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Daily individuals' accessibility to other individuals and the impact of changes in intra-travel time on changes in daily accessibility in Sweden

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Abstract

The overall aim of this study is to understand how average daily individuals' accessibility to other individuals has changed in Sweden and what the impact of changes in intra-travel time is on changes in daily individuals' accessibility in Dalarna County.

This thesis was conducted by applying quantitative research method via secondary data collection method. The required data for the purpose of this study were collected from Official Statistic of Sweden (SCB), Swedish Road Administration (NVDB) and Swedish National Travel Survey (RVU). Research population or target population for this study is all Swedish workforce population, aged 20-64. For the first part of the aim, the entire research population has been investigated and for the second part of the aim, non-probability sampling method (purposive sampling method) has been applied. The datasets have been applied to compute different variables. The variables were computed by using formulas extracted from previous empirical studies and with help of GIS and R software. The relationship between response and predictors variables has been statistically analyzed by multiple linear regression.

The findings indicate that average daily individuals' accessibility increased within the Swedish context between the years 1990 and 2008. It was found that the most increment was related to years 1995 to 2000. Also the statistical analysis showed that the relationship between the changes in average intra-travel time and changes in average daily individuals' accessibility was not significant in municipalities in Dalarna County. Meanwhile, it was concluded that among predictor variables, changes in average daily mobility had a significant relationship with the changes in average daily individuals' accessibility to other individuals within municipalities in Dalarna County.

Keywords: Individuals' accessibility, daily mobility, population redistribution, travel time, road network, GIS, Sweden, Dalarna

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List of Abbreviations

GIS Geographic Information System

ID Identification

KM Kilometers

NVDB Swedish Road Administration

SCB Official Statistic of Sweden

1. Introduction

Accessibility of a geographical space is known to be an important explanatory factor for firms and households. Spatial accessibility can be defined as being the extent to which land-use and transport systems provide an opportunity for people to reach different types of activities. It can be seen as an indicator that determines the locational advantage of an area compared to other areas. Also, accessibility is known to be a product of transport systems and it has been used mainly to evaluate the performance of different types of transport systems (Kwan, 1998). Improving accessibility has an impact on regional development and it increases social and economic performances which shape the spatial patterns of the individual's activities (Spiekermann et al., 2002). Providing the ability to access places, increase the individuals' interaction and enable them to participate in different sort of activities that have an impact on residents' quality of life. Even in an urban context, accessibility is known to be a prerequisite for mobility that promotes interactions and flow sources within urban regions. Also within the rural context, transport improvements increase accessibility of rural regions to urban centers that have an impact on the welfare of rural residences.

1.1 Background of the research

Although the impact of accessibility on economic and social development is undeniable, its measurement and analysis are quite complex and complicated (Wegener, 2004). Due to the purposes of study, accessibility can be defined and applied in different ways. For instance, it can be measured to indicate the level of services that can be provided through the transport system or it can be measured to show the number of individuals or activity locations which can be reached within a specific distance (Euclidean, road network) or time or budget (Kwan 1998 & Crisioni et al., 2016). This measurement can be computed at different spatial scales such as continental, national and regional/local level (Spiekermann et al., 2002). But the most important accessibility measurement regarding spatial scale is at the regional/local, as it indicates the degree of citizens' access to other individuals, job opportunities and essential services within their daily life.

Nowadays, accessibility of a region, as the social and economic development indicator, depends on to what extent a region is connected to long-distance transport, communication networks, and large economic centers. Therefore, it can be said that daily individuals' accessibility is an important factor for a spatial region (parish, municipality or county) that shows the advantage of that location compared to its neighboring regions and other regions in a country. “Regional accessibility is generally considered to be an essential prerequisite for regional economic growth” (Stedler, 2014, p.984). In order to improve regional accessibility there is a need to enhance daily individuals’ accessibility and in this regard, proximity and mobility are key components (Haugen, 2011).

Distance to essential amenities and activity locations act as the obstacle that decreases accessibility (Vilhelmson, 2005). Due to the changes in land-use patterns, distance to different types of activity locations has been changed. Thus, individuals' mobility increased as it was an important means to reach amenities (Hanson, 2004). According to Haugen et al., (2012) the process of spatial centralization and decentralization of amenities location, change distances that influence individuals’ accessibility. Due to the change in land-use patterns, individuals travel longer distances and have longer travel times to reach their destinations. In daily life, travel time becomes an important factor (known as proxy of distance; Haugen, 2011) for individuals in the residential choice process. Long distances between individuals’ residential locations and destinations mean that they spend more time reaching their activity locations.

The main question is how residents adapt themselves to the changes in the land-use patterns. Do they prefer to have longer travel time to activity locations or do such changes in distance and travel time affect residential relocation and population redistribution? Haugen (2011) states that among different activity locations some have priorities (it can be said mandatory locations such as workplace and education) compared to others which make people travel longer to reach there and can’t be replaced easily. The distances have been bridged by transport systems that link activity locations to people. In daily life, road networks are the most available transport network for individuals. Even having access to other types of transport networks can be possible through the road network. The road network enables people to move and facilitates people’s accessibility to daily activities. Moreover, the road network seems to be crucial because it connects individuals to each other and to activity locations. Also, the road network can affect the time it takes individuals to reach their destination.

Among the Nordic countries, Sweden is denser in terms of road networks compared to its neighboring countries (Gløersen et al., 2006). Most cities are well connected by railway, and the road network covers almost the entire country. It has been argued that, "Swedish major road networks can be considered as rather dense with an even higher density of complementary secondary roads" (ESPON, 2013, p.65). In Sweden at the regional level, the road network is the most available transport network for use by individuals to reach their destinations.

There has been a considerable amount of research in the field of accessibility, especially at the European level. Cederlund et al., (1991) and Erlandsson and Törnqvist (1993) measured daily accessibility indicators of European cities. They expressed daily accessibility as the number of people that can be reached from the center of a city during a business day by using the fastest available transport system. Chatelus and Ulied (1995) measured several accessibility indicators in European countries to calculate the average cost to reach a market area by a lorry. Schürmann and Talaat (2000) measured potential accessibility, which indicates the attractiveness of a location in terms of labor force and Gross Domestic Production for passenger and freight transport through the road networks. Vickerman et al. (1999) measured daily and potential rail accessibility for Europe by using raster-based Geographic Information System technology and Schürmann et al.(1997) and Wegener et al.(2000) developed it by adding road and air accessibility. In another study, Gløersen et al. (2006) analyzed the accessibility of some regions in Finland, Norway, and Sweden to universities and hospitals within 50km. In all this research, different types of accessibility indicators have been measured at the European level.

Within the Swedish context, Håkansson (2000) measured daily individuals' accessibility to other individuals between the years 1810 and 1990 within their daily mobility. He investigated in what extend average individuals accessibility to other individuals, affected by population redistribution and mobility changed over the time within the years 1810 to 1990. Haugen et al., (2012) measured individuals' accessibility to different types of amenities within 5km and 50km which were different from actual daily mobility between the years 1995 and 2005 in Sweden.

A review of previous empirical studies demonstrates that little research has focused on daily individuals' accessibility to other people at either the national or regional level by using daily mobility within the Swedish context. In other words, since 1990, daily individuals' accessibility to other people has not studied in Sweden. Moreover, road networks seem to be crucial as the facilitator of individuals' mobility. So far no empirical research has studied the effect of changes in the road networks on daily individuals' accessibility to other people in Sweden.

In this study, the changes in the road networks in the areas were measured in the form of intra-travel time. It can be argued that either change in speed limits or in road constructions (maintenance or new roads) has a direct impact on travel time. Therefore, changes in intra-travel time with an area assumed to be a representative of changes in the road networks. Thus in order to investigate the impact of changes in the road networks on the changes in daily individuals' accessibility, the intra-travel time at the regional level (Dalarna County) has been considered as the proxy.

1.2 Research purpose

Based on the above-mentioned problem statement, this study has been conducted to fulfill the following aims:

"To understand how daily individuals' accessibility to other individuals has changed in the context of Sweden and what the impact of changes in intra-travel time is on changes in daily individuals' accessibility in Dalarna County."

Therefore in order to achieve the study aims, the following research questions need to be answered:

- Did average daily individuals' accessibility to other individuals within their daily mobility increase or decrease in Sweden between 1990 and 2008?

- To what extent did changes in average intra-travel time have an impact on the changes in average daily individuals' accessibility to other individuals at municipality level in Dalarna County between 1996 and 2008?

1.3 Relevance

Based on the previous section, it appears that since 1990 individuals' daily accessibility to other people has not developed and meanwhile no research has been conducted with regard to the impact of changes in average intra-travel time on changes in average daily accessibility to other individuals in Dalarna County. The academic relevance of this research is, therefore, its contribution to close the research gap. Next, in terms of academic relevance, this research intends to be of use for land use and transport planning within Dalarna County and Sweden.

1.4 Structure of the research

This thesis consists of five sections. The first section briefly introduced the background of the research, the research purpose, and the relevance of the research. Section 2 illustrates the information about findings of previous studies. Section 3 describes the strategy, methods of data collection and analysis, followed by reliability and validity of the study. In section4, the statistical results of the conducted analysis are presented. The last section concludes the thesis by summarizing the key findings of the data analysis, highlighting the academic and practical relevance of the research, stating the limitations and giving recommendations for further research.

2. Literature review

This section provides an overview of previous studies regarding daily individuals' accessibility. It outlines the findings of previous research and accessibility components' from different point of views.

The concept of accessibility is complex and it can be operationalized and measured in many ways regarding study context and on the phenomenon that wants to be analyzed (Haugen, 2011). In general and in its simplest way, accessibility as a term can be defined as a number of activity locations or destination that can be reached within a specific distance, travel time or fixed budget by using transport mods (Geurs & van Wee 2004).

Daily individual's accessibility to other individuals (which is the case in this study) also called by Håkansson (2000), daily interpersonal accessibility can be defined as follows: the potential number of individuals that can be reached within daily mobility. Daily mobility refers to a one-way business trip that starts from home (origin) to workplace (destination) in a way that the person sleeps at home at the end of the day (Håkansson, 2000).

Daily individual's accessibility to others can be influenced by two main factors: population redistribution and daily mobility (Håkansson, 2000). Population concentrations in an area increase the daily individual's accessibility. Meanwhile, after motorization, individuals' mobility increased and distance as the obstacle to amenities, has diminished. This phenomenon enables an opportunity for individuals' to travel longer across geographical space. The greater mobility increased the individuals' accessibility even when the population remained unchanged (Håkansson, 2000). It has been argued by Håkansson (2000), that individuals' accessibility within the context of Sweden between 1810 and 1990 was influenced by changes in both population redistribution and daily mobility. Furthermore, he pointed out that population concentration played as an influential factor in some decades compared to the change in the daily mobility.

To have a deeper insight about population redistribution and mobility, Haugen (2011) studied individuals' preferences regarding proximity to destinations within the Swedish context. It was argued that proximity to amenities and daily mobility play as important factors in individual's accessibility (Haugen, 2011). It was stated, that residential choice process is influenced by commuting time and travel cost (Prashker et al., 2008). However, in other studies in Sweden, commuting time became less important as income increased; consequently, the importance of commuting time was related to the individuals’ socio-economic characteristics (Swärdh, 2009).

It was noted, that the residential location and daily mobility can be perceived as a trade-off (Prashker et al., 2008 & Haugen, 2011). The decisions which are made by individuals about residential locations shape the length of daily mobility. Haugen (2011) states that within the context of Sweden, proximity to some activities such as: workplace, relatives, and urban area mostly influence people’s decisions regarding their residential locations. Activity locations such as a workplace, university and child’s school argued as the mandatory destination that can't be replaced (Vilhelmson, 1999). From one point of view, mobility is known to be an important means that increase individuals' accessibility to a different type of destination (Hanson, 2004). From another point of view, geographical proximity to amenities is known as the main factor that increases individuals' accessibility (Haugen, 2011).

According to Haugen et al. (2012), population distribution and proximity can be affected at the structural level and individual level. As a result of changes in land-use pattern and spatial location of economic activities, potential distance to amenities changed; consequently, individuals' accessibility is affected. Because of agglomeration of economic activities in urban area, accessibility and population concentration increased (Haugen et al., 2011). Han et al. (2016) pointed out that population distribution patterns changed over the past centuries at different stages in Sweden. According to Dieleman et al. (2004) and Han et al. (2016) after the Second World War as result of motorization and change in lifestyle, urbanization development was slowed down. Therefore, as an outcome of decentralization (such as urban sprawl and suburbanization), individual’s mobility (personal car usage) increased and proximity decreased (Hanson, 2004 & Dieleman and Weneger, 2004).

Haugen et al. (2012) mentioned above changes in population redistribution, amenities' relocation and motorization as a reason for daily mobility. At individual level Haugen (2011) argued that residential location and individuals’ preferences play as key factors that shape individuals’ accessibility. Partridge (2010) underlined that the main reason for migration at interregional level is having access to amenities. Haugen et al. (2012) studied the potential individuals’ accessibility to different types of activity sites and they found out that even the potential distance to the nearest amenities decreased but daily mobility increased. Therefore, they realized that people chose the amenities at longer distances compared to the nearest one. Also, they argued that potential accessibility increased as result of amenities' relocation and not population redistribution. The results of Haugen et al. (2012) showed that although the proximity to the workplaces and some other amenities act as a key factor in residential location process, their daily mobility increased. Swärdh (2009) studied in what extent commuting time is affected by changes in either home location or workplace. It was argued that the importance of commuting time varies among individuals. To some people commuting time was less important as their wage increased. Swärdh (2009) stated that as result of changes in either residential locations or/and workplaces, commuting time was increased in the context of Sweden. Further, it was pointed that there is a relationship between commuting time and income. Longer commuting time may be accepted as income raised (Swärdh, 2009).

The above-mentioned studies mainly showed that daily mobility becomes a crucial key factor in individuals' accessibility. In the other hand, Weber (2003) argued that travel time to major activity location is a significant factor for individuals' accessibility. The distance is bridged by transport systems and road network is the most available one among others. It is indubitable that roads facilitate daily mobility and accordingly increase the accessibility. Meanwhile, it was argued that travel time to the amenities is one of the influential factors in residential location selection. Chi (2010) argued that having access to highways has a significant contribution to the population change. His result showed that in Wisconsin, highway improvement resulted in rural population growth, in suburban this improvement facilitates the population flows and at the urban area it has no effect on the population distribution. Kotavaara et al. (2011) studied the role of road accessibility and population change in Finland within 1970 to 2007, and the result showed population mainly concentrated in an area with high road accessibility.

As it was motivated above, since 1990 within the Swedish context the individuals' accessibility to other individuals (interpersonal accessibility) is undeveloped. Meanwhile, some studies pointed that travel time plays an important role in home location process and in some cases it was argued that it depends on individuals' socio-economic characteristics. According to the above-mentioned previous studies, the impact of changes in intra-travel time as result of changes in the road networks on individuals' accessibility to other individuals remained untouched in the context of Sweden. Therefore it was aimed to understand how daily individuals' accessibility to other individuals has changed in the context of Sweden and what the impact of changes in intra-travel time is on changes in daily individuals' accessibility in Dalarna County.

According to the above-mentioned studies, in order to answer the second research question the following hypothesis was developed:

H1: Changes in average daily individuals' accessibility is negatively related to the changes in average intra-travel time.

3. Methodology

The subsequent section presents the methodological design for this paper by discussing the research strategy, methods of data collection and analysis, followed by reliability and validity of the study.

3.1 Strategy and method

The purpose of this study is to understand how daily individuals' accessibility to other individuals has changed in the context of Sweden and what the impact of changes in intra-travel time is on changes in daily individuals' accessibility in Dalarna County. To fulfill the above-mentioned purposes, this study is designed as a quantitative research. Quantitative approaches comprise data collection and/or analysis procedures, generate or use numeric data which can be applied in statistical analysis to explain a potential relationship between variables (Saunders et al., 2012).

3.2 Research population, sampling, and data collection methods

Swedish workforce population aged 20-64 is used as research population or target population for this study. Destination in daily mobility is defined as workplace; therefore, workforce population is an appropriate research population to compute daily mobility consequently individuals' accessibility. The entire workforce population within 1990 to 2008 was used to answer the first research question. In order to answer the second research question, Due to the large size of investigated research population (around 5 million individuals per year), computing intra-travel time for all municipalities at the national level was complex and exceeded time. Therefore, Swedish workforce population aged 20-64 at Dalarna's Municipalities was used as a sample instead.

As the traffic congestion was not considered in computing average intra-travel; therefore, municipalities at Dalarna were more suitable for the purpose of this study, compare to the populated county such as Stockholm or Gothenburg. By assuming lesser traffic in municipalities in Dalarna County compared to well-populated counties, the result of intra-travel time might be close to the reality. As such, non-probability sampling method was applied to carry out the second research question. Based on the above-mentioned assumption, purposive sampling method was used. "With purposive sampling, you need to use your judgment to select cases that will best enable you to answer your research question(s) and to meet your objectives" (Saunders et al., 2012, p.287).

This study is conducted by applying a combination of the official population registered datasets from Official Statistic of Sweden (SCB), national road networks from Swedish Road Administration (NVDB) and mobility data through the road networks from Swedish National Travel Survey (RVU). A secondary data collection method was also applied for this study and the required data were collected from the aforementioned organizations by Dalarna University in 2017.

3.2.1 Dalarna County in Sweden

Dalarna is a county in the middle of Sweden with 28,189 km^2 total areas. It has a border with Norway from northwest and with Uppsala from Southeast. The total population of Dalarna at the year 1996 was 288,171 and total workforce population was 160,386. At 2004 Dalarna's total population was 276,042 and workforce population was 155,995. The total population in this County at 2008 was 275,867 and workforce population was 155,643 (SCB, 2017). Dalarna is made up of fifteen municipalities and the capital of Dalarna is Falun. Moreover, the total and workforce population at each municipality in Dalarna County is presented in a form of table in the Appendix 1.

3.3 Data presentation

Population registered data consisted of geo-referenced and longitudinal data comprising the entire Swedish workforce population, aged 20-64 between 1990 and 2008. Each set of population data entails individuals' information in different columns. The individuals' information was consisted of date of birth, age, gender, latitude and longitude of home and work locations with unique Identification (ID), home and work municipality's code and County's code. Each workplace has its own unique ID that links each individual to his/her workplace. This dataset had information about the total miles traveled by each individual with either personal car or motorcycle in two different columns.

National road networks datasets were related to 1996, 2004 to 2014. Each set of data consists of geometric information of nodes, length of edges between the pair of nodes (road) with unique ID and digitized speed limit for each edge. The edges with two different speed limits indicate two ways road and the edges with one-speed limit indicate one-way roads. Data regarding aggregated mobility entails the total mileages, that have been driven in each year by different type of vehicles such as; personal car, motorcycle, and buss from 1950 to 2014. The vehicle mileages reported in million kilometers per year.

To investigate changes in average daily individuals' accessibility at the national level in Sweden, population data of years 1990, 1995, 2000, 2005 and 2008 was extracted. Aforementioned years were selected due to having small population growth rate at Swedish Context. Total number of individuals (before preprocessing) in each dataset was between 5 to 6 million. Aggregated mobility data was used for this part of the analysis to estimate average daily individuals' mobility in corresponding years.

To investigate the impact of the changes in average intra-travel time on the changes in average daily individuals' accessibility at municipality level in Dalarna County, population data in years 1996, 2004 and 2008 was extracted. The total number of individuals (before preprocessing) for this part of the study was 172,824 for 1996; 177,012 for 2004 and this number for 2008 was 179,404. The main reason for choosing aforementioned years was road networks data availability for aforementioned years. As it was mentioned, the collected data regarding road networks was for years 1996, 2004 to 2014 but the population data was from 1990 to 2008. There was a gap between population datasets and road network datasets; therefore analysis was feasible during aforementioned period of time.

3.4 Data preprocessing

Data preprocessing carried out in three steps; each data cleaned and edited in the different process by using the different software as follows:

The population data was transferred to R software and then edited. Each set of population data entails more than five millions individuals. At first, data duplication had been controlled. Some individuals had two personal cars or motorcycles, for those, driving mileages of both vehicles were merged. After merging individuals with two or more vehicles, duplicated data was removed from each data set. Then individuals with missing home coordinates were removed from the data. Also, the misplaced longitude and attitude coordinates were edited and corrected. After data screening, it was stored in Excel formats for further computation in Geographic

Information System (GIS) software (ArcMap) and in RData formats. The data cleaning process applied for entire population data within 18 years.

National road networks dataset cleaning and preprocessing were carried out with GIS software (ArcMap). The speed limits of roads were inspected and some roads with really high-speed limit (999 km/h) were changed to the nearest road's speed limit. In order to have further analysis about the travel time, two new columns, which indicate the travel time of each edge, were added to the dataset. The travel time for each edge calculated based on the length of edge and its speed limit. Units of the length of the edges and speed limits were meter and kilometers per hour respectively. To convert kilometer per hour to meter per minute, conversion factor of 16.6667 was used. By dividing the length of the edges to speed (meter per minute), travel time for each edge was calculated in minute. Two ways roads had two different speed limits so each way (turn or return) has its own travel time. In order to find the shortest path and calculating travel time based on the actual path, one way, and two ways restriction was applied. Therefore one more column was added to the data sheet, which defined the direction of each edge. In GIS software by using build network tool, which is known for creating road network , one way-two ways road can be distinguish through the categorical variable. The alphabet "B" is an indicator for two ways road and "FT" or "TF" indicates one-way roads. After adding required columns and editing roads' speed limit, the road networks were built and the algorithm was set in a way to select the shortest path by considering the travel time with respect to roads' directions (one way-two ways restrictions).

The aggregated mobility data consists of the total miles traveled in the Sweden road networks from1950 through 2014. This dataset was used to calculate average daily individuals' mobility during a year. The total mileages were presented in millions and kilometers. In the mentioned dataset, the types of vehicles were distinguished as: Motorcycle, Personal car, Bus and Lorries and Total. On average, more than 85 percent of total traveled miles belonged to personal cars and almost 2 percent belonged to buss and less than 1 percent belonged to motorcycles. The required age to get a driver license is 18 years old (Transportstyrelsen, n.d.) but the ages 18 and 19 were not considered in the calculation of average daily mobility. To calculate average daily individuals' mobility, total mileages of above-mentioned categories were used without considering Lorries' mileages. The total mileages of the categories (personal cars, motorcycles, and buss) were multiplied to one million (mileage was reported in million) and then divided by the Swedish workforce population. This number indicates the average individuals' mobility per year. Then this numbers was converted to average daily individuals’ mobility. The average daily individuals’ mobility was used to answer the first research question.

3.5 Variables

The purpose of this study was followed by responding to and analyzing two research questions:

- Did average daily individuals’ accessibility to other individuals within their daily mobility increase or decrease in Sweden between 1990 and 2008?

For responding to this research question, average individuals’ accessibility to other individuals was computed in years 1990, 1995, 2000, 2005 and 2008. Aforementioned years were selected due to having small population growth rate at Swedish Context. The computation was done by applying equations (see equations 1 to 3), using average daily mobility through the aggregated mobility data at national level, and longitudinal population dataset for the mentioned year. The objective of this question was to investigate the changes in the average daily individuals’ accessibility. The applied variables were average daily individuals’ mobility and changes in the population. The average daily individuals’ mobility was discussed in data preprocessing of this study, the population considered in this section was entire Swedish workforce population.

- To what extent did changes in average intra-travel time have an impact on the changes in average daily individuals’ accessibility to other individuals, at municipality level in Dalarna County between 1996 and 2008?

To answer the above question, computation of combination of required variables, and statistical analysis are required. The candidate variables consisted of dependent or response and independent or predictor variables. Changes in the average daily individuals’ accessibility were considered as a dependent variable. Changes in the number of job opportunities, average daily mobility, population, and average intra-travel time were considered as independent variables. The response and independent variables were selected based on the previous empirical studies and theoretical literature reviews. The predictor variables were computed by using longitudinal data. Daily mobility was obtained by measuring the length of the shortest path respect to travel time between residential locations and workplaces through the road network. This was assumed that each individual prefers to get to his/her workplace (destination) by minimizing the commuting time.

The impact of predictors on the response variable and the hypothesis was investigated and tested by multiple linear regression model with 95% confidence interval. So if a predictor is statistically significant at a 0.05 level critical value, then it could be concluded that the predictor has an impact on the response variable. The changes in response and predictor variables were used in a form of ratio between 1996 and 2004 as the first period, and between 2004 and 2008 as the second period.

As it was mentioned before, the study area for this research question was municipalities in Dalarna County. The computational method of response and predictors are explained and discussed in more details in the following sections.

Table 1Variables' notations

Variables	**Notations**
- Dependent or response variable:	
Change in average daily individuals' accessibility	ΔA
- Independent or predictor variables:	
1. Change in average daily mobility	$\Delta mobility$
2. Change in average intra-travel time	ΔT
3. Change in population	ΔP
4. Change in number of job opportunities	Δw

3.5.1 Computational method of accessibility

This section explains, the computational method of accessibility measurement, such as applied formulas, creating build-up area unit and tools.

The average daily individuals' accessibility term in this study is defined as, the potential number of individuals that can be reached within daily mobility in an area. The applied accessibility formula is as follow:

$$A_I = P_{im} \qquad (1)$$

$$A_T = \sum_I A_I(\frac{P_I}{P_T}) \qquad (2)$$

$$\Delta A = \frac{A_{T_2}}{A_{T_1}} \qquad (3)$$

$A_I =$ Average daily individuals' accessibility of area I

$P_{im} =$ Number of individuals in an area with average daily mobility (m) distance from i

$i =$ Center of area I

$A_T =$ Average daily individuals' accessibility of an area consisted of I areas.

$P_I =$ Population in area I

$P_T = \sum P_I$ = Total population

ΔA =Accessibility changes

The equations 1 to 3 were taken from previous researches with the same topic in the different period of time (Håkansson, 2000). Instead of computing average daily individual's accessibility at the parish level, build-up areas were created in form of grid cells that represents imaginary areas (I). By defining grid cells and dividing Sweden's area into more homogenous build up area in terms of size, the result of computation of average daily individuals' accessibility will be more accurate.

3.5.2 Accessibility measurement at national level

As it was noted, to measure average daily individuals' accessibility at the national level, the entire map of Sweden was divided into equal size grid cells (5km to 5km) with GIS software. The total numbers of divisions were 18,727 grid cells. The centroid of each grid cell was calculated and recorded as i. Then for each grid cell, a unique ID was assigned. After creating build-up areas with the identified centroids, population datasets were imported to the software and added to the map by using home's longitude and latitude coordinates. Then by using spatial joint option tools in GIS software, number of individuals in a grid cell were recorded as the population of that grid cell (P_I). From the centroid of each grid cell a circle with a radius of mobility was drawn (Euclidean distance) and the number of individuals in each area was recorded ($P_{im} = A_I$). At the end by applying equation 2, the average daily individuals' accessibility to other individuals was computed (A_T). This process was applied for years 1990, 1995, 2000, 2005 and 2008 and the results were stored in Excel file. The table of results consisted of the population, average daily mobility and average daily individuals' accessibility in corresponding years. Another table created to indicates the amount of changes between aforementioned periods. The results of this computation provided information about changes in average individuals' accessibility to other individuals and population redistribution trend at the national level. It should be mentioned, in order to compute the individuals' accessibility by using road networks, there is a need to have local road networks. Therefore, due to the lack of having local road network, the individuals' accessibility was computed by using Euclidean distance. Although Euclidean distance underestimates network travel distance, but it can be considered as an important source of information in individuals' distance judgments regard to destination choice (Raghubir and Krishna, 1996). Also, Apparicio et al. (2008) argued that Euclidean distance is highly correlated to shortest travel distance through the road network in metropolitan areas. It was stated that the relationship between Euclidean distance and travel distance depends on the properties of road networks in an area, but using Euclidean distance provides no major problem for comparability (Haugen et al., 2012).

3.5.3 Accessibility and daily mobility measurement at municipality level

To measure average daily individuals' accessibility at municipality level in Dalarna County, the same equation 1 to 3 was applied. The differences were that the size of grid cells was decreased to 2×2 km as the size of study area decreased. Average daily mobility was computed by using longitudinal home locations and work locations, instead of using the aggregated data. As it was explained in data presentation section, each population dataset included individuals' coordinates related to their residential and work locations with the unique ID. So by having the aforementioned information and using national road networks, it was feasible to find the shortest path respecting to travel time from residential location to work location, individually. At first, this process was carried out by extracting individuals who lived at municipalities in Dalarna County and then the residences of each municipality investigated separately.

In order to measure the length and travel time through the shortest path from home to workplace locations individually, a new column added to the new dataset. This column gave each individual a unique code that linked a person's home to his/her workplace. Even though this type of code with the same function (linking home to the workplace) has already existed in the dataset, but in GIS software (ArcMap), the existed code had no function, therefore, RoutName column was created. At this stage, the population of a municipality was imported to the map by using residential coordinates and then the same population was added to the map by using their workplace coordinates. By using different coordinates, residential location and workplace location were added to municipality map in two different layers. In doing so, the shortest path from dwellers' residential location and workplace respect to travel time were identified individually. By this approach, the travel time and travel distance for each individual from home to work were computed and stored. The average of these distances was calculated and recorded as the average daily mobility of that specific municipality for a specific year. This process was applied for all municipalities in different years in Dalarna County. As it was mentioned before, this part of study covered years 1996, 2004 and 2008.

Average daily individuals' accessibility of each municipality was computed by applying average daily mobility of that municipality. The same approach of measurement at was used for entire municipalities in Dalarna County for years 1996, 2004 and 2008.

3.5.4 Intra-travel time measurement at municipality level

Average intra-travel time measurement for each municipality carried out by using residential locations and the road networks of that municipality. As it was mentioned previously, it was necessary to keep the locations of origin and destination constant, in order to compute the changes in average intra-travel time as result of changes in road networks. Therefore the residential locations in 1996 were assumed as origin and destination points. Then the average intra-travel time in each municipality was computed by using its' population in 1996 (as the origin and destination points) and the road networks corresponding to aforementioned years. Then the origin and destination points were remained unchanged and the road networks were changed to compute the average intra-travel time for each period. By applying origin-destination cost matrix, the costs of going from a set of origin locations (residential location) to set of destination locations (residential location) were computed. This cost was considered as a travel time in this study. In order to measure the travel time of every possible route in the municipality, dwellers in that municipality were considered as the origin and destination points. Then the travel time that takes for individual i to reach other individuals in that municipality was computed. The same approach was applied for entire dwellers in that municipality individually. So if a municipality has N residences, then average intra-travel time and the total number of routs that was computed is as follows:

$$T_m = (\sum_{i}^{N}\sum_{j}^{N} d_{ij})/n) \qquad (4)$$

$$n = \{N \big| d_{ij} > 0\} \qquad (5)$$

$$NR = N^2 - N \qquad (6)$$

$$\Delta T = \frac{T_{m_2}}{T_{m_1}} \qquad (7)$$

$d_{ij} =$ Distance in travel time from i to j

$n =$ Number of individuals (exclude themselves)

$T_m =$ Average intra-travel time in a municipality

$NR =$ Total number of routs for average intra-travel time computation

$\Delta T =$ Average intra-travel time changes

For instance, to compute the average intra-travel time of a municipality with 3000 residences, the travel time of 8,997,000 routs have been measured. For finding average intra-travel time, each municipality was considered separately and the residential locations of its population in 1996 were used as the origin and destination points. The road networks were changed for each period of time and the same approach was followed to compute average intra-travel time. It should be mentioned that average intra-travel time was computed without considering the degree of traffic congestion as a lack of available information. Hence the result for this variable might have some flaws.

3.5.5 Job opportunity and population measurement at municipality level

Other variables that were used in the analysis were changes in population and number of job opportunities in municipalities in Dalarna County. Population datasets were provided information regarding individuals' home locations with corresponding municipality's code. However, the municipalities' code were changed over the time, therefore it was not feasible code to be used. Instead, individuals were assigned to the municipalities by using their coordinates of residential locations spatially. This approach was applied for each period of study and then the changes in population for each municipality were computed as follow:

$$\Delta P = \left(\frac{P_{t_2}}{P_{t_1}}\right) \qquad (8)$$

P_{t_2} = Population in a municipality at year 2

P_{t_1} = Population in a municipality at year 1

ΔP = Change in population in a municipality

The number of job opportunities in the municipalities was computed by using combinations of workplace locations and individuals' information regarding their workplaces. This means that each workplace was assigned to its' correspond municipality by using the work coordinates. Then the number of individuals, which were working in that workplace, was counted by using the unique codes that linked each individual to his/her workplace. In this way, instead of counting the numbers of companies located in a municipality, the numbers of workers in each workplace were counted, aggregated and considered as the total number of job opportunities for a specific municipality. In another words, the number of job opportunities in a municipality was computed as the total number of workers in a municipality. This process was applied for municipalities of each year. It should be noted that this approach is not without flaw as the type of job opportunity and the level of education of individuals were not considered. But according to the available information, it can be argued that this approach was the only possible way to estimate the level of job opportunities in municipalities. For computing changes in the number of jobs in a municipality the following equation was used:

$$\Delta w = \frac{w_{t_2}}{w_{t_1}} \qquad (9)$$

$\Delta w =$ Change in job opportunities in a municipality

$w_{t_1} =$ Number of job opportunity at year 1

$w_{t_2} =$ Number of job opportunities at year 2

3.6 Data quality and expected limitation

When data is collected from the relevant resources using relevant methods then, the quality of quantitative data is reliable and valid (Denscombe, 2010). According to Veal (2006), reliability can be described as "the extent to which research findings would be the same if the research were to be repeated at a later date, or with a different sample of subjects" (p. 41). On the other hand as Denscombe (2010) stated, validity concerns the accuracy of the data or the precision of the measurement.

The author of this research ensured the reliability and validity of this paper by numerous ways. To ensure the reliability the author of this thesis defined appropriate equations, research population, and samples suitable for the purpose of this study. As it was mentioned in the previous section (3.2) the entire Swedish workforce population was selected as research population. Then by applying purposive sample selection method, Dalarna County was chosen as the study area for the second research question. The applied formulas and equations were extracted from the previous empirical studies. Moreover, the reliability was ensured by using appropriate methods for the data screening, variables computations and analysis.

3.7 Ethics and other consideration

According to Saunders et al., (2012) research can be influenced by both moral and ethical issues. Hence, the researcher should take such aspects into consideration when conducting the research. For the purpose of this study, the data were collected through Högskolan Dalarna University from; Official Statistic of Sweden (SCB), Swedish Road Administration (NVDB) and Swedish

National Transportation Survey. These data were given to the researcher by experts' supervisors at Dalarna University with the knowledge that they can be accessed by the researcher. Therefore, It was not necessity to request permission from Official Statistic of Sweden (SCB), Swedish Road Administration (NVDB) and Swedish National Transportation Survey before processing the data in this research. It can further be pointed out that the data were provided for academic research purpose.

4. Results and findings

This section is consisted of descriptive statistics and statistical analysis. The results of computation of variables are presented in form of bar charts and tables. Each research question is answered and analyzed separately. The concluded results are summarized at the end of each subsection.

4.1 Average daily individuals' accessibility to other individuals within 1990 to 2008

To accomplish the purpose, two research questions were followed. As mentioned previously, the first research question was defined as follows:

- Did average daily individuals' accessibility to other individuals within their daily mobility increase or decrease in Sweden between 1990 and 2008?

The answer of this question provided information regarding changes in; average daily mobility, population, population redistribution, and average daily individuals' accessibility at the national level. This question was answered by applying equations 1 to 3, using GIS software tools and computing average individuals' daily mobility. At the national level, average individuals' daily mobility was computed by using aggregated mobility data. The results are displayed in the following Figure:

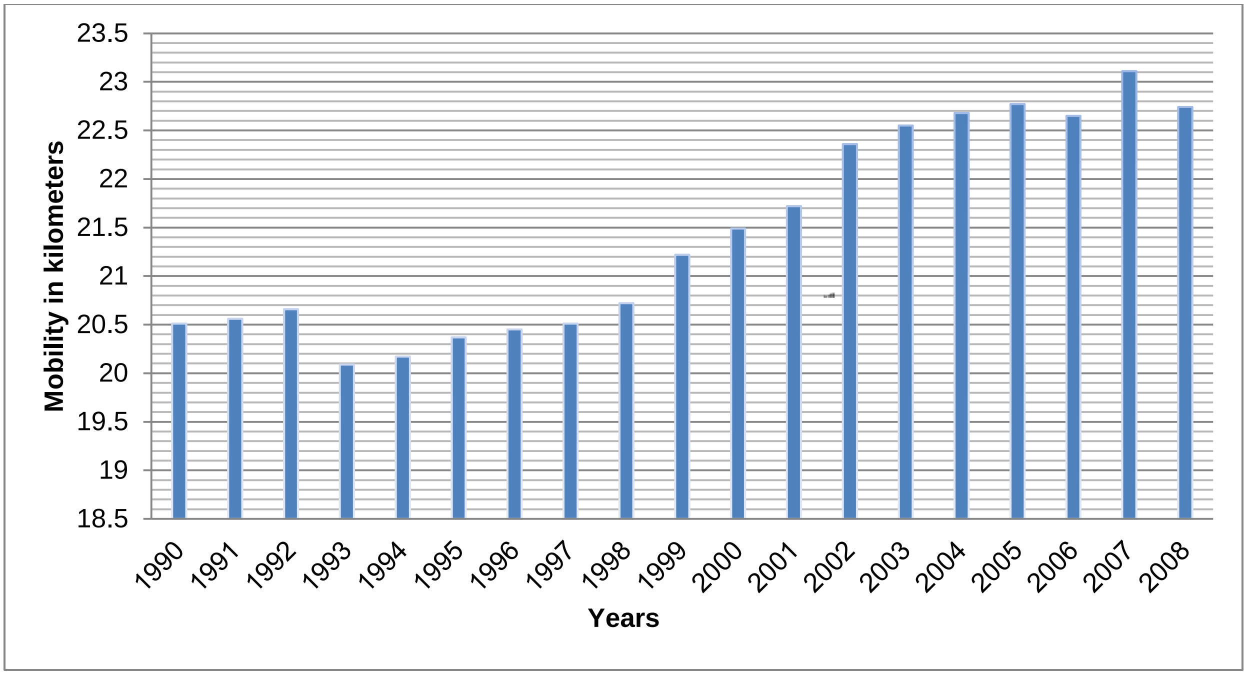

Figure 1 Average daily individuals' mobility (Kilometers)

As it is shown in Figure 1, the average daily mobility had the incremental trend from 1990 to 2008. Even though in some years the daily mobility was decreased, but, the trend increased overall. To compute accessibility at the national level, years 1990, 1995, 2000, 2005, and 2008 were selected. The average daily mobility in these years was; 20.51, 20.37, 21.49, 22.77, and 22.47 kilometers per person respectively. The main increase in the average daily mobility seems to be occurred from 1993 to 2005. The average daily mobility was 20.09 kilometers in 1993 and it was increased to 22.77 kilometers in 2005.

To compute the individuals' accessibility, the entire Sweden's area was divided into 5×5 kilometers grid cells. The total number of grid cells and also grid cells containing dwellers are extracted and displayed in a form of Table as follows:

Table 2 Sweden in grid cells

Year	Sweden's number of grid cells(5x5km)	Number of grid cells with population	Percent of grid cell with population in Sweden	Average population in grid cells
1990	18,727	12,242	65.4	389
1995	18,727	12,082	64.5	401
2000	18,727	12,047	64.3	418
2005	18,727	11,758	62.8	451
2008	18,727	11,653	62.2	464

By creating build-up unit areas, Sweden was made up of 18,727 divisions. The results in the Table 2 show that the numbers of grid cells containing the population decreased over these years, and the average population in each grid cells increased. The Sweden’s population was distributed in 65.4 percent of grid cells in 1990. The population was distributed in 64.5 percent of grid cells in 1995, and 64.3 percent of grid cells were filled by crowds in 2000. The total number of grid cells that contain the population decreased to 11,758 in 2005 which was 62.8 percent of the entire Sweden’s grid cells that year. This trend was continued as the total number of grid cells with residences decreased to 11,653 in the year 2008. The total number of grid cells containing the population was 62.2 percent of the total number of grid cells in 2008. It is concluded that the population redistribution had a concentration trend in Sweden in aforementioned years. Based on the results in Table 2, it seems that the trend of population concentration was more within the years 2000 to 2005 compared to other periods. In overall, based on the above-mentioned results, it could be concluded that the average daily mobility and the population concentration were increased since 1990.

The individuals’ accessibility computation was followed by using the grid cells containing the population and the average daily mobility. From the grid cells’ centroids, circles with the radius of average daily mobility were drawn and the number of individuals in each circle was counted and assigned to the corresponded grid cell (equation 1). Then by applying the equation 2, the average daily individuals' accessibility was computed. The results are recorded in the following Table:

Table 3 Average daily individuals' accessibility

Year	Swedish Workforce Population(20-64)	Average daily mobility (km)	Average daily accessibility (No. of individuals)	Average daily accessibility in percentage
1990	4,699,856	20.51	166,536	3.54
1995	4,789,564	20.37	174,650	3.65
2000	5,035,513	21.49	210,005	4.17
2005	5,227,682	22.77	246,646	4,72
2008	5,411,349	22.74	259,194	4.80

The first column in Table 3 indicates the studied years and the second column shows the number of the workforce population in Sweden in the corresponding years. The third column is related to the average daily mobility in kilometers and the fourth column indicates the number of individuals that can be reached within the average daily mobility. The last column showed the average daily individuals’ accessibility in percentage.

The results showed that on average, 3.5 percent of the population was reachable within the average daily mobility in 1990. The average daily individual’s accessibility to other individuals increased to 174,650 which mean 3.65 percent of workforce population in 1995. The results in Table 3 indicate that the average daily mobility within 1990 to 1995 decreased slightly, while it was found that the population increased; which concluded in increasing the daily individuals’ accessibility. The average daily individuals' accessibility increased to 210,005 which were 4.17 percent of the total population, in the year 2000. The average daily mobility was 21.49 kilometers which increased by 1.12 kilometers compare to 1995.

The average number of individuals that could be reached increased to 246,646 in 2005. Almost 4.72 percent of the population in this year was reachable and the average daily mobility increased by 1.26 kilometers compare to 2000. The results indicate that within the years 2000 to 2005, the average individuals' accessibility increased. According to the findings in Table 2, the number of grid cells containing the population decreased more in this period compare to other periods.

In the year 2008, the average daily individuals' accessibility to other individuals was increased to 259,194. The average daily mobility compared to 2005 decreased slightly but the total population was increased. On average, 4.80 percent of the total population was accessible within the average daily mobility in 2008. In the following Table 4 the changes in; the average daily individuals' accessibility, population, and the average daily mobility are shown:

Table 4 Accessibility changes ratio

Periods	Population growth(20-64) ratio	Mobility change ratio	Daily accessibility change ratio
1990-1995 (1)	1.02	0.99	1.05
1995-2000 (2)	1.05	1.05	1.20
2000-2005 (3)	1.04	1.06	1.17
2005-2008 (4)	1.04	0.99	1.05
1990-2008	1.15	1.11	1.56

The first column in Table 4 shows the different period of time in years and the second column is related to the population growth ratio in corresponding to that period. The third column indicates the changes in the average daily mobility and the last column provides information regarding changes in the average daily individuals' accessibility to others.

The results displayed in Table 4 indicate, that the average daily individuals' accessibility was increased in each period. In the first period (1990-1995), the average daily mobility decreased slightly (1%). Meanwhile, the population growth increased by 2 percent and the average daily accessibility increased by 5 percent. Within the years 1995 to 2000, the population and the daily mobility both increased by 5 percent. The average daily individuals' accessibility grew by 20 percent. The increment in both population and daily mobility seems to have positive effects on accessibility growth ratio. In the third period (2000-2005), the population growth ratio was 1.04 and the average daily mobility increased by 6 percent. The daily accessibility increased by 17 percent within the years 2000 to 2005. Further, the daily mobility in the third period increased by 1 percent compare to the second period, and the population growth ratio was decreased by 1 percent. The daily accessibility in the corresponding period was 3 percent less than period 2. By comparing the third and fourth periods, it was noticed that the population increased with the same ratios but the daily mobility decreased by 7 percent. The daily accessibility was reduced by 12 percent in the fourth period compared to the third period.

Moreover, the results showed that the daily individuals' accessibility during 1995 to 2000 was grown more compare to other periods. In the first period (1990-1995), the daily accessibility growth ratio was less than other periods. All in all, the population increased by 15 percent and the daily mobility increased by 11 percent at the national level since 1990 to 2008. The average daily individuals' accessibility to other individuals increased by 56 percent in Sweden between 1990 and 2008.

The results showed that the average daily individuals' accessibility to other individuals increased, however it is shown in the map (see Appendix 2), that the trend of changes in the daily individuals' accessibility varies in different parts of Sweden. Therefore, in order to have deeper investigation in the changes in the average daily individuals' accessibility, the outliers was detected and removed from the analysis. The findings showed that the municipalities in Stockholm County had much greater daily accessibility compared to other municipalities in Sweden. Almost 20 percent of total research population belonged to the aforementioned municipalities. In the following Table 5 the results of the average individuals' accessibility without considering the outliers is shown:

Table 5 Average daily individuals' accessibility excluding Stockholm County

Year	Swedish Workforce Population(20-64)	Average daily mobility (km)	Average daily accessibility (No.of individuals)	Average daily accessibility in percentage
1990	3,759,885	20.51	59,153	1.6
1995	3,831,651	20.37	60,031	1.6
2000	4,028,410	21.49	68,069	1.7
2005	4,182,146	22.77	80,536	1.9
2008	4,329,079	22.74	83,887	1.9

The results in the above table showed that by ignoring the municipalities in Stockholm County, the average daily individuals' accessibility changed. According to the findings in the Table 5, the average daily individuals' accessibility was 59,153 in 1990. The result in year 1995 showed that on average, 1.6 percent of population was reachable. The average daily individuals' accessibility increased to 68,069 which mean on average, 1.7 percent of population was accessible in 2000. In year 2005 and 2008, the average daily individuals' accessibility increased to 80,536 and 83,887, respectively. In the following table, the average daily individuals' accessibility of Sweden with and without Stockholm County is presented:

Table 6 Average daily individuals' accessibility comparison

Year	Average daily individuals' accessibility in Sweden (Incl. Stockholm County)	Average daily individuals' accessibility in Sweden (Excl. Stockholm County)	Average daily individuals' accessibility in Stockholm County
1990	166,536	59,153	107,383
1995	174,650	60,031	114,619
2000	210,005	68,069	141,936
2005	246,646	80,536	166,110
2008	259,194	83,887	175,307

According to the results in Table 6, it can be concluded that the average daily individuals' accessibility for 20 percent of population who lived in Stockholm County was almost 2 times greater than other 80 percent of population who lived in other counties in Sweden.

In the following table, the result of changes in average daily individuals' accessibility in Sweden without the outliers and Stockholm County are illustrated:

Table 7 Average daily accessibility changes ratio

Periods	Av. daily accessibility changes in Sweden Excl. Stockholm County	Av. daily accessibility changes in Stockholm County
1990-1995 (1)	1.01	1.07
1995-2000 (2)	1.13	1.24
2000-2005 (3)	1.18	1.17
2005-2008 (4)	1.04	1.06
1990-2008	1.42	1.63

The results in the Table 7 indicate that the average daily individuals' accessibility to other individuals increased in Sweden between 1990 and 2008. Although after removing the outliers the changes decreased, but in overall the changes had an incremental trend. In the first period (1990-1995), the average daily individuals' accessibility increased by 1% and by comparing column 2 and 3 in the Table 7, it can be concluded that the changes in the average daily accessibility in Stockholm County were greater than the other parts of Sweden. From 1995 to 2000, the average daily individuals' accessibility without considering the outliers increased by 13%. By comparing the results of changes in the accessibility, this can be realized that changes in Stockholm County were 11% greater. In the third period (2000-2005), the average daily individuals' accessibility increased by 18%. The findings of this period showed that the incremental changes in other parts of Sweden were 1% greater than the changes in the municipalities in Stockholm County (outliers). The average daily individuals' accessibility increased by 4% between 2005 and 2008.

In overall, the results of changes showed that the average daily individuals' accessibility increased by 42% in Sweden from 1990 to 2008. Also by comparing the results of changes in daily accessibility in the Table 7, it can be concluded that the incremental changes were 21% greater in the municipalities in Stockholm County compare to other municipalities in Sweden.

The below table presents the amount of changes in the average daily individuals' accessibility in Sweden and Stockholm County as follows:

Table 8 Average daily individuals' accessibility changes in Sweden with and without Stockholm County

Periods	Av. daily accessibility changes in Sweden Incl. Stockholm County (No. of individuals)	Av. daily accessibility changes in Sweden Excl. Stockholm County (No. of individuals)	Av. daily accessibility changes in Stockholm County (No. of individuals)
1990-1995 (1)	8,114	878	7,236
1995-2000 (2)	35,355	8,038	27,317
2000-2005 (3)	36,641	12,467	24,174
2005-2008 (4)	12,548	3,351	9,197
1990-2008	92,658	24,734	67,924

According to the findings in the above table, almost 89% of incremental changes were belonged to the municipalities in Stockholm County between the years 1990 and 1995. The results showed that 11% of changes were related to other parts of Sweden in the first period. In the second period the 23% of total changes were occurred in the entire Sweden excluding Stockholm County. 77% of incremental changes were related to Stockholm County between the years 1995 and 2000. From 2000 to 2005, the average daily individuals' accessibility in Sweden excluding Stockholm County increased by almost 18% which means 34% of total changes. This shows that the average daily individuals' accessibility was improved compare to the last two periods. In the third period, 66% of total accessibility's improvements were related to Stockholm County. 73 and 27 percent of the changes were related to Stockholm County and other counties respectively in the fourth period. In overall, since 1990 to 2008, the average daily accessibility increased by 56% (Table 4) which 73 and 27 percent of the changes were happened in Stockholm County and other counties respectively.

Although that it seems to be a relationship between the changes in; the daily accessibility, population growth ratio, and the daily mobility, but it was not possible to make any conclusion based on the above tables statistically, due to the few number of observations. Therefore, the population growth ratio and the changes in; the average daily mobility, number of job opportunities, and average intra-travel time were investigated statistically by taking a sample in the second research question.

To summarize, based on the findings, it is concluded that the average daily individuals' accessibility to other individuals increased in Sweden within 1990 to 2008. The results showed that the incremental trend was different in each period. The increment of the average daily individuals' accessibility from 1990 to 1995 was the lowest. The average daily mobility increased the most within the years 2000 to 2005 and the maximum of population growth ratio was in the years 1995 to 2000. In overall, since 1990 to 2008, the Swedish workforce population increased by 15 percent, the average daily mobility increased by 11 percent and the daily individuals' accessibility increased by 56 and 42 percent with outliers and without outliers (80% of research population), respectively. Also, the outcomes showed that at the national level, the number of grid cells with dwellers was decreased. This implied the population redistribution trend moved toward concentration from 1990 to 2008. Meanwhile, it should be noted that the results were in average; therefore it couldn't be applied equally to all individuals.

4.2 Impact of change in intra-travel time on the change on individuals' accessibility

The second research question and the hypothesis were defined as follows:

- To what extent did changes in average intra-travel time have an impact on the changes in average daily individuals' accessibility to other individuals at municipality level in Dalarna County between 1996 and 2008?
- H1: Changes in average daily individuals' accessibility is negatively related to the changes in average intra-travel time.

In order to answer the above research question and test the hypothesis, the changes in the following items were computed at municipalities in Dalarna County; the average daily individual's accessibility to other individuals by using grid cell method (2×2 km), the average daily mobility by using residential and workplace longitudinal dataset and the national road networks, the population, the number of job opportunities, and the average intra-travel time. In the following subsections, the mentioned items are presented and discussed.

4.2.1 Population redistribution trend

The Table 5 indicates the number of grid cells that contain the population in each municipality in Dalarna County. The last column represents the total number of grid cells that formed the municipality. The last row shows the total number of grid cell with population and the total number of the grid cell formed the entire Dalarna County.

Table 9 Municipalities in grid cells (2x2 km)

Name	Grid cells with population(1996)	Grid cells with population(2004)	Grid cells with population(2008)	Total grid cells
Vansbro	124	112	94	564
Malung	219	205	181	1256
Gagnef	120	97	80	311
Leksand	189	184	156	460
Rättvik	144	125	115	637
Orsa	86	78	70	520
Älvdalen	203	184	170	1966
Smedjebacken	140	160	164	362
Mora	213	185	167	672
Falun	308	294	278	634
Borlänge	151	151	146	180
Säter	151	148	145	183
Hedemora	168	167	167	263
Avesta	129	152	153	183
Ludvika	198	210	204	406
Dalarna County	2543	2452	2290	8597

In contrast of the grid cells' analysis at the national level, decreasing in the number of grid cells containing the population do not imply that the population redistribution was concentrated at the municipality level. The reduction in the number of grid cells might be because of the population decrement. In order to investigate the trend of population redistribution, the population change ratio was divided by the grid cells (with population) change ratio. In the following Table, the degree of population redistribution in the different periods of time is presented:

Table 10 Population redistribution trend

Name	**Average population in grid cells in 1996**	**Average population in grid cells in 2004**	**Average population in grid cells in 2008**	**population redistribution's ratio (96-04)**	**population redistribution's ratio (04-08)**
Vansbro	32	35	40	1.07	1.15
Malung	29	29	32	1.01	1.11
Gagnef	46	57	69	1.24	1.22
Leksand	43	46	53	1.07	1.15
Rättvik	39	46	50	1.17	1.09
Orsa	44	49	54	1.11	1.12
Älvdalen	21	22	23	1.06	1.05
Smedjebacken	49	39	37	0.80	0.95
Mora	54	61	68	1.15	1.10
Falun	98	108	115	1.10	1.06
Borlänge	176	182	191	1.03	1.05
Säter	42	42	43	1.00	1.02
Hedemora	54	51	51	0.95	1.00
Avesta	97	83	81	0.85	0.98
Ludvika	75	68	69	0.91	1.02
Dalarna County	**61**	**64**	**68**	**1.03**	**1.07**

In Table 6, the first three columns showed the average population in grid cells in years 1996, 2004 and 2008. The last two columns are related to the population redistribution from 1996 to 2004, and from 2004 to 2008. The results showed that in some of the municipalities, the population distribution moved toward dispersion such as Smedjebacken, Hedemora, Avesta and

Ludvika within the years 1996 to 2004. But on average, the population redistribution had a concentration trend as its ratio was increased by 3 percent at Dalarna Country. Within the years 2004 to 2008, in some of the municipalities, the population was distributed toward dispersion, such as Smedjebacken and Avesta. The number of grid cells increased during the mentioned period and meanwhile their population was decreased. In overall, the average population distribution in Dalarna County moved toward concentration as the population redistribution ratio was increased by 7 percent within 2004 to 2008.

4.2.2 Change in average daily mobility at municipalities in Dalarna County

In order to measure the average daily individuals' accessibility at the municipality level, the average daily mobility in each municipality was computed. For this purpose, as it was explained before, longitudinal data regarding the workplaces, home locations of each dweller, and the national road networks were used. The outcomes showed that there were no unique increment or decrement trends within 1996 to 2008. In the following graph the average daily mobility in the municipalities in Dalarna County are illustrated:

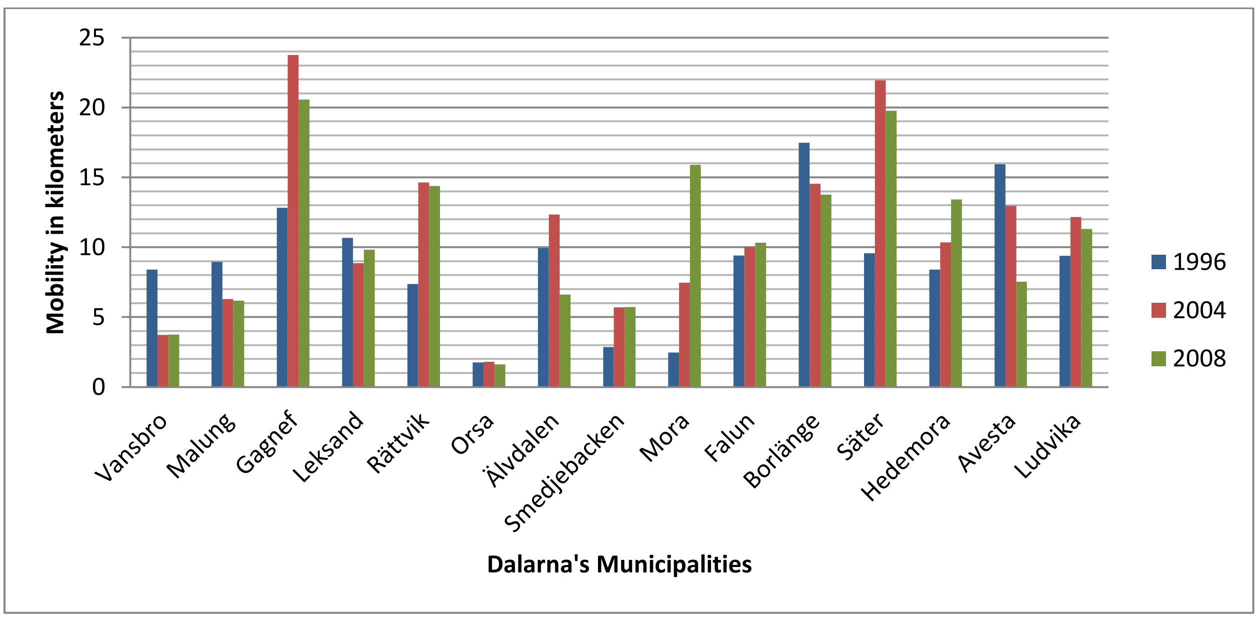

Figure 2 Changes in the average daily mobility at municipalities

The results showed that the changes in average daily mobility for each municipality were different from other municipalities. Some of the municipalities had the incremental trends such as Mora, Hedemora and Falun. In some, the trend of the changes in average daily mobility was decreasing such as Borlänge, Avesta. In some other municipalities, the trends of changes were periodic such as Gagnef, Älvdalen and Leksand. In 1996 the average daily mobility in municipalities in Dalarna County was approximately 10.35 kilometers. The approximate average daily mobility in 2004 and 2008 were 11.52 and 11.44 respectively.

4.2.3 Population change at municipalities

Since the municipalities' code undergone several changes over the time, the total number of residents in each municipality was recorded spatially. The same approach was used for all municipalities in Dalarna County in the aforementioned years. The changes in the population at the municipality level are demonstrated in Figure 3:

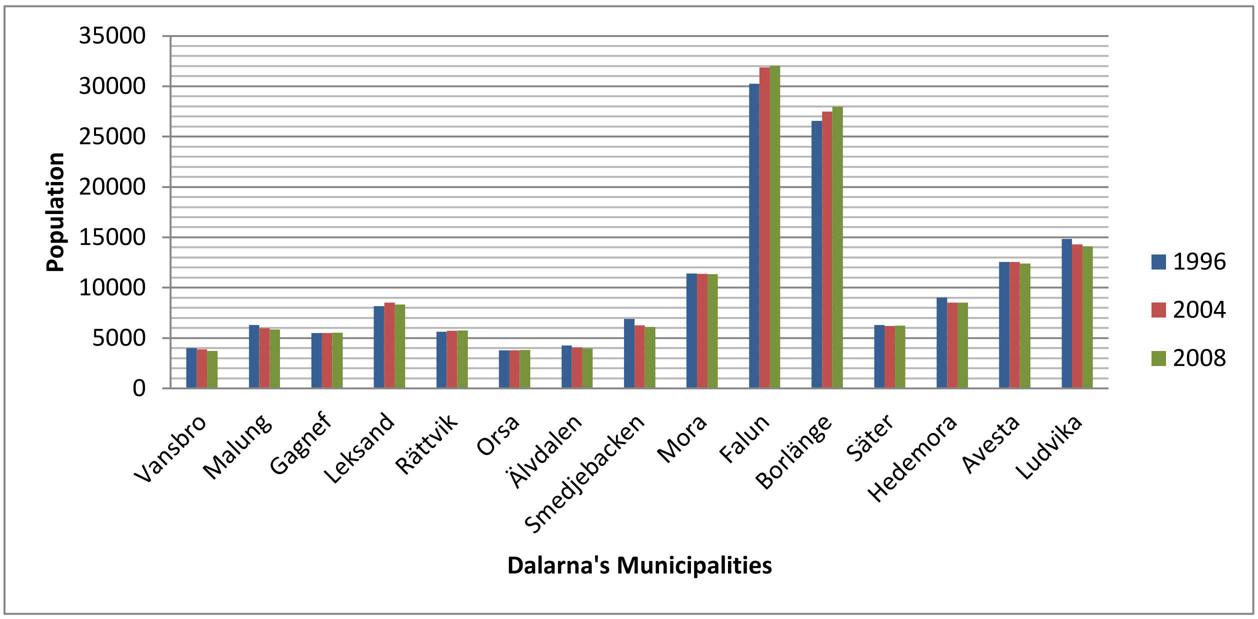

Figure 3 Population change at municipalities

It can be perceived that the population mainly increased in Falun and Borlänge compare to other municipalities from 1996 to 2008. In most, the number of individuals at municipalities decreased within 1996 to 2008. Between the years 1996 and 2004, nine out of fifteen municipalities were faced population decrement and the numbers of residents in the six municipalities were increased. Within the years 2004 to 2008, most of the municipalities had the same trend in terms of change in the population. In overall, the workforce population in Dalarna

County was increased from 155,495 to 155,995 within the years 1996 to 2004, while the number of individuals at this county were decreased to 155,643 in 2008.

4.2.4 Changes in the number of job opportunities at municipalities

As it was discussed in the method section, the numbers of job opportunities was computed by counting the numbers of individuals that work in each company. The total numbers of workers were assigned as the total number of available job opportunities in each municipality. Consequently, the changes in the total number of job opportunities were computed in each municipality. The changes in the numbers of job opportunities are presented in following figure:

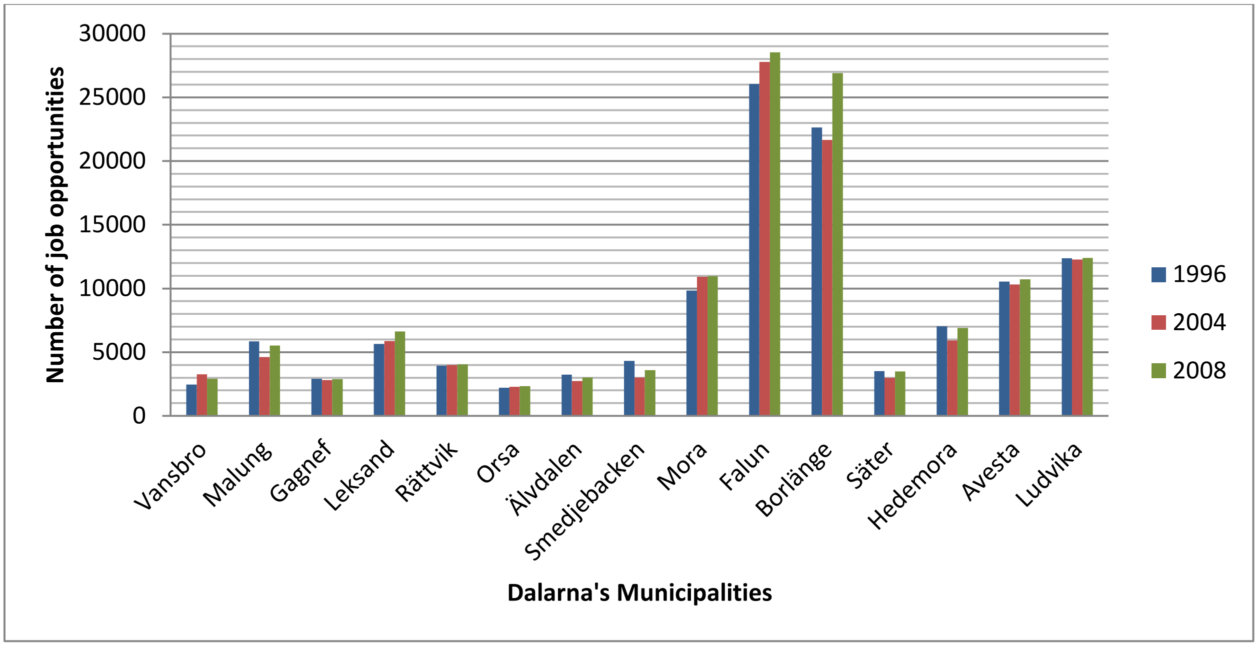

Figure 4 Changes in the number of job opportunities at municipalities

Among the municipalities, Falun and Borlänge had the highest number of opportunities in Dalarna County in the aforementioned years. As it is displayed in Figure 4, the number of job opportunities in 1994 was less than in 1996 and 2008. The number of job opportunities was increased in the six municipalities from 1996 to 2004. However, this number was grown in almost all of the municipalities from 2004 to 2008. The number of job opportunities was 122,589 in Dalarna County in 1996. This number was reduced to 120,506 in 2004 and increased to 130,899 in 2008. Furthermore, the total number of workforce population exceeded the total number of job opportunities in Dalarna County in the aforementioned years.

4.2.5 Changes in the average intra-travel time at municipalities

The method that was used to compute the average intra-travel time in each municipality relied on the average travel time for each individual to reach other people in that municipality. By applying this approach, every possible route was examined. By using GIS software the shortest path according to travel time between dwellers, was computed. As it was mentioned before, in order to investigate the changes in average intra-travel time as a result of changes in the road networks, the origin and destination points (individuals) were kept constant and only the road networks were changed in the computation procedures. As such, that population of each municipality in 1996 was used as the origin and destination points. For studying the average intra-travel time in each year, the national road networks of the corresponding year were used in the computation procedure. Consequently, for studying the next period, only the road networks were changed. Table 7 shows the number of routes that was used for computing the average intra-travel time in each municipality.

Table 11 Changes in the average intra-travel time at municipalities

Municipalities	T.T-1996 (min)	T.T-2004 (min)	T.T-2008 (min)	Number of Routs (in millions)
Vansbro	15.72	13.37	13.56	16.10818
Malung	25.67	24.53	23.3	39.7089
Gagnef	13.5	13.2	12.19	30.10168
Leksand	16.25	15.28	14.38	66.78976
Rättvik	15.93	15.14	14.3	31.80396
Orsa	7.2	6.23	6.17	14.29974
Älvdalen	42.7	40.25	40.41	18.06675
Smedjebacken	20.8	19.9	19.48	47.41011
Mora	16.67	16.3	16	130.1995
Falun	15.91	14.96	13.8	915.6979
Borlänge	23.75	7.34	8.11	706.3635
Säter	16.25	19.98	13.42	39.6963
Hedemora	16.62	21.24	14.45	81.22516
Avesta	27.93	24.55	14.08	157.6908
Ludvika	23.43	26.08	16.49	220.1514

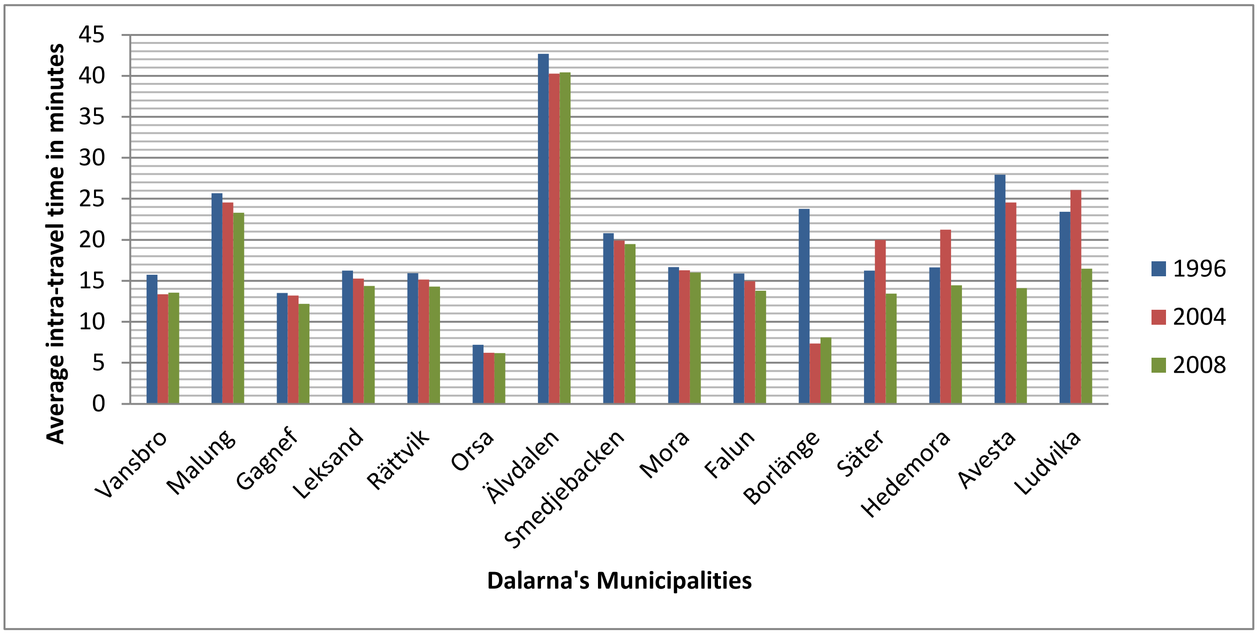

Figure 5 Changes in the average intra-travel time at municipalities

According to the Table 7 and Figure 5, the trend of changes in the average intra-travel time decreased in most of the municipalities within 1996 to 2008. As it is displayed in Figure 5, the average intra-travel time was increased in Säter, Hedemora and Ludvika from 1996 to 2004. Then the average intra-travel time in the mentioned municipalities decreased in 2008. In overall, the trend of changes in the average intra-travel time decreased in most of the municipalities in Dalarna County. The decreasing trend was intense in Borlänge from 1996 to 2004. However, in some of the municipalities such as Avesta and Ludvika, the major decreasing trend, was noted from 2004 to 2008. As mentioned previously, the degree of traffic congestion was not included in the travel time computation procedure.

4.2.6 Changes in the average daily individuals' accessibility at municipalities

As it was mentioned in section 3.5.3, to compute the average daily individuals' accessibility, each municipality was divided into the numbers of grid cells with the size of 2×2km. Then, from the center of each grid cell which contains population a circle with the radius of daily mobility was drawn. Consequently, the number of individuals in the drawn circle was counted and assigned to that grid cell and then the equation 2 was used to calculate the average daily individuals' accessibility at the municipality level. The results of the procedure are depicted as follows:

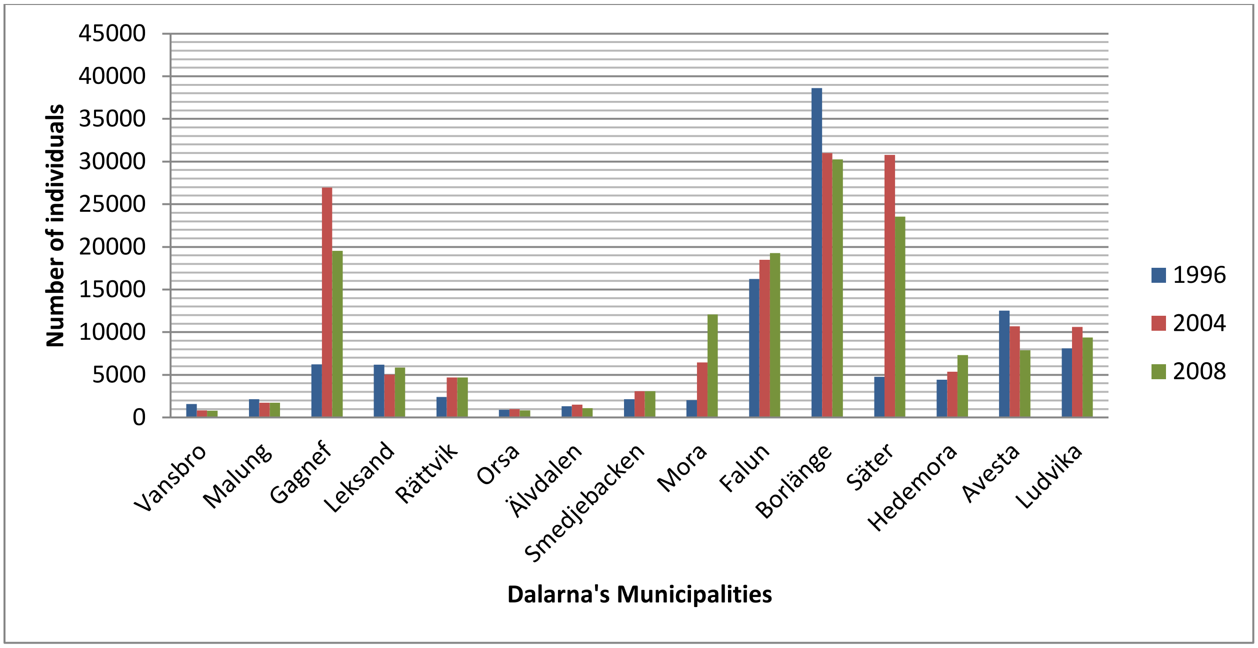

Figure 6 Changes in the average daily individuals' accessibility

According to Figure 6, the average daily individuals' accessibility was increased in ten municipalities such as Gagnef, Rättvik, Mora and Falun within 1996 to 2004. The trend of changes in the average daily individuals' accessibility was decreasing in some of the municipalities and was increasing in other municipalities. Among the municipalities, Borlänge had the maximum average daily individuals' accessibility, and Vansbro and Orsa had the minimum within these years. The average daily individuals' accessibility to other individuals was approximately 13,054, 14,733, and 14,529 in Dalarna County in 1996, 2004, and 2008 respectively. It seems that average individuals' accessibility from 2004 to 2008, decreased in Dalarna County.

4.2.7 Statistical analysis and model building

In the previous sections, the required variables for regression analysis and respond to the second research question was computed and recorded. The final dataset consisted of dependent and independent variables which are illustrated in the Appendix 3. As it was mentioned before, the multiple linear regression model was used to find out the relationship between changes in the response variable and changes in predictor variables.

The required model for statistical analysis was built through several steps and by applying different tests. At the beginning, the multicollinearity of predictor variables with 0.7 as the threshold was examined. The results of the correlation matrix showed that the correlations among independent variables were less than the threshold.

One of the limitation and difficulties in terms of modeling was the number of observations and predictors. The total numbers of observations were 30 and the numbers of predictors were 4. But in order to investigate the variables' level of significant, all predictors were kept in the model. By applying the anove test, it was found that square root of the changes in average daily mobility provides better model compared to its normal form. Further, the response variable was examined to see whether a transformation was required or not. This test was applied by the box-cox function and the result showed that the response variable transformation was required. Therefore the response variable was transformed with power -1 (inverse function).

Then the outliers were detected, and the most influential observation was removed from the dataset. By transforming the response variable, predictor variable (mobility), and also by removing one outlier, the multiple linear regression model was built as follows:

$$\frac{1}{\Delta A} = 4.112 - 0.2227 * (\Delta T) - 1.4751 * \left(\sqrt{\Delta mobility}\right) - 1.57(\Delta P) + 0.165(\Delta w) + \varepsilon \quad (10)$$

The results of the above model are presented as follows (Table 8):

Table 12 Results of the model

Predictors	Estimate ($\hat{\beta}$)	Std. Error	t value	Pr(>|t|)	Significance level
Intercept (α)	4.112	0.93	4.4268	0.00018	***
ΔT	-0.2227	0.15	-1.4892	0.1495	
$\sqrt{\Delta \text{Mobility}}$	-1.47512	0.1433	-10.295	0.000126	***
ΔP	-1.570	0.967	-1.625	0.1173	
Δw	0.1650	0.225	0.736	0.469	

As stated before, the statistical test was in 95% confidence interval with 5% critical level; therefore, variables with P-value less than 0.05 are significant and marked in the above Table 8 by asterisks. The numbers of stars in the results indicate the significance level of that variable. Three stars are considered as high significance and one star indicates low significance.

The R-squared of the above model was 0.881 with 0.13 as residual standard error on 24 degrees of freedom. According to the results in Table 8, the changes in the square root of average daily mobility ($\sqrt{\Delta \text{Mobility}}$), became as a high significant factor among others predictors with t-value of -10.30. The P-value for changes in the average daily mobility was quite smaller than 0.05, therefore, this factor is significantly related to the changes in average daily individuals' accessibility. Furthermore, the results showed that the changes in average intra-travel time (ΔT) with -1.48 as t-value and 0.14 as P-value was not significant and therefore, the hypothesis was rejected. This means that the changes in average intra-travel time had no direct impact on the changes in average daily individuals' accessibility. The changes in the population (ΔP) with t-value of -1.624 and P-value of 0.117, was not significant. The Changes in number of job opportunities (Δw) with t-value of 0.7 and P-value of 0.46 was not significant either.

The results of the statistical model implied that among the above-mentioned predictor variables, only changes in the average daily mobility play a crucial key on the changes in the average daily individuals' accessibility at municipalities in Dalarna County. In other words, one unit change in the ($\sqrt{\Delta \text{Mobility}}$) reduces the transformed response variable (ΔA^{-1}) by -1.48, when other variables remained constant. As the response variable was transformed by the inverse function, it was concluded that the negative signs of estimated coefficients imply positive effect on the normal form of response variable.

The results showed that there was no significant relationship between the changes in average intra-travel time and the changes in average daily individuals' accessibility at municipality level in Dalarna County. Also, it can be concluded that the population of the neighboring municipality could affect average daily individuals' accessibility. Thus, the changes in average daily mobility play an important role in the changes in daily individuals' accessibility compared to the effect of changes in the population.

For instance, in this study; the population of Gagnef municipality remained almost unchanged (Figure3), but its' average daily mobility increased (Figure2), and consequently its' average daily individuals' accessibility increased intensely (Figure 5). These changes were mainly because of the number of individuals at Gagnef's neighbor municipalities such as Borlänge. Furthermore, in overall, the changes in the population of municipalities were almost constant in Dalarna County but the average daily mobility changed more, which caused the changes in the daily individuals' accessibility. The changes in average intra-travel time were not a significant factor in the changes in average daily individual's' accessibility. According to the results, the main involved factor in the accessibility changes was the changes in average daily mobility. The changes in average daily mobility were dependent on the distances from home locations to the workplaces. It should be mentioned that these results could be applied only for municipalities in Dalarna County in aforementioned years.

To summarize, according to the findings, the population redistribution in most of the municipalities in Dalarna County moved toward concentrations from 1996 to 2008. Also, the average daily mobility in each municipality was varied in different years and it was different from other municipalities. At county level, the average daily mobility increased within 1996 to 2004 and slightly decreased in 2008. The results of population changes showed that in some municipalities the population decreased and in some increased. But in overall, the population in Dalarna County increased between the years 1996 and 2004 and then decreased within 2004 to 2008. The number of job opportunities varied in each municipality in Dalarna County. The number of jobs decreased between the years 1996 and 2004, however it increased in 2008 in Dalarna County. The results showed that the average intra-travel time decreased in most of the municipalities in Dalarna County. The trend of changes in the average daily individuals' accessibility fluctuated in most of the municipalities, some had decreasing trend and some had the increasing trend. In overall in Dalarna County, the changes in average daily individuals' accessibility followed an increasing trend within 1996 to 2004 which followed by a decreasing trend up to 2008. By applying a multiple linear regression model and testing the hypothesis, it was concluded that the changes in average intra-travel time had no direct impact on changes in the average daily individuals' accessibility. Moreover, the results indicated that the main influential factor in the changes in average daily individuals' accessibility was the changes in average daily individuals' mobility at municipalities in Dalarna County.

5. Conclusion

This section concludes the paper by summarizing the key findings of the data analysis, stating the limitations as well and giving recommendations for further research.

5.1 Summary of the research findings

The overall purposes of this research is *to understand how daily individuals' accessibility to other individuals has changed in the context of Sweden, and what the impact of changes in intra-travel time is on changes in daily individuals' accessibility in Dalarna County*. In order to achieve the mentioned purpose, this study sought to find answers the following research questions:

- Did average daily individuals' accessibility to other individuals within their daily mobility increase or decrease in Sweden between 1990 and 2008?

- To what extent did changes in average intra-travel time have an impact on the changes in average daily individuals' accessibility to other individuals at municipality level in Dalarna County between 1996 and 2008?

Based on the empirical findings of this study and statistical analysis the followings are concluded:

From 1990 to 2008, the accessibility to other individuals increased by 56 and 42 percent with outliers and without outliers respectively. Also, the population redistribution leaned toward the concentration. This is concluded with regard to changes in average daily individuals' accessibility in Sweden within aforementioned years. Moreover, the daily mobility and workforce population were increased by 11 and 15 percent, respectively. Next, to that, the results showed that within 2000 to 2005 the average daily individuals' accessibility to other individuals increased by 18%, which was more comparing to other periods. The results showed that daily individuals' accessibility didn't increase equally everywhere in Sweden. According to the map (see Appendix 2) in some area it increased while decreased in other areas. Also by comparing the results of changes in the average daily individuals' accessibility with respect to outliers and without outliers, it was found that 73% of incremental changes mainly occurred at municipalities in Stockholm County. Also by studying the average daily accessibility changes, it was found that the average daily individuals’ accessibility to others was improved in other parts of Sweden over the time. The results showed that the average daily individuals’ accessibility for 20% of population that lived at the capital of Sweden and its’ neighbor municipalities were almost 2 times greater than others in other parts of Sweden. This means that population concentration was greater in Stockholm County compared to other counties in Sweden between 1990 and 2008.

Based on the impact of changes in average intra-travel time on the changes in average daily individuals’ accessibility at municipality level by using Dalarna County as a sample, it is concluded, that average intra-travel time had no direct impact on change in average daily individuals accessibility. The results showed that among of different predictors, changes in average daily mobility rolled a significant factor. Lastly, it was found that the changes in the average daily mobility have a positive impact on the changes in the average daily individuals' accessibility.

All in all, this research has contributed to the general academic understanding of how daily individuals' accessibility has been changed and the impact of changes in average intra-travel time on changes in average daily individuals' accessibility in Sweden and Dalarna County respectively. Moreover, it helped to close the gap for the under-researched field of daily accessibility to other individuals in the context of Sweden.

5.2 limitations and recommendations

The research acknowledges the following limitations:

Firstly, because of the identified gap between population datasets and national road datasets, the researcher could not investigate more periods of time. This is mainly limited the number of observations used in the statistical model. Certainly, the outcome might change by having more observations. Another limitation is the fact that the road networks were related to the national roads while excluding the local roads. As the main part of this study concentrated on municipalities; hence the local road network needs to be considered and the findings by using both national and local roads might have a better outcome. Due to lack of having local road dataset, the daily individuals' accessibility was computed by using Euclidean distance instead of the road network. Lastly, the concept of population and road network changes need to be studied within a longer period of time and in the short term might be difficult to have outstanding results.

In line with the discussion and the limitation of this research the following recommendations for further research can be made:

The second part of this study (second research question) has put its focus on the Dalarna context. Therefore, it is suggested to find the further statistical analysis in other Swedish counties. In this study, the local road networks were not used in average intra-travel time computation, so future study by using local road networks could contribute to find a better estimation of average intra-travel time. A future study could also apply road network distance instead of Euclidean distance in daily individuals' accessibility computation, thus the result would more accurate. Lastly, further study on the impact of change in average travel time on average daily mobility is recommended.

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Appendices

Appendix1: population in the municipalities in Dalarna County

Table 13 Population in the municipalities in Dalarna County

Source: SCB, 2017

	1996		2004		2008		
Municipality	Total Population	Workforce Population	Total Population	Workforce Population	Total Population	Workforce Population	Areas in $Sq.km$
Vansbro	7576	4014	7122	3866	6916	3731	1539.57
Malung	11279	6302	10557	5959	10385	5853	4085.06
Gagnef	10389	5487	10091	5506	10107	5537	767.15
Leksand	15497	8173	15504	8515	15288	8336	1221.23
Rättvik	11226	5640	10864	5717	10850	5757	1920.66
Orsa	7330	3782	7031	3797	6990	3811	1730.85
Älvdalen	8153	4251	7515	4074	7287	3959	6871.51
Smedjebacken	12561	6886	10923	6258	10734	6098	947.92
Mora	20787	11411	20083	11375	20153	11336	2812.56
Falun	55005	30261	54994	31863	55297	32032	2040.13
Borlänge	48457	26578	46988	27485	48185	27954	583.87
Säter	11669	6301	10980	6203	10957	6215	570.33
Hedemora	16690	9013	15506	8531	15259	8528	835.1
Avesta	23688	12558	22102	12542	21937	12382	613.25
Ludvika	27864	14838	25782	14304	25522	14114	1490.42

Appendix2: Daily individuals' accessibility changes in Sweden

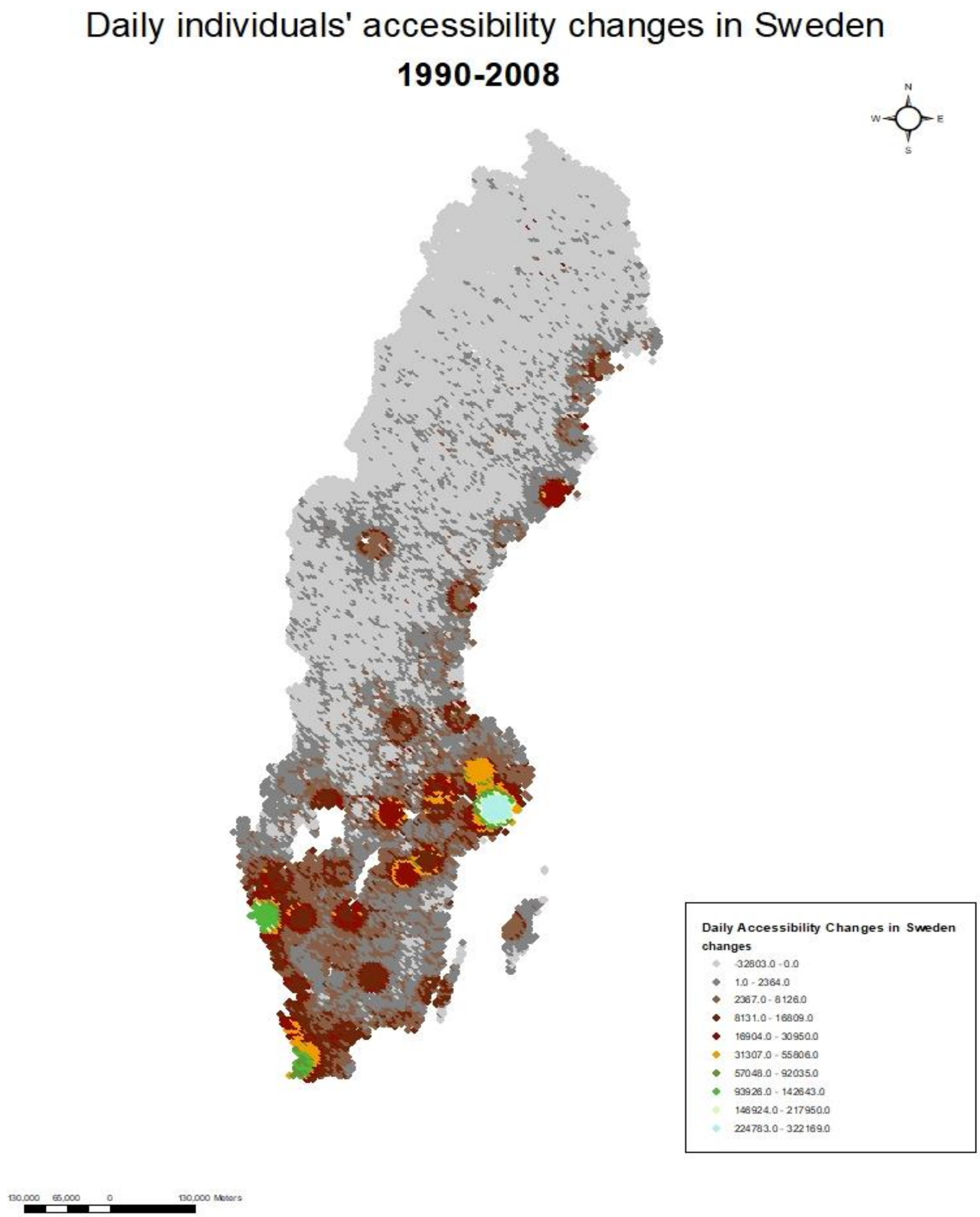

Figure 7 Daily accessibility changes in Sweden between 1990 and 2008

(Source: author creation)

Appendix3: Final dataset for statistical analysis

Table 14 Final dataset for regression model

Source: author creation

Mobility	Intratime	Accessibility	Population	Wp	kod
0.442857	0.850509	0.525272	0.963129	1.326423	2021
0.703911	0.95559	0.812237	0.945573	0.788764	2023
1.85113	0.977778	4.33012	1.003463	0.972815	2026
0.829428	0.940308	0.809731	1.041845	1.038564	2029
1.985075	0.950408	1.949188	1.013652	1.01651	2031
1.028571	0.865278	1.068928	1.003966	1.031617	2034
1.241449	0.942623	1.152042	0.958363	0.84841	2039
2	0.956731	1.438086	0.9088	0.702389	2061
3.028455	0.977804	3.149071	0.996845	1.109475	2062
1.06383	0.940289	1.139837	1.052939	1.065861	2080
0.831236	0.309053	0.803201	1.034126	0.956767	2081
2.294979	1.229538	6.458972	0.984447	0.847506	2082
1.232143	1.277978	1.210289	0.946522	0.843221	2083
0.813049	0.878983	0.85319	0.998726	0.978742	2084
1.29393	1.113103	1.314332	0.964011	0.991917	2085
1.005376	1.014211	0.980512	0.96508	0.895188	2021
0.979365	0.949857	0.985624	0.982212	1.196796	2023
0.865684	0.923485	0.725357	1.00563	1.022993	2026
1.109605	0.941099	1.166335	0.978978	1.12928	2029
0.982912	0.944518	1.00235	1.006997	1.009995	2031
0.894444	0.990369	0.843398	1.003687	1.018827	2034
0.536467	1.003975	0.728168	0.971772	1.101892	2039
1.005263	0.978894	1	0.974433	1.187913	2061
2.132886	0.981595	1.873817	0.996571	1.003021	2062
1.033	0.92246	1.040984	1.005304	1.027295	2080
0.947006	1.104905	0.975685	1.017064	1.241623	2081
0.901094	0.671672	0.765442	1.001935	1.169231	2082
1.296618	0.68032	1.36223	0.999648	1.166695	2083
0.581019	0.573523	0.736798	0.987243	1.039853	2084
0.930041	0.632285	0.882209	0.986717	1.011327	2085

Appendix4: QQplot of the model

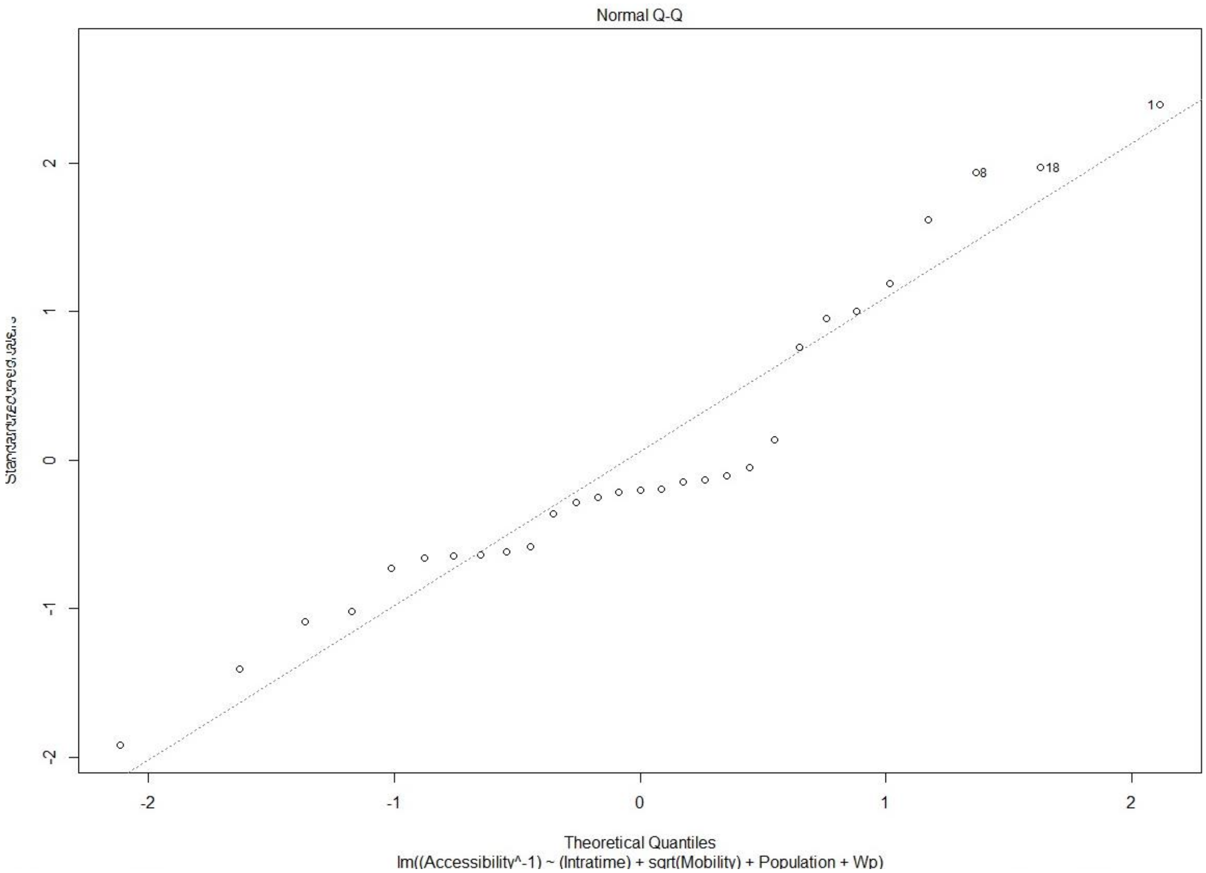

Figure 8 QQplot of the fitted model