 minutes.

Socioeconomic differences between the catchments of the different surgical hospitals were also investigated, but no significant differences could be determined because of a large variance within the catchments. Socioeconomic variables such as purchasing power, median income and level of education did not appear to correlate to travel time to the nearest hospital. There were also no significant differences found between the different hospital catchments on average. Further research on a different spatial scale should be performed. For example, socioeconomic differences between the SAMS served by a particular hospital such as the hospital in Malmö could be investigated. Also, a comparison between patient records and their respective residential SAMS could be studied.

This study had several strengths, but also several important limitations. It was assumed, for example, that potential pediatric patients would make their way to the nearest surgical hospital in Scania using a private automotive vehicle and using the most obvious route on major highways. Travel by bus, train and ambulance on alternate routes and to alternative hospitals within and outside of the county were not studied. Travel times were furthermore underestimated in urban areas because rush-hour conditions on major thoroughfares and the time necessary for stopping at stop signs, waiting at traffic lights and performing turns was not taken into account. The locational sensitivity analysis showed that calculated travel times using the population-weighted centroids within each of the SAMS may not have been representative on the whole – especially in areas particularly close and particularly far from the nearest hospital. In future studies turn restrictions and other geographical barriers in urban areas may need to be taken into account to accurately model travel times within cities.

Nevertheless, the results herein may prove helpful in planning and improving healthcare in Scania. This study may also prove helpful as part of a more thorough and extensive investigation of socioeconomic factors that may affect where, when, why and how various pediatric patients in Scania seek medical care.

7.1 Further Studies

- Perform an in-depth analysis of larger cities and the accessibility to health care in different urban areas correlated to socioeconomic variables.
- Model catchment scenarios (Shuurman 2006) to further investigate the rural population's accessibility to different healthcare services in Sweden compared to urban populations' accessibility.
- Investigate the correlation between travel time and health outcome among children in Sweden by using geographically coordinated patient data.
- Perform an upscaled analysis to include the whole of Sweden using the same study method. This would require high data-processing capabilities and a large storage capacity.
- Investigate how socioeconomic factors and geographic barriers may affect where, when, why and how various pediatric patients in Scania (or Sweden) seek medical care.

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