# Measuring Modal Accessibility Gap (MAG) between Different Travel Modes: case study in Arnhem—Nijmegen City Region

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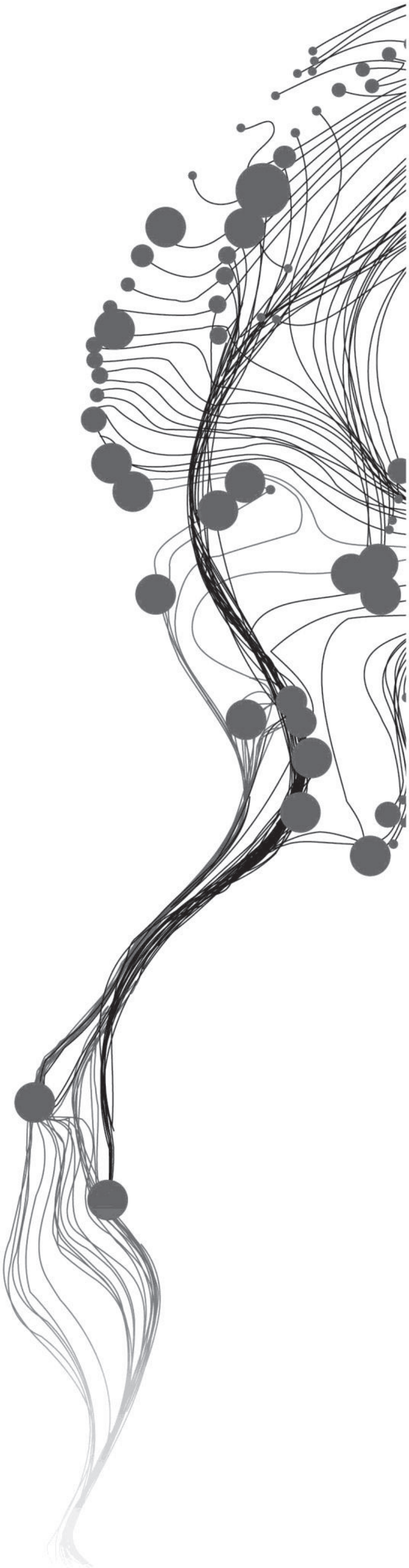

# Measuring Modal Accessibility Gap (MAG) between Different Travel Modes: case study in Arnhem—Nijmegen City Region

JIE GAO
Enschede, The Netherlands, [February, 2014]

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: [Urban planning and management]

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# ABSTRACT

With rapid urbanization and increasing individuals' income, people have a better quality life and more and more roads are possible easier access to cars. In a consequence, people are becoming more automobile dependency. However, if continue the current direction of urban transport development, it will certainly cause more problems of living environment, such as traffic congestion, air pollution, sickness for residents and so on. One solution for those is to find out alternatives that would match the accessibility of private motorized transport. In this research, the major concern is to make use of MAG (Modal Accessibility Gap) to evaluate the job accessibility gap between car and other travel modes in Arnhem Nijmegen City Region, and explore to reduce the gap for achieving more sustainable development in their transport planning.

Modal Accessibility Gap (MAG) by Kwok et al. (2004) is proposed to measure and monitor sustainable transport development by GIS. In this study, it is calculated based on two accessibility measures—contour measures and potential accessibility measures, and the travel time threshold 15-, 30-, 45-minute are examined in the contour accessibility measure. The MAG value is range between -1 and +1. The lower it is shown, the more possible for people less dependent upon the car and the city development sustainable. Firstly, the current job accessibility and MAG situations are analyzed for the study area—Arnhem Nijmegen City Region—in the Netherlands. Then, three scenarios are constructed—from the perspective of transport, land use and their hybrid— to examined their effectiveness to narrow the accessibility gap between car and the other travel modes for encouraging the use of alternative to the car and sustainable transport development.

Results show that car has the absolute advantage over other travel modes in the two job accessibility measures. The high average MAG value based on the two accessibility measures implies the gap between the reality and sustainable transport in Arnhem Nijmegen City Region. Furthermore, the average MAG value is decreasing as the travel time threshold increases for all the MAG types. It means that when the distance for job becomes longer, car would lose some advantage and other travel modes may be popular among people. The MAG between car and other travel modes is relatively low in the two job opportunity abundant areas—the Arnhem municipality and the Nijmegen municipality—and in the adequate transportation supply areas, such as the area around the railway stations or along the railway lines. These indicate the influence of land use type (or job opportunity distribution) and transport supply on the MAG value. For exploring to reduce the MAG value of the study area, scenarios analysis provides valuable information. The MAG variation is influenced not only by the distribution of job opportunity and transport supply, but also by the travel time to abundant job opportunities, and the travel time threshold. Despite the complication of detail situation, scenario 1 shows more effectiveness than scenario 2 in the MAG improvement (decrease), scenario 3, as the combination of scenario 1 and 2, shows the most significant effects. This implies that the efforts combined the transport and land use would make more achievements in the sustainable transport development.

This research provides planners and decision makers with useful information on the level of accessibility in Arnhem Nijmegen City Region by different transport modes. And then use the Modal Accessibility Gap (MAG) make the comparison car and other travel modes. The results show the relationship between urban planning and transport planning and help planners and decision makers to understand how to develop sustainable transport by using less private motorized transport.

Key words: Sustainable development, Job accessibility, Modal Accessibility Gap (MAG)

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# 1. INTRODUCTION

## 1.1. Background

Buses, bicycles, trains and cars about modern cities like blood pulsing through the body. But with urban growth comes challenges—one of them is how to improve transportation. Ideas about accessibility have been framed within the context of concerns for improving the sustainability of cities and achieving more sustainable transport outcomes (Curtis et al., 2010).

Although governments from most countries have invested in improving quality of public transport, public transport is still less than private transport in most developed countries. The significance of public transport for urban mobility in developed cities varies greatly from just over 2% of all trips in Atlanta and Los Angeles to between 26% and 31% of all trips in Barcelona, Vienna and Singapore (Kenworthy et al., 2001). What may cause this fact? The answer can be given from analyses on the accessibility level provided by both modes.

Based on the Traffic and transport survey (CBS, 2013b) shown in Figure 1, at distances up to five kilometers are people who choose the bicycle or moped almost as fast as by car. By bus, tram or metro takes a trip over this distance about twice as much time. The train is especially packed for longer distances; the average trip distance by train is 48 km and 18 km by car.

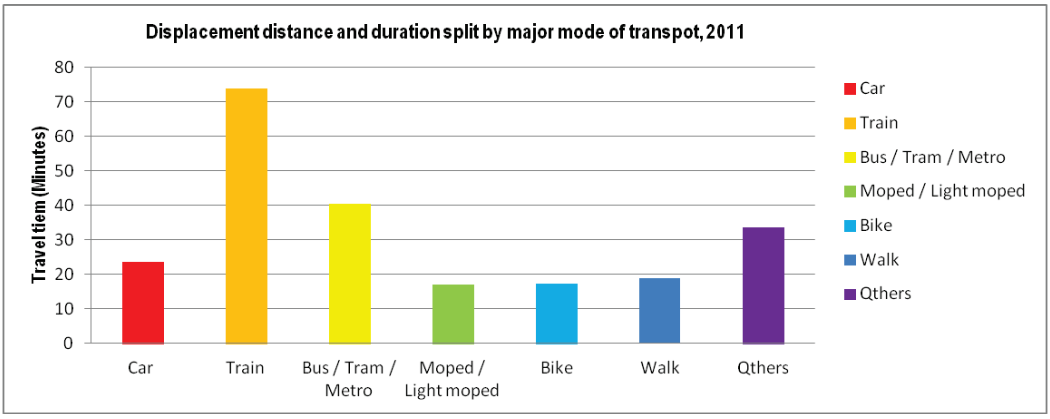



Figure 1: Displacement distance and duration split by major mode of transport, 2011 (source: CBS)

It is generally accepted that encouraging public transport over cars and promoting intensive land-use can help to maintain a more sustainable environment (Newman et al., 2006). Therefore, in order to tell whether a city's transport development is more sustainable, we can evaluate the city's land use patterns and transit system. The concept of accessibility can reflect these because decreasing the gap of accessibility between private transport and public transport means a more sustainable urban development choice. When everything is equal (i.e. the balance between car-based accessibility and transit-based accessibility), increasing the intensiveness of land-use pattern in a city means increasing the accessibility (Kwok et al., 2004).

In most Western cities, large gaps in accessibility levels pose substantial challenges for policy makers. The question can be raised as to whether the current gaps do not provide a serious barrier for transit captive to participate in the activities considered "normal" by their society, such as access to employment and essential services(Farrington et al., 2005). Moreover, the possibilities to achieve a substantial modal shift toward seem bleak as long as accessibility gaps remain so large. Modal Accessibility Gap (MAG) will be considered into addressing this problem. It is calculated by finding the difference between accessibility to opportunities such as the number of population, jobs, shops and schools by public and private transport.

The accessibility gap is calculated by finding the difference between the accessibility levels of public and private transport. These will have an impact on individuals' choice of transport mode in their daily life.

However, current studies just focus on analyzing the gap between different travel modes without further measurements for how to narrow the gap. Using scenarios based on the accessibility evaluations, development and assessment of various scenarios on the accessibility impact of different travel modes can fill this problem.

## 1.2. Justification

Accessibility is a key concept in land-use and transport policy in the Netherlands and in many other Western countries (Geurs et al., 2004). It seems that the accessibility difference between travel modes is more dependable to explain the mode choice than only one travel mode accessibility is considered (Hendricks et al., 2005; Kwok et al., 2004). This leads to the concept of Modal Accessibility Gap (MAG) (Kwok et al., 2004). MAG is used to represent the difference between the accessibility level of public transport and private transport in Kwok et al. (2004) study. To redress the car dependency for sustainable transport development, it is the important to understand the Modal Accessibility Gap. This study will evaluate the MAG between car and other travel modes based on contour accessibility measure and potential accessibility measure.

Despite some studies can be found (Geertman et al., 2003; Ludin et al., 2006) for developing scenarios for future impacts and alternatives of methods; there has been relatively few studies Kwok et al. (2004) done on the development of accessibility scenarios to strengthening of transit-based accessibility and to decrease the MAG. Therefore, for this study, the challenging and most needed includes the development of scenarios to improve public transport accessibility and to decrease the MAG between car and other travel modes. By the development of scenarios, it is easy to run various scenarios and use these results to find a reasonable interpretation method, which can help planners to develop sustainable transport and formulate schemes enhancing accessibility of public transport.

## 1.3. Research problem

Modeling approaches to support evaluation of accessibility gap are essential for continued improvement. Dealing with this issue, this study will use two different accessibility measures for measuring the different travel modes, and then calculate MAG in Kwok's model

In order to measure the accessibility gap, it should be fully aware of both the current situation and the effects and benefits of different travel modes through analyzing and visualizing different scenarios. At this point, different accessibility measure and different travel time threshold should be applied for the MAG calculation to get different perspectives on the current MAG situation. Based on the analysis of the current MAG situation, different measurements can be provided to develop scenarios. Finally using results from various scenarios planners enable to formulate schemes or polices to encourage the development of public transport.

Thus, with this argument **the research problem basically addresses two questions**: how to examine the Modal Accessibility Gap (MAG), and how to construct accessibility scenarios to decrease the MAG.

## 1.4. Research objectives and questions

### 1.4.1. Main objectives

The main objective is to evaluate the Modal Accessibility Gap (MAG) based on two different accessibility measures—contour measure and potential accessibility measure. Then construct accessibility scenarios to analyse the accessibility gap between car and other travel modes in order to to reduce the gap for achieving more sustainable development in the transport planning.

#### 1.4.2. Sub-objectives and Questions

Based on the main objective of this research, the following sub-objectives and research questions are posed:

**Sub-objective (1): to measure the accessibility levels for different travel modes and to calculate modal accessibility gap (MAG) by Kwok's model.**

1) What kind of measurement will be used to analyze the accessibility for different transport modes?
2) What method can be used to improve Kwok's model for calculating modal accessibility gap (MAG)?
3) What data are required for the analytical process for Arnhem-Nijmegen city region?

**Sub-objective (2): to analyze the implication of the current modal accessibility gap (MAG).**

1) What is the influence of the travel time threshold on the modal accessibility gap (MAG)?
2) What difference is shown in the modal accessibility gap (MAG) based on different accessibility measure?
3) What is the implication by the result of modal accessibility gap (MAG) analysis for Arnhem-Nijmegen city region?

**Sub-objective (3): to construct accessibility scenarios and assess the potential contribution of the constructed scenarios to accessibility for Arnhem-Nijmegen city region.**

1) What are the factors to be considered in qualitative description of scenario?
2) What is the result of quantitative and qualitative analysis of the constructed scenarios for their potential contribution in accessibility for city region?
3) What policies can be formulated to reduce the accessibility gap?

### 1.5. Conceptual framework

The conceptual framework, as explained below in Figure 2, has been designed to show the major components and their interactions. The mainly task for this study is to develop accessibility scenarios to encourage public transport and decrease MAG in the Arnhem Nijmegen city region. However, before developing scenarios, it needs to analyze the accessibility for different travel modes.

Thus, firstly, it focuses on the influence of accessibility on two components; land use component on characteristics and spatial distribution of activities and transport component and its characteristics such as travel time. These effects of land use and transport component ultimately have an influence on accessibility of potential population to choose the travel modes. Secondly, it tends to develop the accessibility model for different travel modes through Car-based Accessibility and Transit-based Accessibility (train, bike, and bike+train) and to compare the effects of different transport modes using Modal Accessibility Gap (MAG). Last but not the least; different scenarios are developing to evaluate each transport mode.

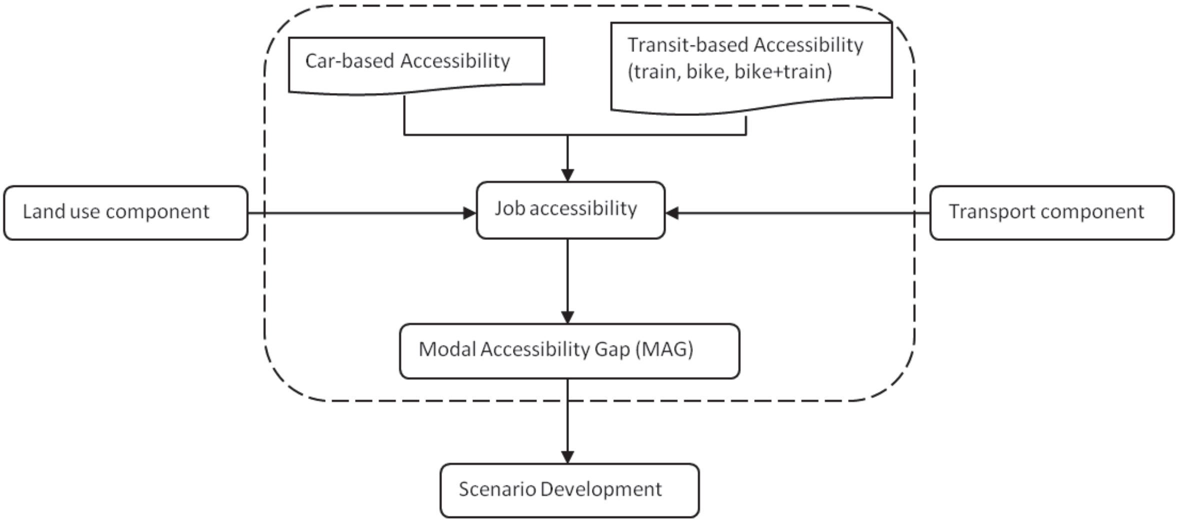


Figure 2 Conceptual framework

## 1.6. Research design and methods

### 1.6.1. Research design

The main objective is to develop scenarios for evaluate the accessibility gap. Figure 3 outlines the operational plan under which the whole study will take place. It incorporates four stages which will be introduced following. And Table 1 in research matrix outlines the methods proposed for answering specific questions under each of the sub-objective identified in previous section. The more details about the research methods and the justification of chosen method are also described below.

The first phase involves the establishment the linkage between Modal Accessibility Gap (MAG) and mode choice. These rely largely on literature review. General overview of the study area further helps in scoping and identification of data need for the further study.

The second phase is to measure the accessibility for different transport modes. Firstly, it needs to assess the existing accessibility measures. And then it tends to analyze the different transport modes based on the specific accessibility measurement. Last but not the least; calculate the Modal Accessibility Gap (MAG) by Kwok's model.

The third phase is to develop accessibility scenarios for evaluating accessibility gap between different travel modes. In this study, it will be focused on the pair wise comparison for modal accessibility gap (MAG). The different assumptions or policies for future transport and land use development could be assessed by MAG value through scenario development and modeling approach.

The development of alternative scenarios of accessibility for different travel modes (sub-objective 2) which follows sequence of steps (Mahmoud et al., 2009). The first step is the formation of qualitative description of scenario. It includes defining time horizon, driving forces such as population, existing policy measures etc., assumptions, uncertainties. The second step is scenario construction which includes the choice of model or development of model for generation of scenarios. Business as usual scenario and alternative scenarios with identified MAG are generated.

The fourth phase is the qualitative and quantitative analysis of alternative scenarios by evaluating the accessibility for different travel modes and the contribution of each alternative scenario on decreasing the accessibility gap.

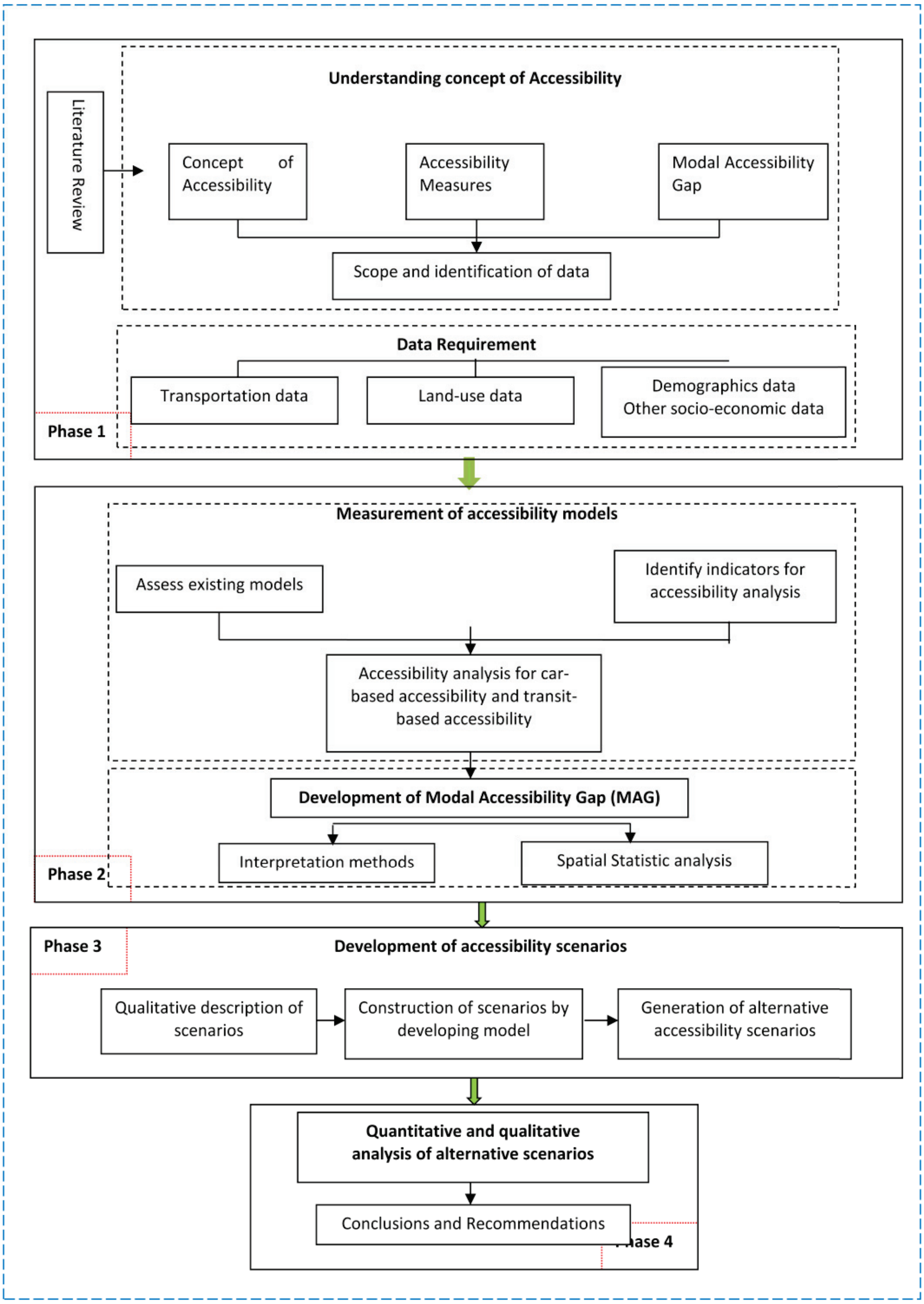


Figure 3: Research design

### 1.6.2. Research methods

The following research matrix in the Table 1 shows the research questions to meet each research sub-objectives, data required and their source, the method to be adopted.

| Research objectives | Research Questions | Data Required | Data Source | Method adopted & expected output |
|---|---|---|---|---|
| **To measure the accessibility levels for different travel modes and to calculate modal accessibility gap (MAG) by Kwok's model.** | What kind of measurement will be used to analyze the accessibility for different transport modes? | Spatial and non-spatial data, demographics data, cadastral data | Literature, secondary data | Evaluating the accessibility using different accessibility models based on available data. Using the developed model to measure accessibility of each travel mode. |
| | What method can be used to improve Kwok's model for calculating modal accessibility gap (MAG)? | Result from question 2, available data | Literature, Secondary data | Using Kwok's model showing the modal accessibility gap (MAG) between different travel modes. |
| | What data are required for the analytical process for Stadsregio Arnhem-Nijmegen (SAN)? | Available data | Literature, secondary data | Selecting proper data which is available for this study and adapt it in the MAG model. |
| **To analyze the implication of the current modal accessibility gap (MAG).** | What is the influence of the travel time threshold on the modal accessibility gap (MAG)? | MAG value, demographics data | - | Qualitative description. |
| | What difference is shown in the modal accessibility gap (MAG) based on different accessibility measure? | MAG value, demographics data | - | Qualitative description. |
| | What is the implication by the result of modal accessibility gap (MAG) analysis for SAN? | Result from previous questions | - | Analyzing the results of MAG and comparing the difference between car-based and transit-based accessibility. |
| **To construct accessibility scenarios and assess the potential contribution of the constructed scenarios to accessibility for Stadsregio Arnhem-Nijmegen (SAN).** | What are the factors to be considered in qualitative description of scenario? | Demographics data, population growth rate | Secondary data | Qualitative description of each scenario. |
| | What is the result of quantitative and qualitative analysis of the constructed scenarios for their potential contribution in accessibility for SAN? | Result from sub-objective 3 | - | Each alternative scenario is compared with the baseline scenario for the accessibility as well as to each other in terms of potential population and transit service. And qualitative analysis of each scenario regarding its contribution in decreasing accessibility gap. |
| | What policies can be formulated to reduce the accessibility gap? | Result from previous questions | - | Based on the previous analysis, it tends to interpret the results to guide policy making for reducing the MAG value. |

Table 1: Research Methods

## 1.7. Structure of thesis

This thesis comprises following chapters in following sequence:

**Chapter 1: Introduction**

This includes general introduction including background and justification, research problem, research objectives, research questions, research design and methodology and general overview of how the research aims to achieve its objectives.

**Chapter 2: Literature Review**

This includes theoretical background for the study, concepts of Accessibility, accessibility measures and the Modal Accessibility Gap (MAG).

**Chapter 3: Study area and data, methodology**

This provides the insight into the study area according to literature and includes a general description about the data used in this research. This describes the modeling framework for accessibility measures, Modal Accessibility Gap (MAG).

**Chapter 4: Accessibility analysis and Results**

The results of job accessibility levels for different travel modes based on the contour accessibility measure and potential accessibility measure will be discussed. Then the MAG value between car and other travel modes will be analyzed and the general patterns of the accessibility and the MAG will be summarized.

**Chapter 5: Scenario Development**

This includes the qualitative description of formed scenarios for decreasing accessibility gap. Then, the accessibility and MAG of different travel modes are calculated based on these scenarios. And finally the MAG variation between those scenarios and the baseline scenario are analyzed to find the proper measurement to improve the public transport and to decrease the MAG in SAN.

**Chapter 6: Conclusion and Recommendations**

This includes the summary of the findings and the methodology followed in the research as well as the recommendations on the quality of data and further research directions.

# 2. LITERATURE REVIEW

This chapter includes four parts. The first part is the definition of accessibility. Second, it reviews the general accessibility measures. And the accessibility measures used in this study will be explained details. Third, the Modal Accessibility Gap (MAG) will be detailed introduced. And finally, it shows the development of scenarios.

## 1.8. Accessibility

### 1.8.1. Definition of accessibility

The sustainable development of cities calls for the integration of transport and land use planning (Bertolini et al., 2005). Accessibility as the central concept to transportation Berechman (1981) integrated this two aspects, therefore, researches advocate the focus on accessibility instead of mobility in urban transport planning (Couclelis, 2000; Le Clercq et al., 2003; Vale). With concern of sustainable development of a city, it is generally accepted that the automobile dependency must be redressed. One fundamental problem during this is the lack of alternatives to match the quality of accessibility by automobile. Therefore, the inevitable need is to evaluate the accessibility of car and other travel modes.

Accessibility is a key concept in land-use an transport policy in the Netherlands and in many other Western countries (Geurs, 2006). A number of scientific fields have defined and operated in many different ways by many authors. Hansen (1959) defined the accessibility as the potential of opportunities for interaction. Accessibility reflects the ability to reach frequently—visited places efficiently and conveniently (Cheng et al., 2007). From Geurs et al. (2001), they listed some common concepts of accessibility, such as "the amount of effort for a person to reach a destination" or "the number of activities which can be reached from a certain location". Furthermore, they mentioned that there are four components of accessibility. The transport component includes the travel time, cost and effort to during the movement from origin to destination. The land use component reflects the both sides (supplied and demand) for the spatial distribution of activities. The temporal component measures the time restraints individuals available for activities at the certain time of the day. The individual component examines the needs, abilities and opportunities from both socio-economic and demographic aspects of individuals. In their opinion, accessibility should facilitate people to participate in different activities in anywhere. In summary, it means that accessibility made a further definition that accessibility is the extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport modes (Geurs et al., 2004). Although there are many descriptions of accessibility, they have the similar main ideas, which evaluate the access to the certain activities (work, education, and shopping) in different locations.

From these definition of accessibility, we can see that most study for accessibility seldom mention the influence of social-economic for the accessibility, which causes excessive private transport travel and finally contributes to traffic congestion, air pollution, and traffic accidents (Murray et al., 1998). Thus, accessibility analysis between different travel modes especially private and public transport assist urban and transport planners to develop the public transport system for the higher access level.

## 1.9. Overview of accessibility measures

Accessibility measures have been studied over many years. There are many review articles of accessibility measures written by researchers such as (Bhat et al., 2000; El-Geneidy et al., 2006; Geurs et al., 2001; Geurs et al., 2004). These contain several of methods to evaluate accessibility for a region. For instance, Geurs (2006) used the utility-based balancing measurement to analyze the job accessibility benefits of integrated land-use and transport strategies in the Netherlands. And in his earlier article for computing job accessibility for the Netherlands, Geurs et al. (2003) demonstrated that the balancing factor and the potential measures are similar to the spatial distribution of job accessibility. Among these methods, four major types of accessibility measures was identified by(Geurs et al., 2004), which will be introduce below:

1. **Infrastructure-based measures** analyze the performance or service level of transport infrastructure, including the average travel speed on the road network, and the level of congestion. This kind of measure is often used in transport planning.
2. **Location-based measures** examine the level of accessibility of a location within certain minutes (e.g. the number of jobs within 30 minutes can be reached). This measure, which prefers for urban planning and geographical studies, provides insight into evaluating the capacity location for both supply and demand sides.
3. **Time-space measures or person-based measures** evaluate accessibility at the individual level, for instance, the number of people travelling during the peak-hour.
4. **Utility-based measures,** which analyze the travel cost during the trip. According to the travel cost, individuals will choose their travel modes, routes and destination.

Among these measures, Infrastructure-based measures are only based on the characteristic of infrastructure facilities, instead of taking account into different needs from different kinds of group people. Person-based and Utility-based measures are limited to the micro-level accessibility evaluation. In other words, both of these two types of measures are too detailed to get the data in reality study. However, for this research will focus on comparing the different accessibility levels between different travel modes, especially measuring the difference between public and private transport for job-accessibility. Location-based measures can be used in this research.

A wide variety of location-based measures have been demonstrated in many works. For the purpose of this study, the contour measure and potential accessibility measure are chosen.

### 1.9.1. Contour measure

The contour measure or cumulative opportunities is the simplest measure introduced in many articles (El-Geneidy et al., 2006; Wachs et al., 1973). This measure makes insight into accessibility through the number of potential activities within the certain threshold (travel time or distance).

$$A_t = \sum_t O_t \tag{2.1}$$

Eq. (2.1) represents the number of opportunities (jobs, shopping) can be reached within a certain threshold $t$. For this method, it needs to know the total number of locations in the destination within the proposed threshold. For example, Lutter et al. (1992) measured average travel time for different transport modes (road, rail, air) for 194 economic centers in Europe. The number of reachable opportunities within a desirable travel cost (Wachs et al., 1973).

The advantage of contour measure is easy to explain depended on the number of reachable opportunities in the destination without any other assumptions. And the visualized results are easy to be understood. However, for this type of measure, there are some disadvantages that it takes the same weight to each opportunity in a certain threshold without considering the opportunities beyond the threshold and the measures cannot evaluate effect of land use and transport(Geurs et al., 2004).

### 1.9.2. The potential accessibility measure

Potential accessibility measure has been often used in urban and transport planning. Hansen (1959) was the first one using the potential accessibility to measure the accessibility to opportunities, especially for jobs. The formulation of potential accessibility measure has been shown below:

$$A_i = \sum_j^n D_j f\left(c_{ij}\right) \tag{2.2}$$

Eq. (2.2) is a measure of accessibility in zone $i$ to opportunities D in all zones $j$, $c_{ij}$ is the travel time between $i$ and $j$ and $f\left(c_{ij}\right)$ is an impedance function.

For this measure, different kinds of decay functions can be chosen based on different research purposes and data availability. It can be the original power function which comes from Newton's law of gravity (Hansen, 1959), negative exponential function (Handy et al., 1997), Gaussian functions (Ingram, 1971) and logistic functions (Hilbers et al., 1993). The distance decay function has a significant influence on the potential accessibility measures.

Potential accessibility can be calculated many times in terms of measuring the level of accessibility for different travel modes. Then comparison between travel modes will be applied easily.

Although, both contour measure and potential accessibility measure are easy interpretation and visualization, they do not take insight into competition effects for some reachable opportunities in supply and demand sides. This may sometimes leads a misunderstanding or inaccuracy results in analyzing the job accessibility levels. In this study, the competition will be assumed not impact on the accessibility levels.

## 1.10. Modal Accessibility Gap (MAG)

Accessing the sustainable transport development based on the consideration of energy-efficient difference between public transport and private transport, the concept of Modal Accessibility Gap (MAG) was first proposed by (Kwok et al., 2004). There is another potential assumption, which is not usually pointed out explicitly, that the higher accessibility measure value one travel mode gets, the more likely this travel mode will be used by people in the daily life. So the difference between accessibility by different travel modes is meaningful to be discussed for understanding the transport, especially under the condition of more and more congestion during the city development.

Some researchers have paid attention on this aspect by different methods, as talked about by Kawabata (2007). Based on the accessibility measure methods adopted in research, two categories are distinguished: the cumulative method (Blumenberg et al., 2003; Hess, 2005); Shen, 2001) and the potential method (some studies with the consideration of competition on demand side (workers competes for jobs)) (Kawabata, 2007; Kwok et al., 2004; Shen, 1998, 2001). Another method has been proposed by Benenson et al. (2010) to calculate the area rather than opportunity. But the categories could be divided further by the method about how to compare the difference between accessibility by different transport modes: simply calculate the ratio of accessibility by different transport modes (Benenson et al., 2010; Blumenberg et al., 2003; Hess, 2005), calculate the ratio of the difference and sum of accessibility by different transport modes (Kawabata, 2007; Kwok et al., 2004), and compare the difference directly without any further processing of the accessibility value (Kawabata & Shen 2007; Shen, 1998, 2001).

To research the employment accessibility of low-wage workers, Shen (1998) distinguish the effect of location from that of workers' auto ownership by computing the job accessibility of low-wage workers through public transport and car respectively. The accessibility measure applied by Shen (1998) is a refined potential accessibility by accounting for job competition among workers (the demand side). The results show that the low-wage workers living in the central location of inner-city does have some advantage by their location characteristics, but the auto ownership has more influence on the job accessibility than the location. The compare of job accessibility by public transport and car is based on the same six scales of accessibility value directly. The work by Shen (2001) shows the similar result that the "accessibility differentials among locations are small as compared to accessibility differentials between transportation modes". Also concentrating on the low-income residents, Blumenberg et al. (2003), Blumenberg (2004) and Hess (2005) research the transportation role in the job accessibility. Different to Shen (1998) and Shen (2001), Blumenberg et al. (2003), Hess (2005) and Blumenberg (2004) make a ratio of the accessibility value between the different transportation modes to show the accessibility differentials. Kwok et al. (2004) introduce the conception of modal accessibility gap (MAG), which gives another method to calculate the accessibility differentials between transportation modes. One of the advantages of this method is that the value of MAG is between -1 and 1, which gives a more intuitive compare of the accessibility differentials between transportation modes than the ratio method. Different to the results of most other research, the results of Kwok et al. (2004) show that the public transport have more advantage over the private transport in Hong Kong, China. This similar method is also applied in the work of Kawabata (2007), which explores the spatial and temporal variations of modal accessibility disparity. Also concentrating on the modal accessibility gap, but not through the way of Kwok et al. (2004) and Kawabata (2007), which improve the calculation method of modal accessibility gap, Benenson et al. (2010) and LIU & GU (2010) remain apply the ratio method but make some extension on the accessibility measure. Benenson et al. (2010) introduce the conception of access area and service area as accessibility measure, and LIU & GU (2010) introduce Location Entropy Indicator as the job opportunities into the contour accessibility. Those researches are list as below in Table 2.

| Study | Sample Size and Unit of Analysis | Accessibility measure method | Method of comparing different accessibility | Variables Controlled | Results |
|---|---|---|---|---|---|
| Shen (1998) | Boston Metropolitan Area: 787 TAZs in 1990 | Potential accessibility taking into account competition on demand side without travel time threshold | Talk the accessibility difference directly | Control for travel mode (by car and public transport), income and location | The central location of inner-city residence still gives the low-wage workers some advantage, auto ownership is the more important determinant. |
| Shen (2001) | Boston Metropolitan Area: 775 TAZs in 1980 and 1990 | Cumulative accessibility taking into account competition on demand side within travel time threshold 15, 30, and 45 minutes | Talk the accessibility difference directly | Control for travel mode (by car and public transport) | Central-city low-income neighborhoods, in comparison with a great majority of peripheral and suburban locations, still had some advantage in accessibility of job openings; Accessibility differentials among locations are small as compared to accessibility differentials between transportation modes |
| Blumenberg et al. (2003) | Alameda, Fresno, and Los Angeles: census block groups | Potential accessibility within 30 minutes | Ratio of jobs via autos to jobs via | Control for travel mode (by car and public | Job accessibility provided by private |

| | | | | | |
|---|---|---|---|---|---|
| | | | public transit | transport), income, job distribution and residential location (central-city and suburban) | transport is higher than by public transit for welfare recipients, but the ratio varies substantially across households depend on spatial distribution of the welfare recipients and job opportunities |
| Blumenberg (2004) | Los Angeles: 7 households | Potential accessibility within 30 minutes | Ratio of jobs via autos to jobs via public transit | Control for travel mode (by car and public transport), income, job distribution and residential location (central-city and suburban) | Welfare recipients who commute by car can access many more jobs within a 30-minute commute than recipients who rely on public transit. |
| Kwok et al. (2004) | Hong Kong, China: 253 traffic zones in 1991 and 1996 | Potential accessibility taking into account competition on demand side without travel time threshold | Ratio of the difference to the sum of accessibility by different travel modes | Control for travel mode (by car and public transport) | Accessibility is found to be actually much higher for public transit than for cars; The transport development in Hong Kong is less sustainable in 1996 than in 1991. |
| Hess (2005) | Buffalo–Niagara Falls metropolitan statistical area: 14 neighborhoods in 2000 | Potential accessibility with a distance threshold 5 km | Ratio of automobile to public transit job accessibility | Control for travel mode (by car and public transport), population characteristics (race/ethnicity, age, household structure and education), work location | Apart from one neighborhood, all other neighborhoods in Erie County have two or more jobs accessible by automobile for every job accessible by public transit and the ratio varies only slightly across |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | neighborhoods. |
| Kawabata & Shen (2007) | San Francisco Bay Area ： 1099 RTAZs in 1990 and 2000 (1998) | Potential accessibility taking into account competition on demand side in travel time threshold 30 min (15, 45, 60, 75, 90 analysis for sensitivity) | Talk the accessibility difference directly | Control for travel mode (by car and public transport) | In both 1990 and 2000, greater job accessibility was significantly associated with shorter commuting time for driving alone as well as for public transit, but the degree of this association was considerably greater for public transit than for driving alone. |
| Kawabata (2007) | Boston: 986 TAZs in 1990 and 2000<br><br>San Francisco: 1099 RTAZs in 1990 and 2000 （1998） | Potential accessibility taking into account competition on demand side in travel time threshold 30 min, 45 min and 60 min | Ratio of the difference to the sum of accessibility by different travel modes | Control for travel mode (by car and public transit) and travel time threshold | Considerably lower job accessibility by public transit than by car; Between 1990 and 2000 the accessibility disparity at the regional level decreased in both metropolitan areas. |
| Benenson et al. (2010) | Tel Aviv metropolitan area, Israel | Access Area and Service Area in travel time threshold $\tau$ (with time threshold 30, 40, 50, 60 minutes in study) | Ratio of bus access area (service area) to car access area (service area) | Control for travel mode (by car and public transit), transfer, travel time threshold and departure time | Large gaps exist between car-based and transit-based accessibility for a vast majority of the travel activity zones |
| LIU & GU (2010) | Nanjing Metropolitan Area: 566 TAZs | Cumulative accessibility within travel time threshold of 20, 40 and 60 minutes | Ratio of accessibility via autos (or bicycle) to accessibility via public transit | Control for travel mode (by bicycle, car and public transport) and opportunities categories (Location | The strength of car accessibility relative to bicycle and urban transit is apparent； Comparing the |

| | | | | | |
|---|---|---|---|---|---|
| | | | | Entropy Indicator of residential, commercial and industrial land) | modal accessibility of urban transit and bicycle， the strength of urban transit accessibility is relatively high when the isochrones time is assumed to be 40 or 60 minute ， but the strength is weak when the isochrones time is assumed to be 20 minutes |

Table 2 : Studies for comparing accessibility by different travel mode

There is a need to point that not all these studies in the Table 2 concentrate on the accessibility difference by travel modes, and not all these studies used the terminology of Modal Accessibility Gap (MAG) as well. The accessibility difference by travel modes is only one element within consideration to facilitate to understand and interpret the core augment which the authors put in their studies, such as location characteristics of inner-city neighborhoods in Shen (1998), the commuting inequality between cars and public transit in Kawabata & Shen (2007), the spatial mismatch of low-income women in Blumenberg (2004) and so on. Most studies don't have a specific term for the accessibility difference by travel modes, the name of modal accessibility disparity (MAD) is applied in Kawabata (2007) and Kawabata & Shen (2007), the term of accessibility gap is applied in Benenson et al. (2010) and the term of Modal Accessibility Gap (MAG) is applied in Kwok et al. (2004) and LIU & GU (2010).

As to the travel modes talked about in these studies in the Table 2, most are car and public transit, and the bicycle transport is considered in LIU & GU (2010). And as to the accessibility measure method adopted, except the classification mentioned above (cumulative, potential, and potential with competition on demand side), another classification could be made as: cumulative method, potential method (with or without competition), and the compound of cumulative and potential method, which stands for the potential accessibility model with the time/distance threshold. This compound measure model, can also be called non-standard potential accessibility measure, is applied in most of these studies listed in the Table 1. And Kawabata (2007) makes a little explanation about this in his study for the interpretability and practically of the dichotomous approach using the travel time threshold.

As to the method about comparing the accessibility difference by travel modes, there different process modes have been distinguished above. The direct method, which means no process, only be used in special conditions that the accessibility by different travel modes show small and stable value, such as average score 0.09-1.08 in Kawabata & Shen (2007), 0.03 and 0.31 for public transit and automobile in Shen (2001). The ratio of accessibility via autos (or bicycle) to accessibility via public transit is a straightforward approach, but the ratio values generated by this method may vary so greatly that make it difficult for comparison (Kawabata (2007). The method that ratio of the difference to the sum of accessibility by different travel modes seems quite well in its application (Kawabata, 2007; Kwok et al., 2004). But there is still a difference between the two studies that their sign of numerator is opposite. The difference shows below:

The method in Kwok et al. (2004):

$$MAG = \frac{A^p - A^c}{A^c + A^p} \tag{2.3}$$

The method in Kawabata, (2007):

$$MAG = \frac{A^c - A^p}{A^c + A^p} \tag{2.4}$$

$A^p$ represents accessibility of public transport and $A^c$ represents the accessibility of private transport.

### 1.11. Scenario development

According to Van der Heijden (1996), scenario planning was considered as a method for military planning during the World War II. And then Kahn et al. (1967) firstly defined scenario in his book as "a set of hypothetical events set in the future constructed to clarify a possible chain of causal events as well as their decision points". Scenario planning is a process of evaluating alternative futures event through the trends and policies. It is not absolutely equal the current situation, but provide a dynamic view of the future. In the USA and Europe, there are two major geographical scenario developments. In the USA, the scenario planning was used by the Royal Dutch/Shell Group as a strategic planning tool in the industrial field in the early 1970s. And in the mid-1970s, Bradfield et al. (2005) developed scenarios for different kinds of institutions and companies, which it contributed by the *La Prospective* school. Hickman et al. (2012) emphasized that the importance of scenario analysis in the transport field is to facilitate to *'think the unthinkable'*. Applications of scenario in transport planning are studied by many researches. Such as Steen et al. (1998) explored how to construct scenarios for sustainable mobility based on a back casting approach, Zegras et al. (2004)proposed a framework which applies the scenario planning techniques in the regional strategic transportation planning, and 80 scenario planning projects from more than 50 U.S. metropolitan areas are reviewed by Bartholomew (2007)to reveals some structural obstacles in the practice of land use-transportation scenario planning.

The definition of scenario is described by Porter (1985) an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome. Saliba (2009) also mentioned that scenario analysis including future development and illustrating the path from the current situation to the possible future.

According to Mahmoud et al. (2009), there are five progressive phases: scenario definition, scenario construction, scenario analysis, scenario assessment, and risk management. During these phases different kinds of stakeholders participate in it, such as scenario developers, modellers, government, and so on. In this paper, the formal scenario constructs for environment studies. But except the risk management, the others can be proposed for normal scenario development.

**Scenario definition**
This phase identifies the characteristics of scenarios including the both spatial and temporal scales of the scenario, the critical forcing and the time horizon. It includes the objective of scenario, the story line and the qualitative descriptions of proposed scenarios.

**Scenario construction**
After the scenario definition, the next phase is to develop scenarios. The scenario construction is generally composed of three major steps: system conceptualization, model development, and data collection and processing. System conceptualization is to describe the concepts of the current system and do the propose which is based on the scenario definition process. Moreover, the major assumptions and decision factors, according to Mahmoud et al. (2009), for conceptual model is to build the connections between the definition of scenarios and the models to be used. The next steps are to develop the outcomes of potential future views, data collection and processing.

**Scenario analysis**
This phase concentrates on identifying the consequences of interconnection among the boundary conditions, driving forces and system components. The interpretation uses different kinds of statistical

analysis in order to facilitate easy understanding. Model outputs include trends, thresholds and cascading effects.

**Scenario assessment**

Scenario assessment identifies the potential opportunities and rewards to stakeholders so that they can audit scenario plans and manage it. In this phase a series description of scenarios illustrate from different dimensions to evaluate the outcomes of the scenarios and finally provide a clearly alternative future view to the stakeholders and researchers.

# 2. STUDY AREA, DATA, AND METHODOLOGY

This chapter includes four parts. The first part gives the description about the study area in this study. The second part presents the data source explanation, and time threshold assumption. The third part presents the methodology about job accessibility measure that will be applies to the study area. There are two accessibility measure applied in this study, the potential accessibility measure and the modified accessibility measure with consideration of competition on both demand and supply sides. The fourth part illustrates the methodology about how to measure the accessibility gap of different travel modes based on the method of Kwok et al. (2004).

## 2.1. Study Area

### 2.1.1. Overview of Arnhem Nijmegen City Region

Arnhem Nijmegen City Region is a metropolitan area that consist 20 Dutch municipalities (Figure 1), which is one of the four major metropolitan areas together with the Randstad, Twente, South Limburg and the Eindhoven region. The region with the purpose of enhancing the qualities of the area and becoming the second biggest economic area in the Netherlands after Randstad by 2020 (De Stadsnegio Arnhem Nijmegen, 2012).

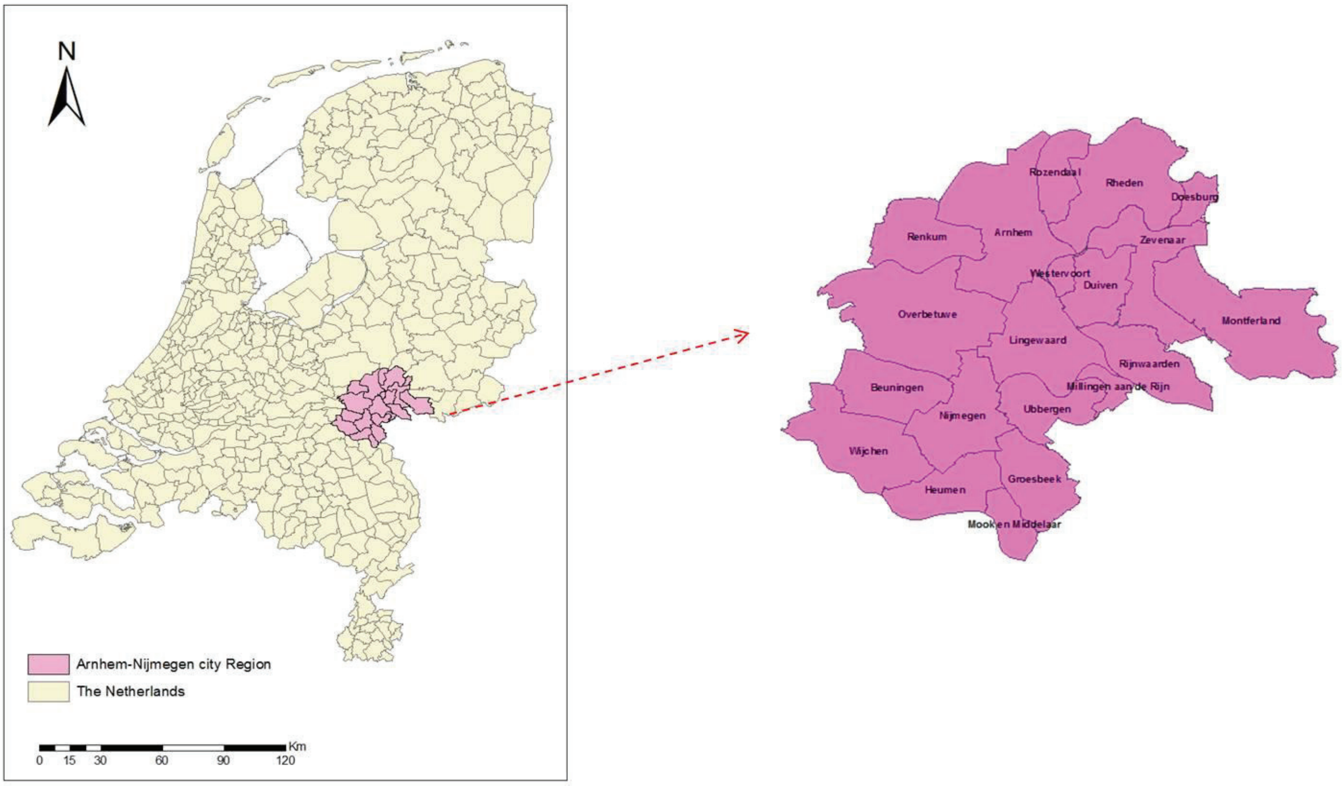



Figure 4: General position of Arnhem Nijmegen City Region in the Netherlands

In this region, there are more than 70 percent is covered by forests, natural sites and agricultural. On the contrary, there are only 15 percent areas are residential, commercial and industrial places, which is shown in the below (Figure 5).

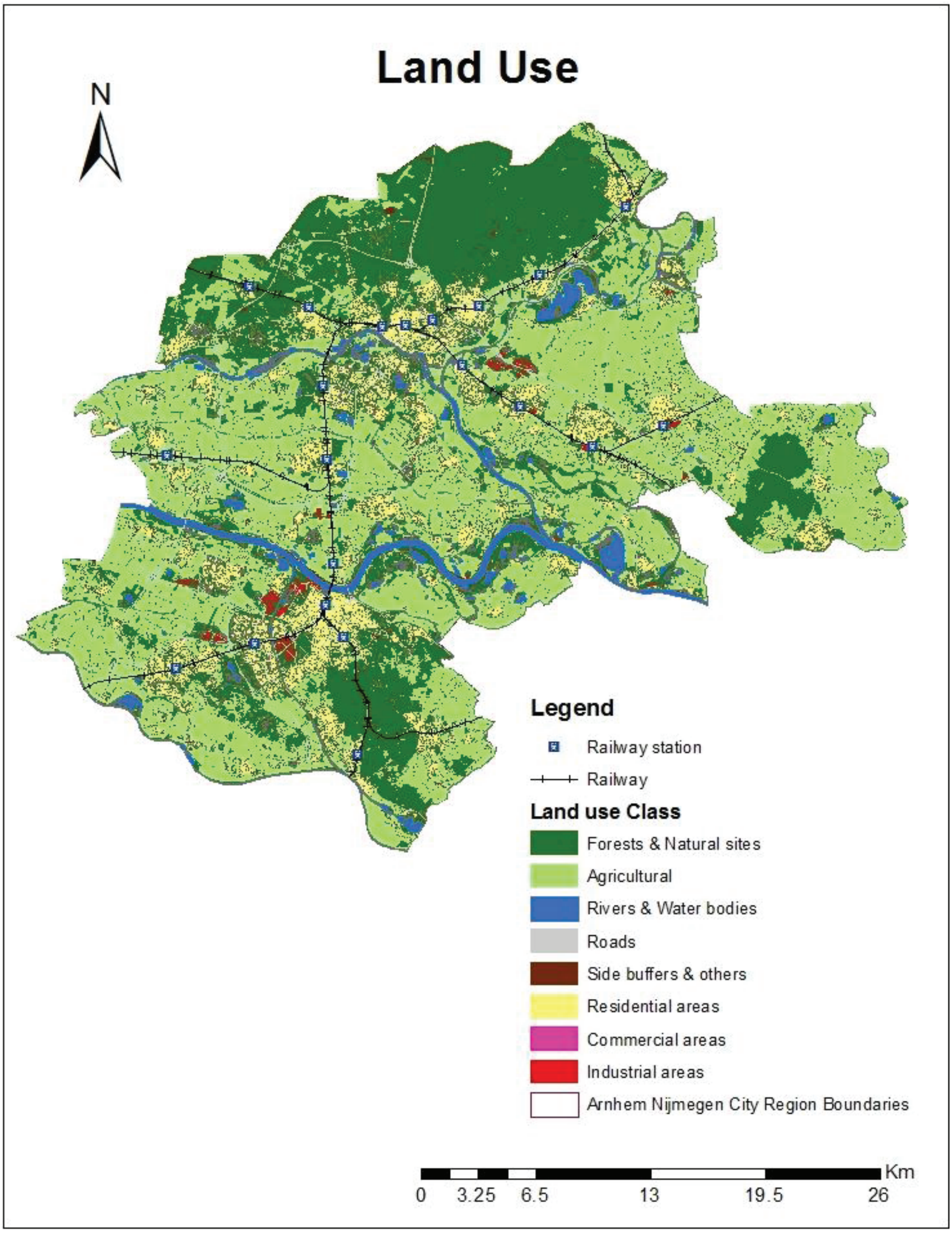



Figure 5: Land use map of Arnhem and Nijmegen City Region

The region has 716798 inhabitants (September 2013, (CBS, 2013a)) is more than 1000 $km^2$ and more than 40 percent of them are living in Arnhem and Nijmegen city municipalities in which have the relatively highest population (Figure 6) among 20 municipalities. By the same token, most of the jobs distributes here. And the detail method of computing job density can be seen in the following section.

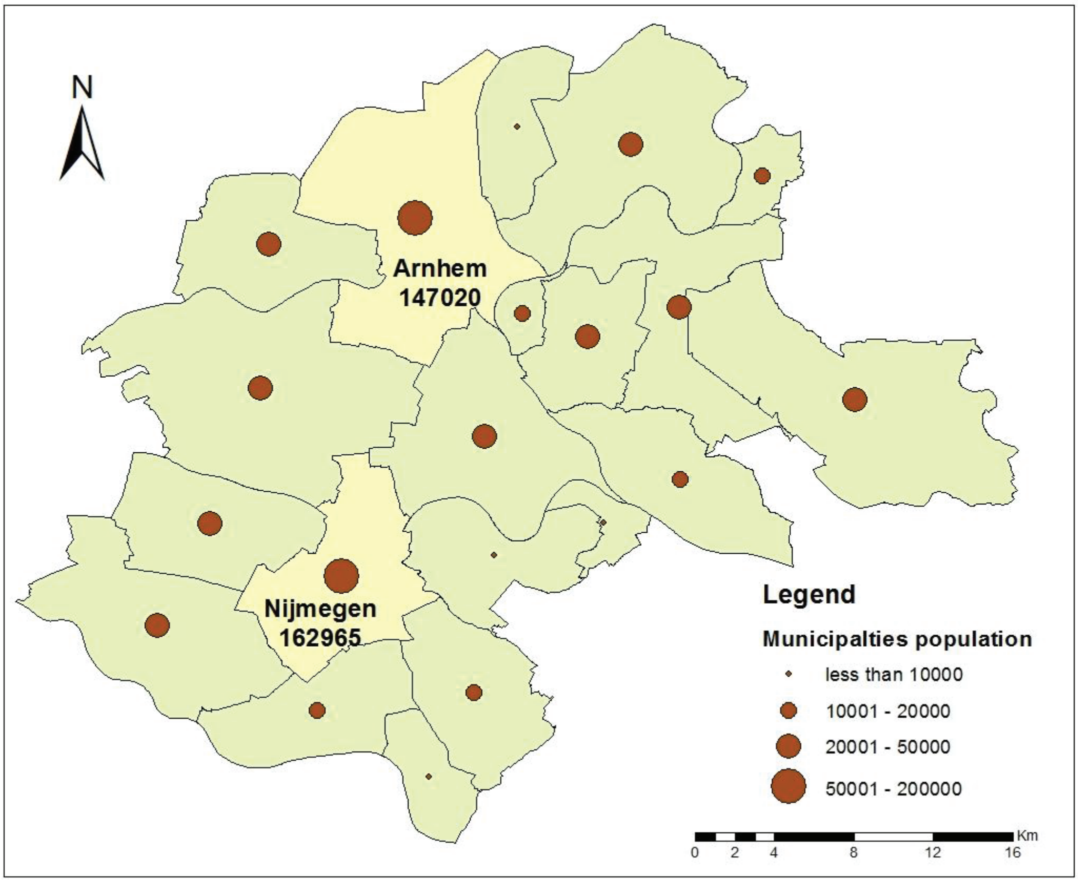



Figure 6: Population distribution in Arnhem Nijmegen City Region (Source: CBS)

### 2.1.2. Transport and accessibility

Arnhem Nijmegen City Region is growing into economic and logistics hotspot of the country. Good accessibility is thereby an absolute must. The Arnhem Nijmegen region owns the advanced transport system, in which can be reached easily by different travel modes. For example, according to De Stadsnegio Arnhem Nijmegen (2013), A12 and A73 motorway has been connected to Arnhem and Nijmegen city separately. And the A325 motorway makes a connection between these two cities of municipalities, where are also near the A50 and A15 motorways. Besides of well developed road infrastructure, the railway system including 21 operational rail stations bridge the connection both within this region and the main cities in the whole Europe. These bring much more potential business investment and improving the economic position for the region.

In order to continue and enhance the strong competitive position, the local municipal councils work for the mobility and regional development. They prefer to invest public transport and implement infrastructural projects. There are three polices mentioned in (City Region Arnhem Nijmegen, 2013) as follow:

- Aligning public transport with private transport;
- Promoting spatial development of areas around traffic junctions;
- Making public transport into a coherent and distinguishable whole.

## 2.2. Data base

Data needed for this research is listed in Table 1 as below, which includes two categories: spatial data and non-spatial data. There will be **448 traffic analysis zone（TAZs）** according to the number of neighbourhood (Dutch: buurt) level in this region. The data requirements in these neighbourhoods include population, the number of jobs available. All these data needed are intended to calculate the accessibility levels for different travel modes in this study. The non-spatial data includes travel behavior survey data from CBS (Centraal Bureau voor de Statistiek) in order to get accuracy parameters for impedance function of different travel modes. The spatial data mainly includes the transportation and land use data to show different travel modes.

| Data category | | Feature type | Data source |
|---|---|---|---|
| Road network | Road segments | poly line | ESRI Netherland-TOP 10NL (2011) |
| | Road nodes | point | |
| Train network | Train routes | poly line | |
| | Train stops | point | |
| Bus network | Bus routes | poly line | Google Directions API |
| | Bus stops | point | |
| Bicycle network | Bicycle routes | poly line | ESRI Netherland-TOP 10NL (2011) |
| | Bicycle stops | point | |
| Demographics data | | raster | CBS (2010) |
| Administrative boundary | | polygon | CBS (2010) |
| Land use pattern | | polygon | ITC former projects archive, Open Street Map |
| Travel behavior | | | CBS（2010） |

Table 3: Data source

There are five travel modes in this network including car, walking, bicycle, bus and train (public transport). Table 4 shows the travel modes type and the average speed for each travel mode.

| Travel mode | Average Speed (Km/h) | Data source |
|---|---|---|
| Walking | 3.5 | CBS |
| Cycling | 15 | CBS |
| Bus | *1 | Breng (http://www.novio.nl/) Google Map |
| Car | *2 | CBS |
| Train | *3 | NS website |

Table 4: Travel mode type

Measuring car accessibility levels in the morning peak hour, there is no relative government or statistic documents for these specific datasets currently. However, according to NTTP (2001)—the National Traffic and Transport Plan 2001-2020—the minimum speed of 60 km/h on the main motorway network during peak hours, for this study will make assumption of the average speed for each kind of road in order to be close the real situation as much as possible (Table 5).

| Type of road | Average speed during peak hours (km/h) |
|---|---|
| Auto road | 75 |
| Regional road | 65 |
| Local road | 55 |
| Street | 40 |
| Others | 40 |

Table 5: Average speed for each kind of road

Those travel speed data are used to calculate the travel time by different travel modes. While the travel time by train between each two train stations are acquired from the NS website, there is no need to

[1] No average travel speed is assumed for bus and the travel time data is collected by Google Map API explained in section 3.2.2

[2] Each kind of road has its own speed (reference in Table 5).

[3] Measuring for train is get travel time for each route from NS website.

assume an average speed for train.

The data of road network comes from ESRI Netherland which is called TOP 10NL. The following figures show the road network in Arnhem Nijmegen City Region. The figure shows road network distribution and the purple one is Auto road, the orange one is Local road, the red one is Regional road, the black one is Street and the gray one is other type road in the following figure.

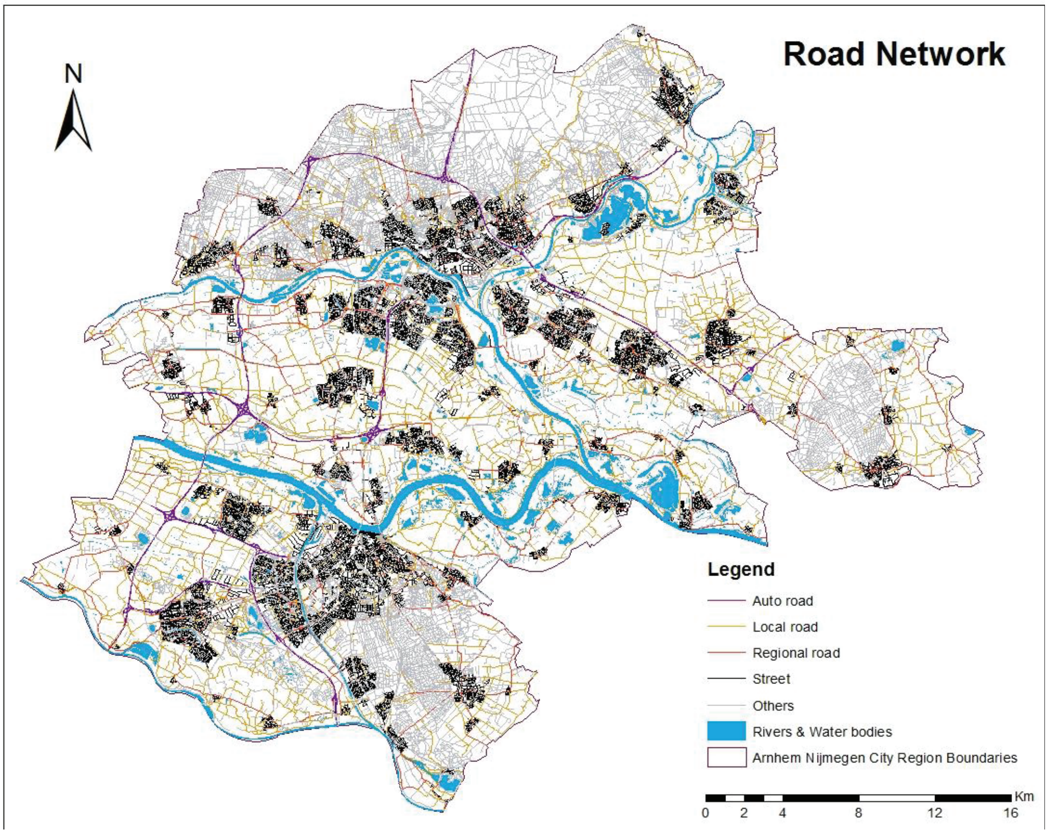



Figure 7 Road network in Arnhem Nijmegen City Region

Based on the data provided, job accessibility of TAZs in Arnhem Nijmegen City Region is calculated with the methodology showed below.

#### 2.2.1. Data collection for developing future scenarios

There are many definitions of scenarios from different researchers. Greeuw et al. (2000) used to state that scenarios are archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present and future developments. And Engelen (2000) defined that the robustness of the chosen policy measures can be tested by imposing effects on the system that in the real world are beyond his control. These effects are called scenarios.

In this research, the latter one will be used. According to Bodegraven et al. (2009)—the Arnhem Nijmegen City Region task for 2010-2020—the external driving force for this study is jobs growth rate which is got from (Rabobank, 2012). The internal variables will be the transport speed for each travel mode and the land use change (Nijmegen, 2006). Different scenarios will be developed based on these documents for Arnhem Nijmegen City Region. Both primary data and secondary data will be used for constructing scenarios on decreasing MAG gap.

#### 2.2.2. Data collection with Google Directions API

In terms of no data about the bus network, the travel time data of bus cannot be computed though the ArcGIS as other travel modes. The travel time data of bus is collected by programming through the Google Directions API. However, the travel time data collected through the Google Directions API is actually the multimodal of bus and train, the term of bus&train is applied in the follow of the paper.

The Google Directions API is a service that calculates directions between locations using an HTTP request. You can search for directions for several modes of transportation, include transit, driving, walking or cycling. Directions may specify origins, destinations and waypoints either as text strings or as latitude/longitude coordinates(Google, 2013). For this research, it proposes to make use of specific origins and destinations in each neighbourhood (448 neighbourhoods) to get the detail travel time for all of them by bus&train travel mode.

## 2.3. Methodology for job accessibility measures

### 2.3.1. Job accessibility measurement

In this section, two accessibility measures are applied to Arnhem Nijmegen City Region in their current situation. There are some reasons why it needs to use two kinds of measures. First of all, the contour measure is less close to the reality than the latter one but easy to calculate and visualization. Both of them help us to calculate the MAG for different travel modes. Then, the both of the MAG value based on the two different measures will be compared to see if the accessibility measurements have an influence on the results of MAG.

First, contour measure using travel time threshold measures the number of opportunities within catchment areas shown by the following equation:

$$A_i = \sum_{j:t_{ij}<t} O_j \qquad (3.1)$$

$t_{ij}$ represents the travel time from zone $i$ to zone $j$ , $t$ as the travel time threshold, $O_j$ is the opportunities in zone $j$ .

Second, the potential accessibility measure (Hansen, 1959) shown by the following equation is applied:

$$A_i = \sum_{j}^{n} O_j f\left(c_{ij}\right) \qquad (3.2)$$

Eq. (3.2) is a measure of accessibility in zone $i$ to opportunities $O$ in all zones $j$ , $c_{ij}$ is the travel cost between $i$ and $j$ and $f\left(c_{ij}\right)$ is an impedance function, which represented by travel time in this study.

### 2.3.2. Computing job accessibility

#### 2.3.2.1. Job distribution

To calculate the job accessibility, the first important process is to prepare the job numbers for each analysis unit, which is equal to neighbourhood in this study. Considering the data source about job could be acquired on the municipality level, there is a need to distribute the jobs from municipality level to neighbourhood level.

The job data at municipality level are classified as industrial, commercial, non-commercial separately, so the job distribution also conducts three times separately from municipality to neighbourhood. For each kind of jobs, the number of company in each neighbourhood is calculated firstly, and then the total number of company for this kind of jobs is calculated in each municipality. Distribute the jobs of this kind from municipality to neighbourhood by the company proportion. Finally, accumulate the distributed three kinds of jobs together to get the total jobs in each neighbourhood. The process is shown in Figure 8 below. The red colour represents the initial data, the grey colour represents the middle data, and the orange colour represents the result data.

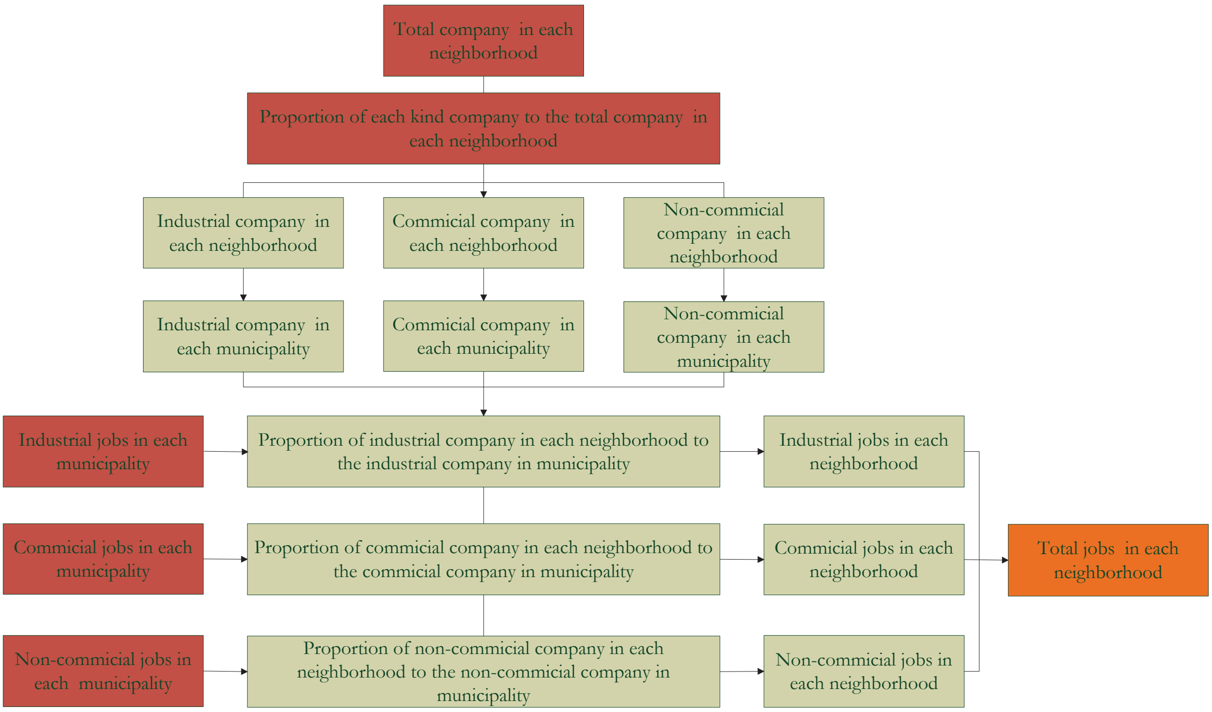



Figure 8: Method to distribute jobs from municipality to neighborhoods

The following figure displays the job density after distributing jobs from municipality to neighborhoods.

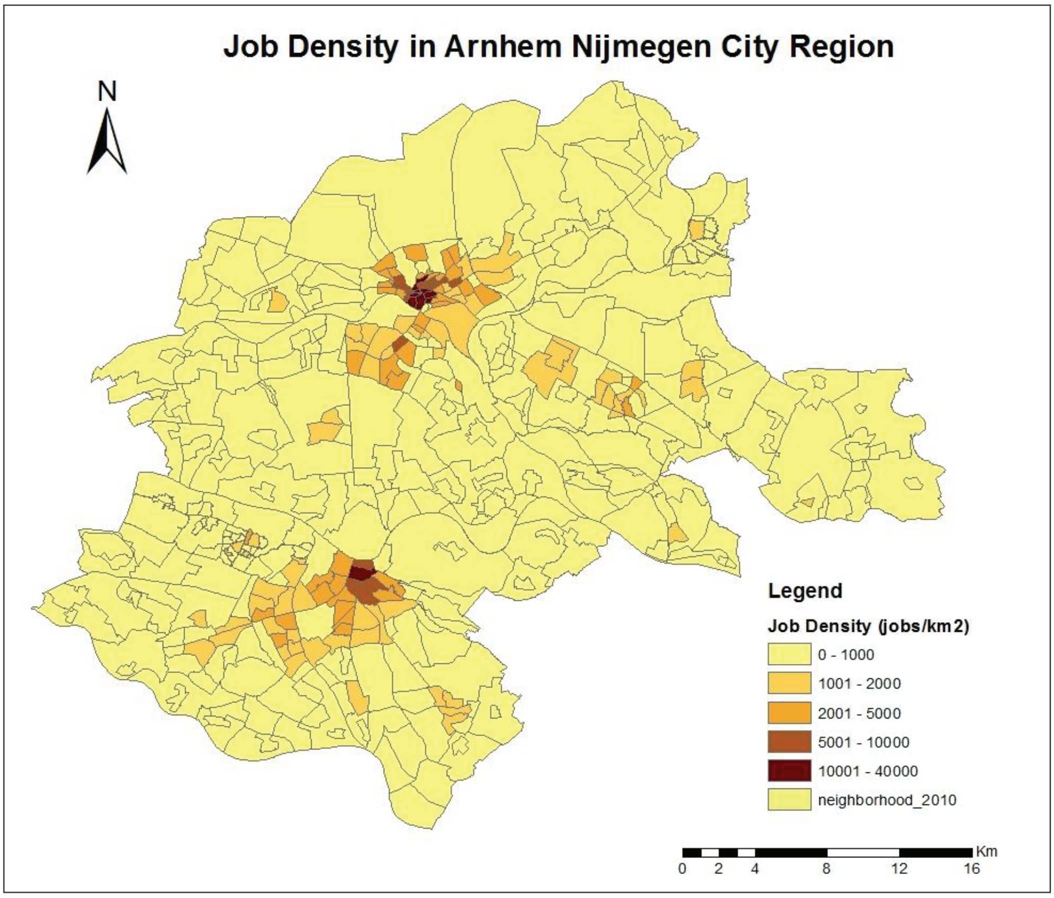



Figure 9: Job density in Arnhem Nijmegen City Region

#### 2.3.2.2. Travel time

This study focuses on the accessibility difference of different transport modes (bus, train, car, and bicycle) as well as the multi-modes (bus & train, and bicycle + train). The accessibility of these different travel modes will be discussed in the below.

It should be pointed out that when public transport (train, bus) is discussed, the walking is always considered as the auxiliary part including the public transport. For example, when travel mode train is discussed in this study, actually it is the "walking + train" travel mode is discussed.

The walking speed is set by 3.5 km/h in this study. And the walking time is calculated based on the real road network. The network analyst in ArcGIS is used to find the distance from origin to destination. And the neighborhood is the smallest analysis unit in this study, the centroid of each neighborhood is thus used to represent that neighborhood in the network analysis.

As the multiple modes of transport different from the normal travel mode, in this session it will explain how to calculate the total travel time of the multiple modes of transport in detail. And the "walking +train" travel mode can be seen as the simplest multi-modes, so the following will take this as an example.

The total travel time from one neighborhood to another by the "walking + train" travel mode:

$$T_{iA-Bj} = t_{i-A} + t_A + t_{A-B} + t_{B-j} \qquad (3.3)$$

$T_{iA-Bj}$ represents the total travel time neighborhood $i$ (nearby train station $A$)to neighborhood $j$ (nearby train station $B$) by the "walking + train" travel mode.

$t_{i-A}$ is the walking time from neighborhood $i$ to train station $A$.

$t_{B-j}$ is the walking time from train station $B$ to neighborhood $j$.

$t_A$ is the waiting time at train station $A$.

Actually, there is another preparation to do before conducting the equation (3.3), which is to assign a train station for each neighborhood. This is easy to understand for residents in neighborhood $i$ will chose the nearest train station $A$ as their original train station, and chose the train station $B$, which is nearest to their travel destination neighborhood $j$, as the destination station. This assignment is based on the network analyst as mentioned above to find the nearest train station for each neighborhood by walking.

Other multiple modes of transport, bicycle + train for example will use the similar method to calculate the total travel time.

#### 2.3.2.3. Impedance function

The impedance function $f\left(c_{ij}\right)$ represents the degree to which zone $i$ is attracted by other zones based on the travel cost (represented by travel time in this study).

In the accessibility measure equation, impedance function of travel time depends on the actual trip modes, trip purpose, and household characteristics such as gender, age, income and educational level (Geurs et al., 2001). The form of impedance function is varied from simple inversely linear regression to more complicated negative exponential function or logistic function (El-Geneidy et al., 2006; Geurs et al., 2004). And the most common used impedance function in most literature to measure the accessibility is an inverse power function or a negative exponential function.

Attributed to the work of (Geurs et al., 2001), there is an explicit better choice for log-logistic function as the impedance function in this study. Based on the 2012 Dutch National Travel Survey (Appendix Ⅰ), they estimated several forms of impedance functions and the result shows that the log-logistic function fits the observed travel behavior (all modes and all trip purposes taken together)best.

$$f\left(c_{ij}\right)=\left(1+e^{a+b\ln c_{ij}}\right)^{-1} \tag{3.4}$$

In this study, the parameter of impedance function is estimated based on the observed travel behavior data. This work is conducted by Curve Fitting Tool (cftool) in the Matlab software environment in this study. According to CBS (2012) for Dutch National Travel Survey (Appendix Ⅰ). And this impedance function will be applied to the potential accessibility measure by different travel modes in this study. The parameter $a$ and $b$ for log-logistic function is $a=-5.106$， $b=1.842$. And the log-logistic function applied in this study is shown as below:

$$f\left(c_{ij}\right)=\left(1+e^{-5.106+1.842\ln c_{ij}}\right)^{-1} \tag{3.5}$$

The result of curve fitting is showed below in Figure 10. The observed travel behavior data is represented by blue curve and the fitting curve of impedance function (log-logistic function) by the red one in this figure. It shows that the log-logistic function with these parameters is fitting quite better to the observed data, except the part of travel time more than 120 minutes due to the data qualification. This part does not influence the analysis of accessibility measure.

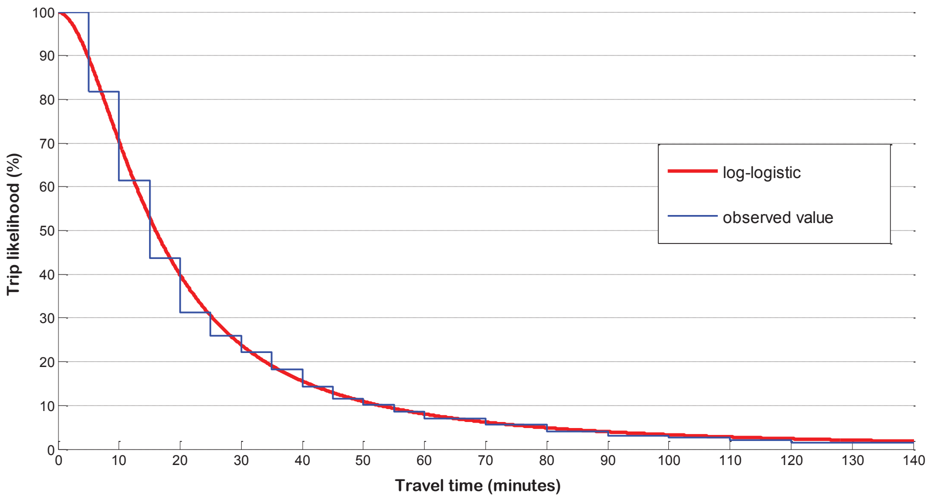



Figure 10: Fitting curve for impedance function

#### 2.3.2.4. Job accessibility

After the calculation of total travel time and impedance function, equation (3.1) and (3.2) will be applied to compute the accessibility of each travel mode. For the contour measure by equation (3.1), there travel time thresholds 15, 30, 45-minute are applied in this study. However, for potential accessibility measure by equation (3.2), no travel time threshold is assumed in this study.

After all those steps above, the job accessibility by different travel modes can be obtained. The final step is normalization, which maps the accessibility value of each neighborhood to some small range. To maintain the relative accessibility advantage or disadvantage of different travel modes, the normalization applied in this study is based on LIU & GU (2010) as follow:

$$A_i^{m\prime}=100\times\frac{A_i^m}{\sum_{j=1} O_j} \tag{3.6}$$

$A_i^{m\prime}$ represents the normalization value of accessibility by travel mode $m$ in neighborhood $i$.

$A_i^m$ represents the accessibility by travel mode $m$ in neighborhood $i$.

$O_j$ represents the job opportunities in neighborhood $j$.

The result value of normalization is range from 0 to 100, the bigger the value is, the more advantage the accessibility is.

### 2.4. Methodology for MAG

Modal Accessibility Gap (MAG) is measured as follow:

$$MAG = \frac{A^c - A^p}{A^c + A^p} \qquad (3.7)$$

$A^p$ represents accessibility of public transport and $A^c$ represents the accessibility of private transport.

As discussed in section 2.3, this measure is based on the research of Kwok et al. (2004)and Kawabata, (2007). And as discussed in the research of Kwok et al. (2004)and Kawabata, (2007), the value of MAG varies between -1 and +1. A value of zero means that the accessibility of the two travel modes are equal, and the accessibility advantage by car will be stronger as the value moving to +1, weaker as the value moving to -1.

This study focus on the accessibility difference between different travel modes, especially the auto and non-auto travel mode. So the MAG between car and other travel modes will be measured in this study. And the change in equation (3.7) is to replace the $A^p$ by other symbol like $A^{bi}$ (bicycle), $A^t$ (train), $A^b$ (bus & train), $A^{bi-t}$ (bicycle + train).

# 3. ACCESSIBILITY ANALYSIS AND RESULTS

This chapter includes four parts. The first part gives the job accessibility measure results of different travel modes using the contour accessibility measure (Hansen, 1959).The second part presents the job accessibility of different travel modes by potential accessibility measure in detail. The third part shows the job accessibility gap of different travel modes by the method of (Kwok et al. (2004)) for the two accessibility measures respectively. And the fourth part conducts the spatial statistical analysis about the accessibility and the MAG results. The fourth part summarizes the general patterns shown in the accessibility and the MAG results.

## 3.1. Contour Accessibility measure

According to the methodology about accessibility measure explained in Chapter 3, the job accessibility for different travel modes in contour measure is computed. For each travel time threshold, the statistical feature of **448 neighbourhoods**' accessibility by different travel modes is shown in the Table 6 below. These accessibility values are normalized by the method explained in the 3.3.2.4 section.

| Travel mode | Time threshold | Minimum value | Maximum value | Average value | Improvement as travel time threshold increasing | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|---|---|
| Car | 15 minutes | 2.3249 | 77.5001 | 37.1508 | | 15.7462 | 0.4238 |
| | 30 minutes | 32.7963 | 100.0000 | 86.6698 | 133.29% | 14.3566 | 0.1656 |
| | 45 minutes | 83.1931 | 100.0000 | 99.2987 | 11.99% | 1.8121 | 0.0182 |
| Train | 15 minutes | 0.0000 | 1.8447 | 0.0177 | | 0.1588 | 8.9876 |
| | 30 minutes | 0.0000 | 17.7597 | 0.5110 | 2787.01% | 2.0841 | 4.0785 |
| | 45 minutes | 0.0000 | 39.5530 | 2.7469 | 437.55% | 6.5955 | 2.4011 |
| Bicycle | 15 minutes | 0.0000 | 22.2359 | 4.6289 | | 6.2776 | 1.3561 |
| | 30 minutes | 0.1429 | 35.5024 | 14.0026 | 202.50% | 11.9859 | 0.8559 |
| | 45 minutes | 0.3342 | 45.2548 | 25.3911 | 81.33% | 14.7689 | 0.5817 |
| Bike+Train | 15 minutes | 0.0000 | 20.5683 | 2.0819 | | 4.3887 | 2.1081 |
| | 30 minutes | 0.0000 | 61.3847 | 13.3236 | 539.97% | 14.3651 | 1.0782 |
| | 45 minutes | 0.0000 | 85.5935 | 31.6678 | 137.68% | 22.0848 | 0.6939 |
| Bus&Train | 15 minutes | 0.0000 | 15.9788 | 1.7757 | | 2.8912 | 1.6282 |
| | 30 minutes | 0.0000 | 45.6667 | 9.2163 | 419.02% | 9.3743 | 1.0171 |
| | 45 minutes | 0.0000 | 80.1157 | 22.6067 | 145.29% | 17.1589 | 0.7590 |

Table 6: Job accessibility by different travel modes in contour measure

In the table 6, the coefficient of variation represents the dispersion of accessibility index in different travel time thresholds for different travel modes. As the threshold increased, the value of coefficient of variation is decreased and the average accessibility reaches the maximum value ($A_{max}$=100). Moreover, the difference accessibility is gradually reduced, which is same as the contour accessibility measures. There is a significant difference for the value of coefficient of variation among different transport modes, especially for train, the value for dispersion is highest, the second is 'bike + train', and the smallest one is car. When the threshold is 45 minute, the coefficient of variation for car is only 0.0182. It indicates that car has the absolute accessibility advantage over other travel modes among all three travel time thresholds.

And the quite high accessibility value of car for 15-minute travel time threshold also indicates that the relative poor job accessibility neighbourhoods take only a small part. And the job accessibilities of these poor accessibility neighbourhoods increase dramatically when the travel time threshold move to 30-minute (the minimum from 2.3249 to 32.7963).

The Figure 11 below shows the Population distribution in Stadsregio Arnhem Nijmegen (SAN) **at the**

**neighborhood scale**. According to this figure, it is clearly to find out that most of people are cluster in the two major cities—Arnhem and Nijmegen. For the other municipalities, people always live around the train station. Also, in this map it is shown in the northern of Arnhem which is in **the blue dotted box**, there are almost no people live there in terms of forests and natural sites. In the eastern part of municipality of Montferland **(the red dotted box)**, although there are some residents, the major areas there are still forests and natural sites, and that is why these places have the relative low accessibility levels comparing the other places.

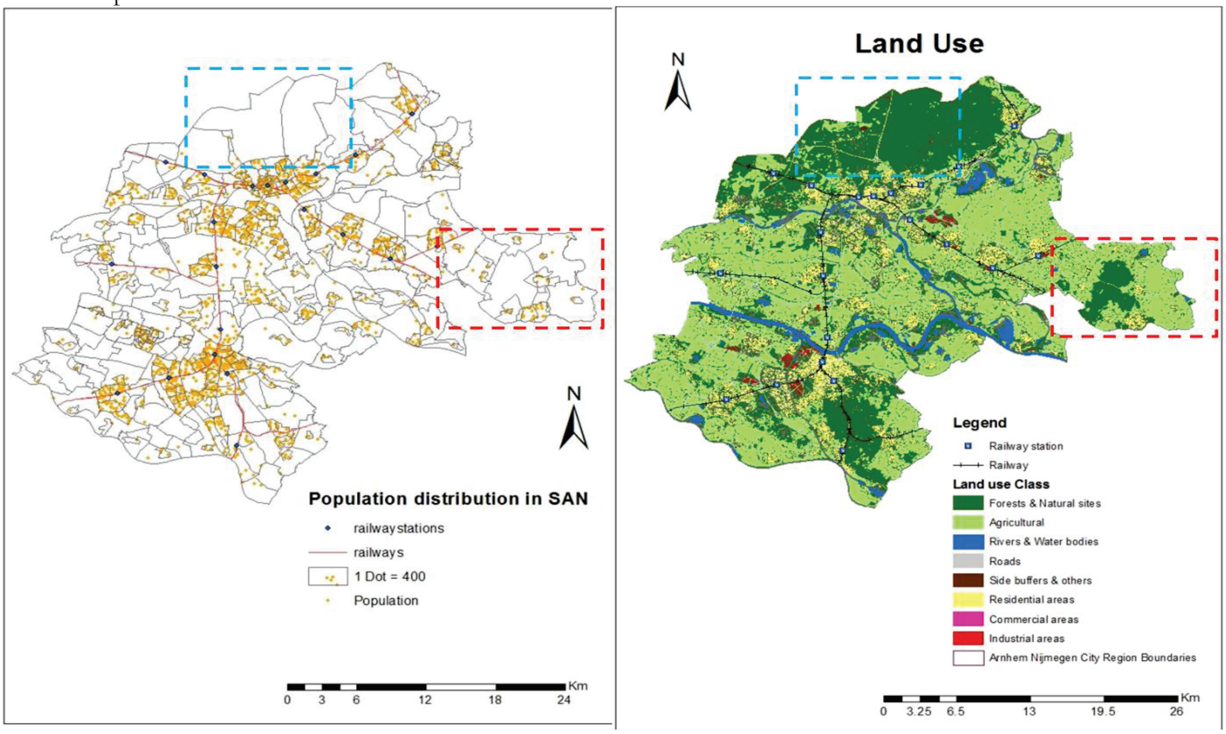



Figure 11: Population distribution in SAN at the neighborhood scale

This situation of contour accessibility value by car is displayed clearly in the Figure 12 below (the contour accessibility for other travel modes are displayed in Appendix Ⅱ). From the Figure 12 it shows that the relative low accessibility area of car locates in border of the study area, especially the North and East part of the study area.

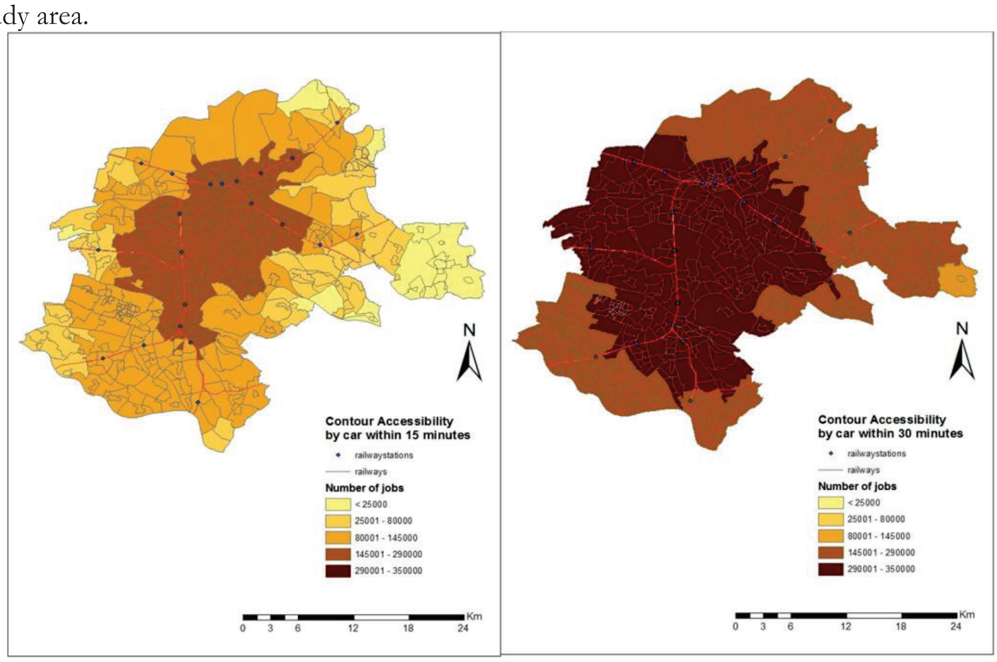



Figure 12: Contour accessibility value by car within 15-, 30-, 45-minute travel time threshold

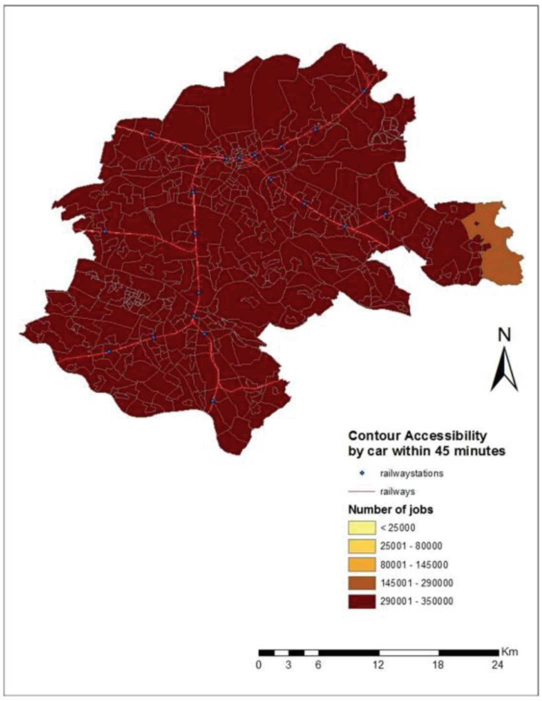



Figure 12: continued

The average accessibility value of different travel modes in 15, 30, 45-minute are shown in Figure 13 below, which gives a more intuitional perspective to understand these.

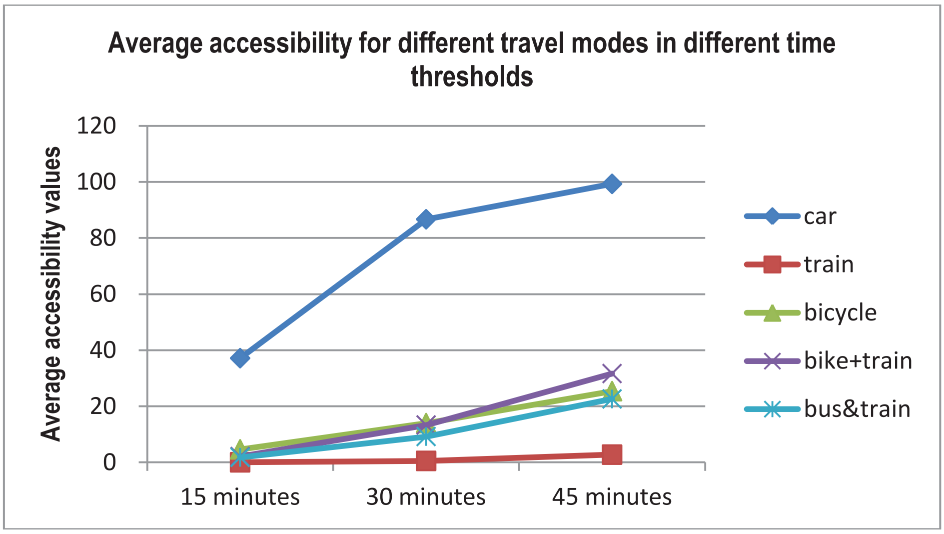



Figure 13: Average accessibility for different travel modes in different time thresholds

From the Figure 13 it can be seen that the train travel mode shows the poorest accessibility among all the travel modes. This is mainly caused by the physical feature of the train travel mode: the railway network and railway stations are limited in number and fixed in spatial location. The neighbourhoods around the railway stations only show relatively high accessibility value compare to the neighbourhoods away from the railway stations.

For bicycle, the average accessibility value remains steady. This is understandable for that on the one hand it can’t achieve its maximum in such travel time thresholds as the car performance, there thus need to be improved. However, the bicycle is a more flexible travel mode compared to train; it should go up for accessibility levels as the travel time threshold increases.

For the "bike + train" travel mode, there are some interesting conclusions could be reached from the Figure 13. Firstly, it is very similar with the bicycle travel mode from perspective of the average accessibility value. This means that the physical limitation of train could be eliminated by the flexible travel mode bicycle so the accessibility value increases as the travel time threshold increases. Secondly, the accessibility value by "bike+train" shows more improvement than by bike, this may illustrate that the potential for accessibility level improvement by multi-mode is bigger than the normal mode.

The change trend of accessibility value of bus&train is similar with the bike and "bike+train" as the travel time threshold increasing. And the accessibility value is even smaller than the bike and "bike+train" when the travel time threshold is 15-minute and 30-minute. This indicates that the average travel time by bus is quite long.

### 3.2. Potential accessibility measure

In this region, it is obviously that job accessibility by car is generally highest among all travel modes. For the other travel modes, some TAZ (neighborhoods) have the higher job accessibility near the train station where there are relative sufficient public transport supplies. For bike and bus&train modes, the major cities, Arnhem and Nijmegen form an area with easy to use bus, train, and bike. Although the level of job accessibility by these modes around train station is still less than by car, the differences can be acceptable. More details have been shown in Figure 14. And the table 7 below describes the statistical feature of the potential accessibility by different travel modes.

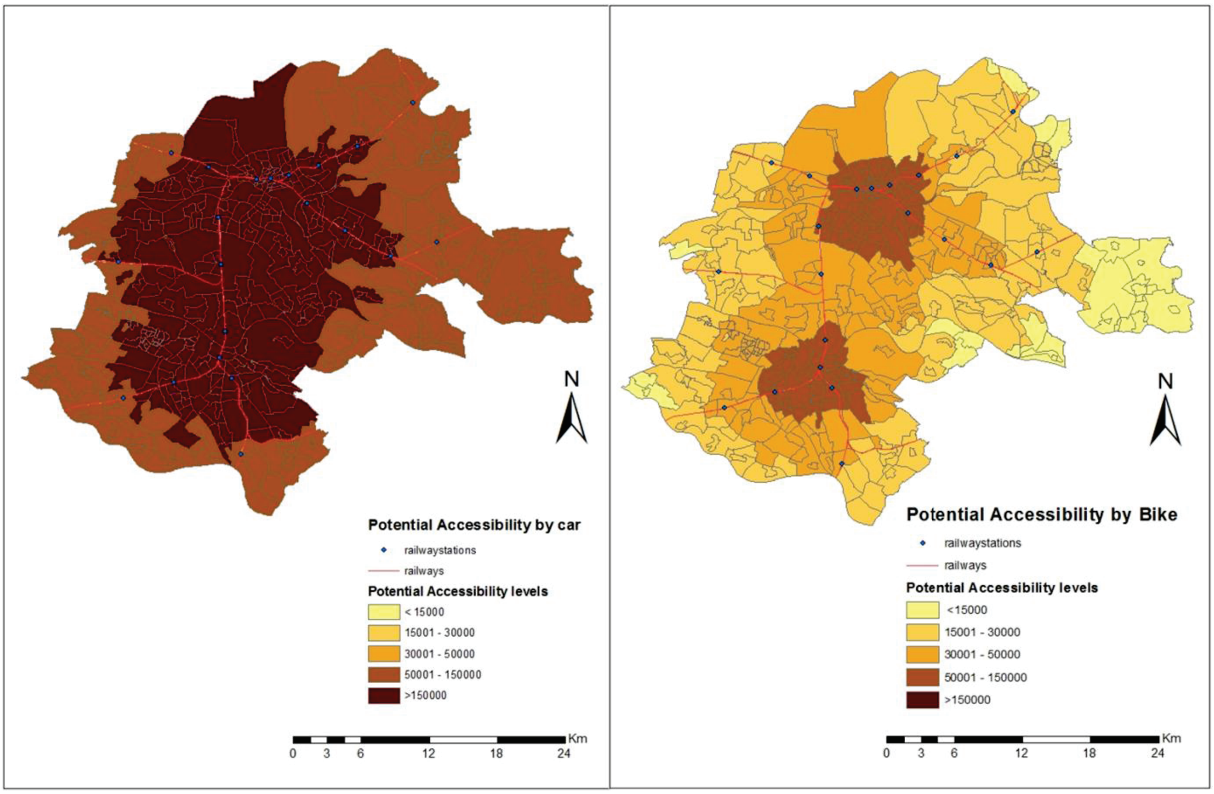



Figure 14: Potential accessibility value of different travel modes

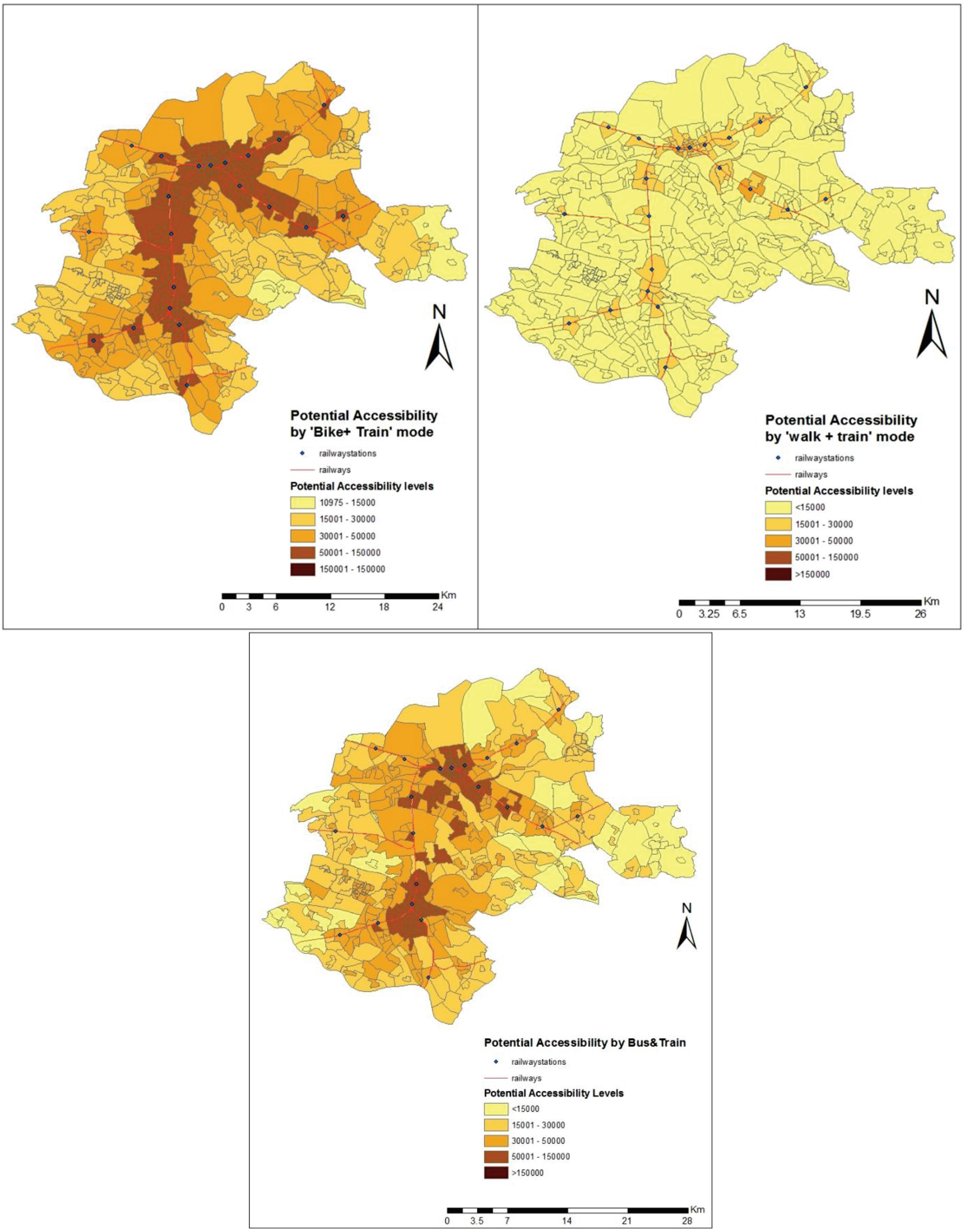



Figure 14: continued

The coefficient of variation is the smallest (0.1994) for car. Conversely, the value for train is the biggest. This comparison shows that the distribution of accessibility value by car is larger than by train, which is consistent with the feature of those travel modes. The more intuitional comparison of average accessibility value by different travel modes is shown in Figure 15 below:

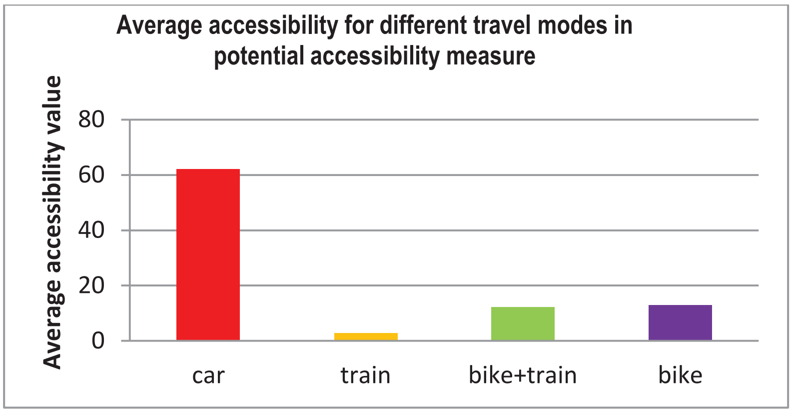



Figure 15: Average accessibility for different travel modes in potential accessibility measure

The potential accessibility measure without travel time threshold in this study counts all the job opportunities in the study area for each neighbourhood. While in the contour accessibility measure, only the job opportunities within the travel time threshold (15, 30, 45-minute) are counted for each neighbourhood. This is the first difference between the two measures. The second is that the potential accessibility measure considers the time decay effects on the job opportunities while the contour accessibility measure only counts the job numbers within the travel time threshold.

In a consequence, the first difference makes the potential accessibility measure reaching more area than the contour accessibility measure, and the job opportunities in those areas are counted by the potential accessibility measure and not counted by the contour accessibility measure. This effect may result in higher accessibility value for potential accessibility measure than the contour accessibility measure. And this effect is much more obvious when the travel time threshold is short in the contour accessibility measure. The second difference makes the potential accessibility measure shows less job opportunities comparing to the contour accessibility measure when they contain same area. This effect may result in lower accessibility value for potential accessibility measure than the contour accessibility measure. This effect is, especially, more and more notable when the travel time is becoming longer.

## 3.3. Accessibility Gap of different travel modes

### 3.3.1. Contour Accessibility Gap

This section analyses the Modal Accessibility Gap (MAG) based on the contour accessibility measure. The MAG between car and train, car and bicycle, car and "bike+train", and car and "bus&train" are shown in Figure 16, Figure 18 and Figure 20 and Figure 22 in the following separately.

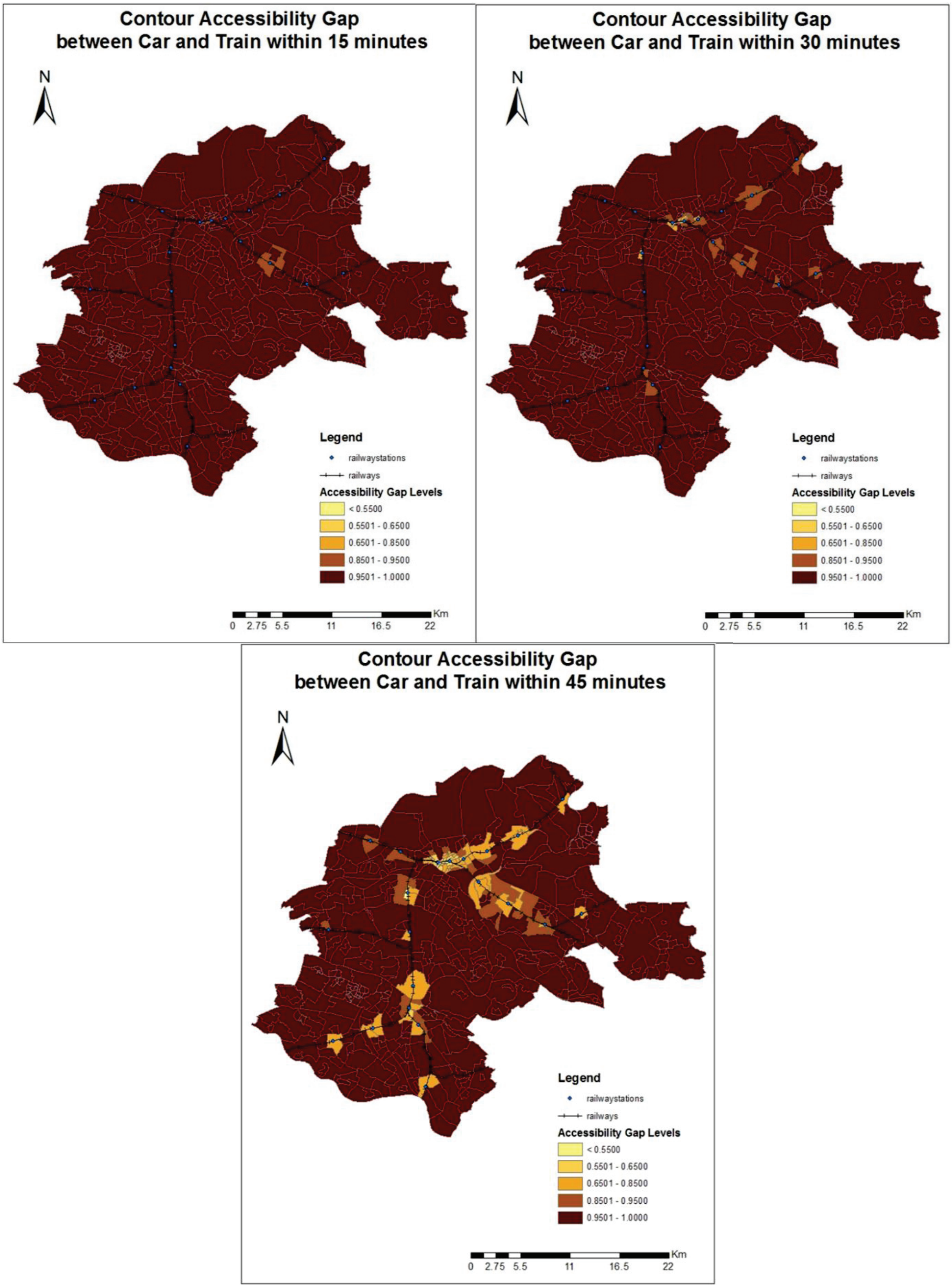



Figure 16: MAG between car and train based on the contour accessibility measure

From the Figure 16 is that the dark color takes most of the area, only little area where concentrates around the stations shows light color. As the travel time increases, there are much more neighborhoods near train stations easily reached by train. This means that the influence area of the train travel mode is confined to the station around area without considering the combination with other travel modes. More specifically, there is the large improvement space for the train travel mode to develop the combination with other travel modes.

To decrease the MAG value between car and train, one way is to promote the infrastructures. There are four new railway stations during the planning period now, the Nijmegen Goffert station, the Keerspoor Wijchen station, the Keerspoor Elst station and the Zevenaar Oost station, and will be applied in the next few years. But this approach cannot be done in a large scale considering the economic and environmental factors. Another approach is to change the job opportunity distribution in current situation to locate more job opportunities around the railway stations. While considering that those job opportunities can also be reached by car, the effect of MAG value between car and train through this method may not obvious.

The Figure 17 below gives the population distribution by the MAG value within 15-, 30-, 45-minute travel time threshold. The vertical axis in the Figure 17 represents the population percentage. The blue bar, red bar and cyan bar all concentrates within 0.9-1.0. The crest changes little as the travel time threshold changes. And this result suggests that the travel time threshold value has little influence on the value of MAG.

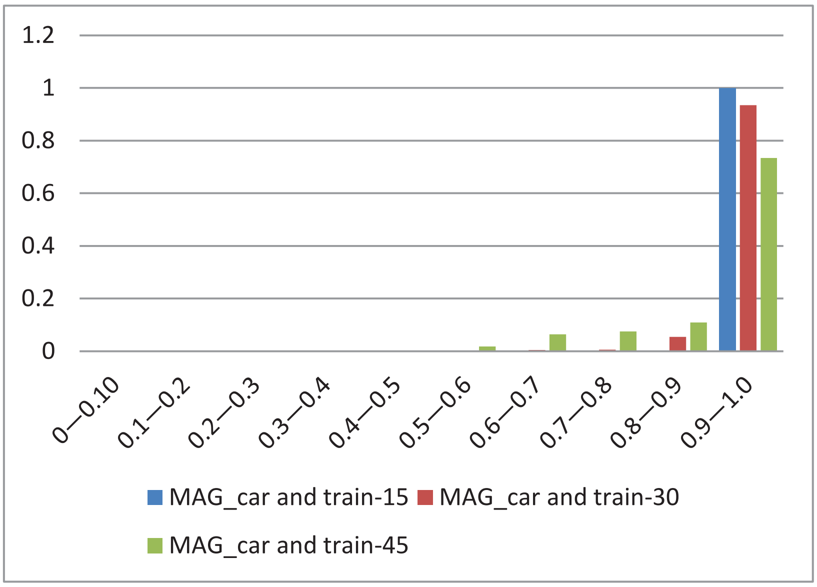



Figure 17: Population distribution of MAG value (between car and train)

The MAG statistical feature between car and train in contour measure within different travel time threshold shows below in Table 7. The average value of MAG declines about 0.009 when the travel time threshold moving from 15-minute to 30-minute, and when the travel time threshold moving from 30-minute to 45-minute, the value is 0.0369. The variation is quite small and the coefficient of variation increases during this process, which means that the decrease of MAG value happens not at a large scale in spatial distribution but concentrates at the railway station area.

| Time threshold | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| 15 minutes | 0.925 | 1 | 0.9992 | 0.0062 | 0.0062 |
| 30 minutes | 0.6964 | 1 | 0.9902 | 0.0376 | 0.0380 |
| 45 minutes | 0.4331 | 1 | 0.9533 | 0.1074 | 0.1126 |

Table 7: MAG statistical feature between car and train in contour measure

There are no neighbourhood that the MAG values become larger when the travel time threshold is 30-minute than 15-minute. The Table 8 below shows the statistical feature of the variation of MAG as the travel time threshold changes. The “MAG-up” means the number of neighbourhood whose MAG value become higher as the travel time threshold changes, and “MAG-down” means the number of neighbourhood whose MAG value become lower as the travel time threshold changes, and the “MAG-equal” means that the number of neighbourhood whose MAG value stays the same as the travel time threshold changes. As can be seen from the Table 8, the MAG value for most of neighbourhoods remains the same when the travel time threshold from 15-minute to 30-minute and when the travel time threshold from 30-minute to 45-minute.

| | MAG-up | MAG-down | MAG-equal | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|---|---|---|
| From 15 to 30 | 0 | 55 | 393 | -0.259 | 0 | -0.0090 | 0.0338 | -3.7495 |
| From 30 to 45 | 0 | 123 | 325 | -0.3721 | 0 | -0.0368 | 0.0802 | -2.1746 |
| From 15 to 45 | 0 | 123 | 325 | -0.525 | 0 | -0.0459 | 0.1051 | -2.2895 |

Table 8: MAG variation statistical feature between car and train in contour measure as travel time threshold varies

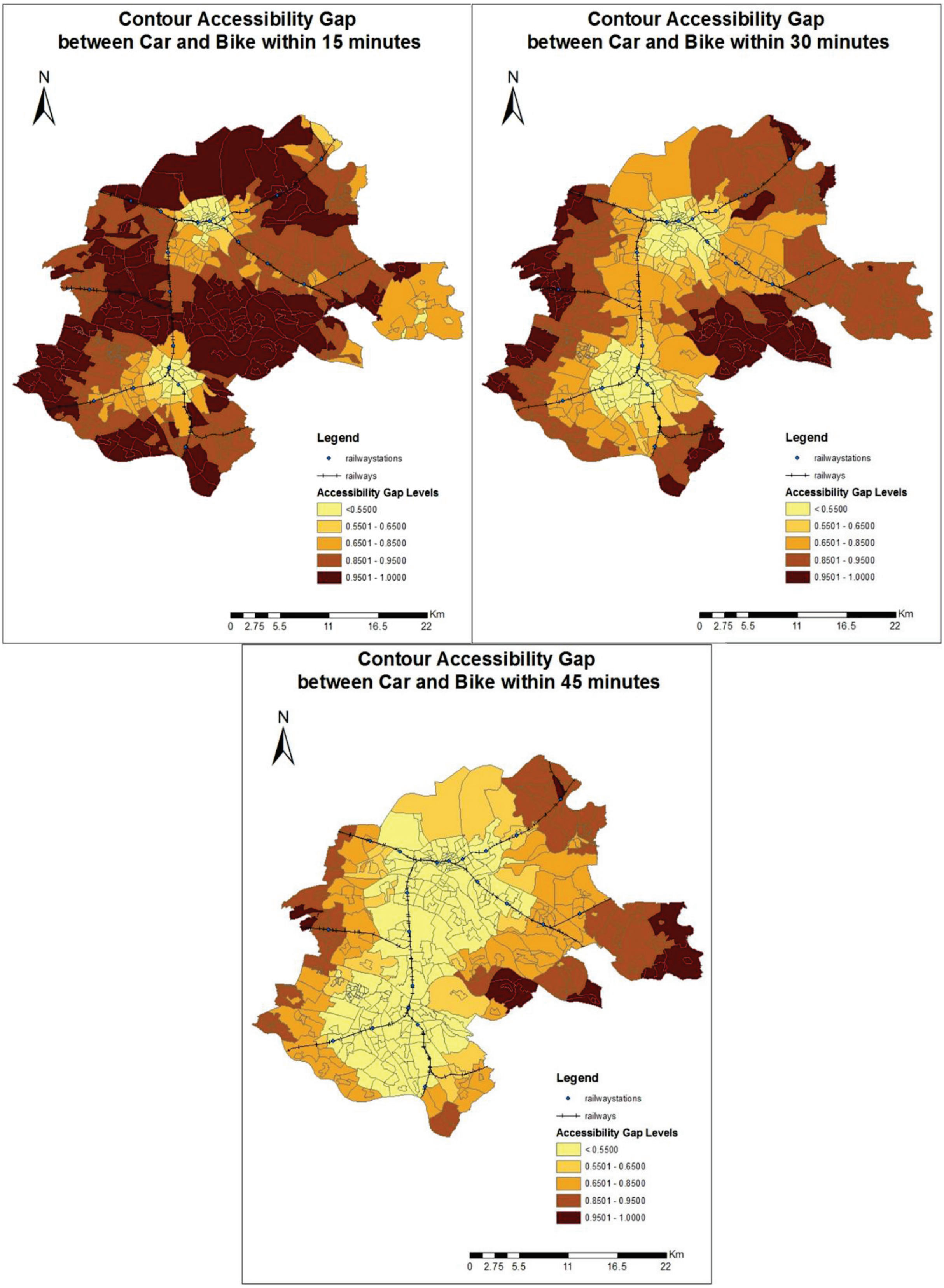



Figure 18: MAG between car and bicycle based on the contour accessibility measure

According to the Figure 18, the car shows significant advantage over bicycle within 15-minute travel time threshold in most of the study area. The light colour shows relative high job density (reference Figure 10), mostly concentrating in the Nijmegen and Arnhem municipalities when the travel time threshold is 15-

minute. This concentration is owing to the relative low speed by bicycle, so that the neighborhoods away from the abundant job opportunity area, especially the Nijmegen and Arnhem municipalities, cannot reach much job opportunity within 15 minutes.

The area covered by dark color in the figure with 15-minute travel time threshold can be distinguished as two situations. One is the area filled with forest and agriculture, like the North and Southwest of the study area, little job opportunities can be found in those area and nearby, the car thus has advantage over bicycle in finding job opportunities in the distant area within a short time threshold. The other one is the area mixed of agriculture, residential and commercial & industrial, like the middle part of the study area, where is also the middle the two job opportunity centres (Nijmegen and Arnhem municipalities), so it is more easy to reach the job opportunities centres within a short time threshold by car than by bicycle. However, as the time threshold increasing, the area will show lighter colour if it is possible to reach the job opportunities by bicycle, and keep dark colour if not. This may explain the situation in the middle part of the study area that the colour becomes lighter in a ladder form as the time threshold increasing.

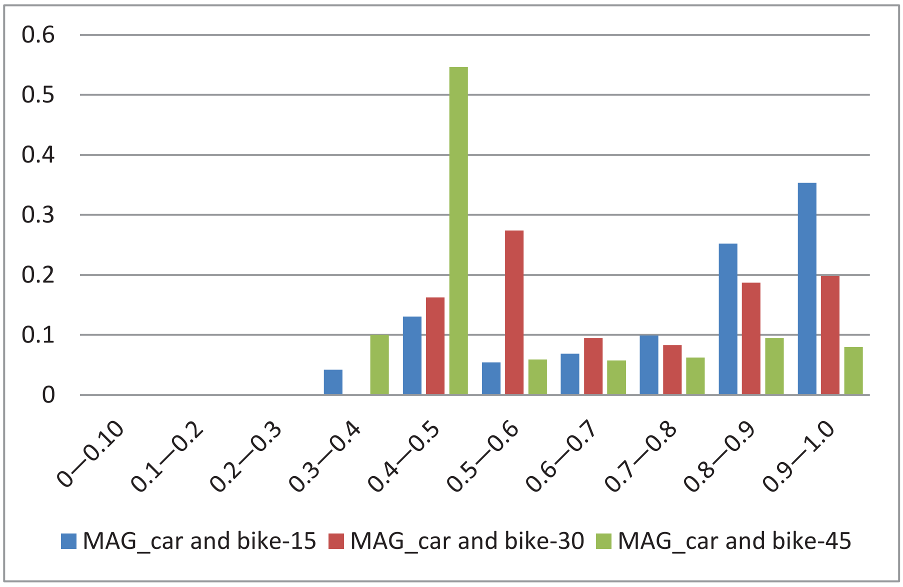



Figure 19: Population distribution of MAG value (between car and bicycle)

As to the corner reached out at the East of the study area, it is interesting that the color becomes darker as the time threshold increasing. Those areas are far from the job opportunity centres that the job opportunities can be reached by bicycle increasing little as the time threshold increasing, while job opportunities can be reached by car increasing much more than by bicycle as the time threshold increasing (as in Figure 12). Therefore, it makes sense for the accessibility gap enlarge as the time threshold increasing.

In general, the accessibility gap relieves in most area when the travel time threshold moves from 15-minute to 30-minute, and those area mainly concentrates on the inner side of the study area, where the job opportunities are relatively high. More specifically, the following gives the statistical feature of the MAG value and MAG variation value as time threshold increasing. The Figure 19 above gives the population distribution by the MAG value within 15-, 30-, 45-minute travel time threshold.

The influence of travel time threshold is more clear in this figure that nearly 35 percent of population living in the area with the MAG value within 0.9-1.0 when the travel time threshold is 15-minute, while there are more than 50 percent of population living in the area with the MAG value within 0.4-0.5 when the travel time threshold is 45-minute.

And the MAG statistical feature shows below in Table 9. Compared with Table 7, the average value of MAG between car and bicycle is smaller than MAG between car and train. It means that bicycle shows the advantage over train.

| Time threshold | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| 15 minutes | 0.3291 | 1 | 0.8255 | 0.1764 | 0.2137 |
| 30 minutes | 0.4697 | 0.9955 | 0.7566 | 0.1779 | 0.2352 |
| 45 minutes | 0.3769 | 0.9932 | 0.6172 | 0.1986 | 0.3217 |

Table 9: MAG statistical feature between car and bicycle in contour measure

However, when taking a more detail perspective, there are some neighbourhoods that the MAG values become even higher when the travel time threshold is 30-minute and 45-minute than 15-minute. This situation can be shown more directly below. The Table 10 below shows the statistical feature of the variation of MAG as the travel time threshold changes. The "MAG-up" means the number of neighbourhood whose MAG value become higher as the travel time threshold changes, and "MAG-down" means the number of neighbourhood whose MAG value become lower as the travel time threshold changes, and the "MAG-equal" means that the number of neighbourhood whose MAG value stays the same as the travel time threshold changes. There are 135 neighbourhoods that the MAG value become higher when the travel time threshold from 15-minute to 30-minute, and 12 neighbourhood that the MAG value become higher when the travel time threshold from 30-minute to 45-minute.

| | MAG-up | MAG-down | MAG-equal | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|---|---|---|
| From 15 to 30 | 135 | 312 | 1 | -0.3431 | 0.4318 | -0.0689 | 0.1279 | -1.8574 |
| From 30 to 45 | 12 | 436 | 0 | -0.4112 | 0.0412 | -0.1393 | 0.1018 | -0.7304 |
| From 15 to 45 | 46 | 402 | 0 | -0.5711 | 0.4597 | -0.2082 | 0.1915 | -0.9195 |

Table 10: MAG variation statistical feature between car and bicycle in contour measure as travel time threshold varies

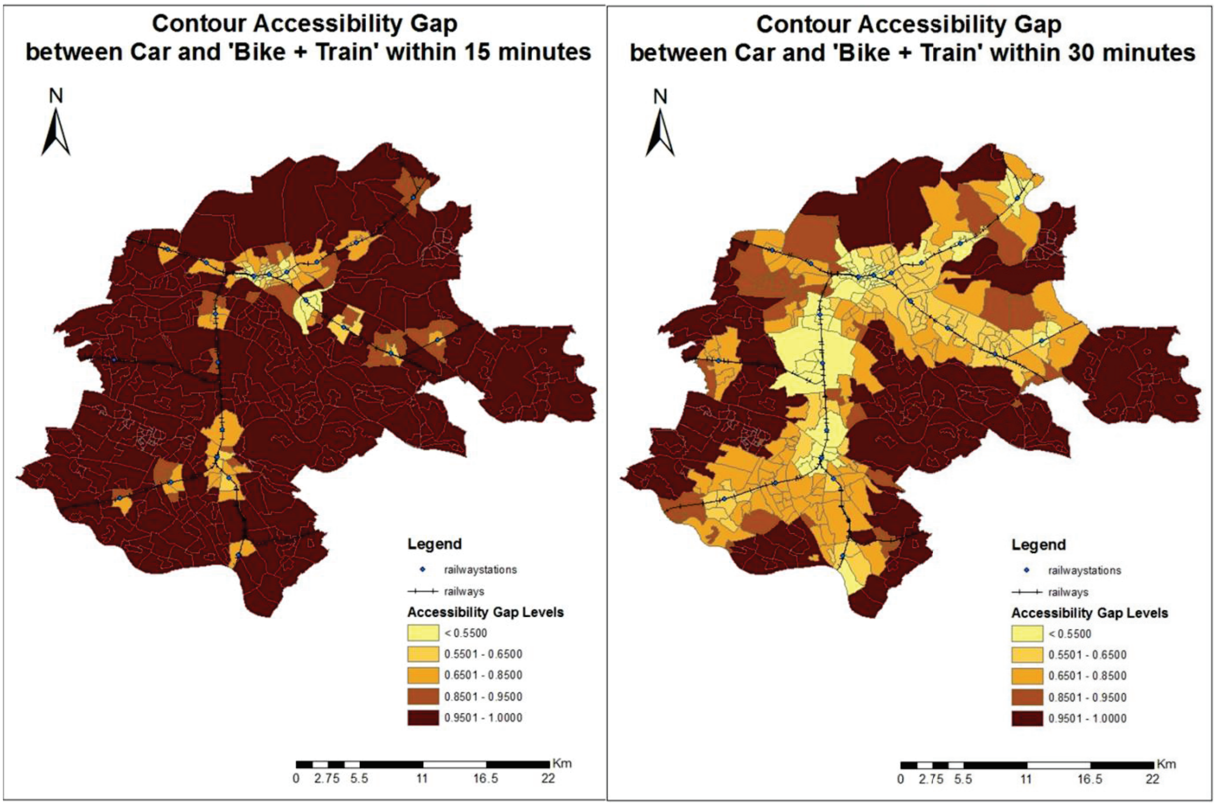



Figure 20: MAG between car and "bike+train" based on the contour accessibility measure

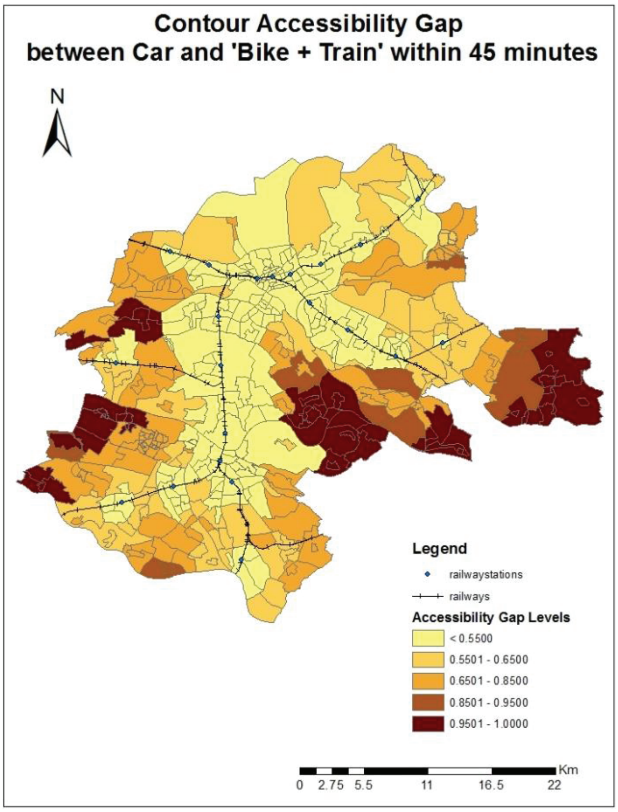



Figure 20: continued

The Figure 20 above shows that the light color area concentrates around the stations when the travel time threshold is 15-minute and rail lines when the travel time threshold is 30-minute. And this spatial characteristic caused by the feature of railway still exists as the travel time threshold increasing to 45-minute.

Compared to Figure 16, the Figure 20 with 15-minute travel time threshold is similar with the Figure 16 with 45-minute travel time threshold. Firstly, the influence of "bike+train" travel mode is still limited around the station area as shown in the Figure 16, and the second is that the combination of bicycle and train does expend the influence of train travel mode to a larger area considering the influence of 15-minute travel time threshold by "bike+train" is comparable to 45-minute travel time threshold by train. While the Figure 20 with 30-minute and 45-minute travel time threshold is similar with the Figure 21 with 30-minute and 45-minute travel time threshold, especially for the colour changing in a ladder form as the time threshold increasing.

The Figure 21 below shows the population distribution of MAG value (between car and "bike+train"). There are nearly 60 percent of population living in the area with the MAG value within 0.9-1.0 when the travel time threshold is 15-minute from the Figure 21. But the crest of blue bar within 0.9-1.0 are disappeared when the travel time threshold increases to 30-minute. It means that most residents are dependent on private car in daily life especially in 15-minute travel time threshold. On the contrary, as the travel time increases, more and more people would like to prefer to chose "bike+train" to go out for job, which can be seen in the below.

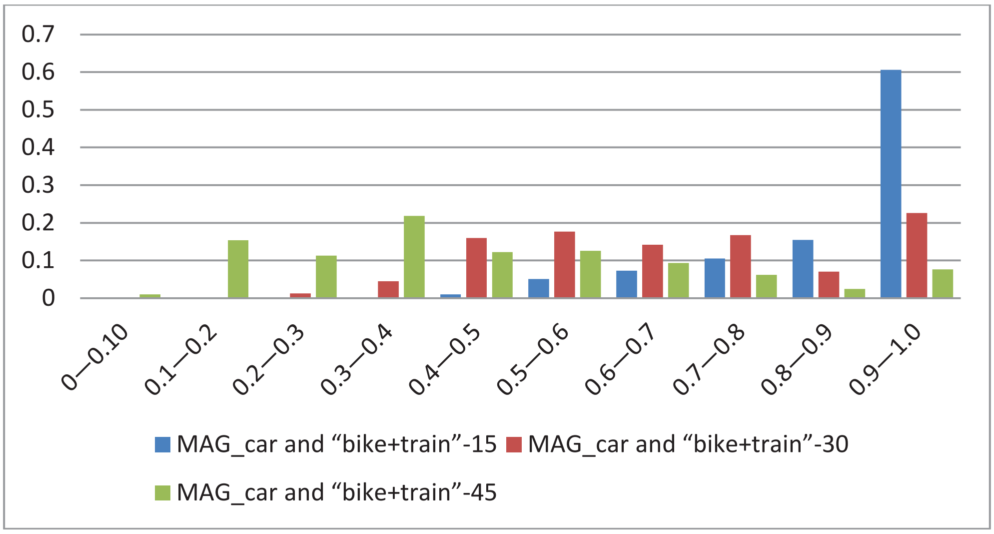


Figure 21: Population distribution of MAG value (between car and “bike+train”)

The MAG statistical feature between car and “bike+train” shows below in Table 11. Similar as the situation in Table 9, the average MAG value reduces obviously as the travel time threshold increases. The average value of MAG declines about 0.15 when the travel time threshold moving from 15-minute to 30-minute, and about 0.22 when the travel time threshold moving from 30-minute to 45-minute. This shows that as the travel time threshold increases, the accessibility advantage of car over the “bike+train” is reducing. Especially, the minimum MAG value when the travel time threshold is 45-minute is close to zero, implies that in some neighbourhoods, it is nearly even for car and “bike+train” on the job accessibility.

| Time threshold | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| 15 minutes | 0.4309 | 1 | 0.9290 | 0.1369 | 0.1473 |
| 30 minutes | 0.2370 | 1 | 0.7749 | 0.2145 | 0.2768 |
| 45 minutes | 0.0776 | 1 | 0.5597 | 0.2523 | 0.4507 |

Table 11: MAG statistical feature between car and “bike+train” in contour measure

There are still some neighbourhoods that the MAG values become even higher when the travel time threshold is 30-minute than when the travel time threshold is 15-minute. This situation can hardly be seen directly in the Figure 20. The Table 12 below shows the statistical feature of the variation of MAG as the travel time threshold changes. The “MAG-up”, “MAG-down” and the “MAG-equal”have the same meaning as in Table 8. There are 127 neighbourhoods that the MAG value remains the same when the travel time threshold from 15-minute to 30-minute. This means that there is no influence for those 127 neighbourhoods when the travel time threshold moving from 15-minute to 30-minute.

| | MAG-up | MAG-down | MAG-equal | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|---|---|---|
| From 15 to 30 | 10 | 311 | 127 | -0.5449 | 0.0435 | -0.1540 | 0.1559 | -1.011 |
| From 30 to 45 | 5 | 407 | 36 | -0.5373 | 0.0476 | -0.2152 | 0.1247 | -0.5797 |
| From 15 to 45 | 0 | 412 | 36 | -0.8433 | 0 | -0.3693 | 0.1983 | -0.5371 |

Table 12: MAG variation statistical feature between car and “bike+train” in contour measure as travel time threshold varies

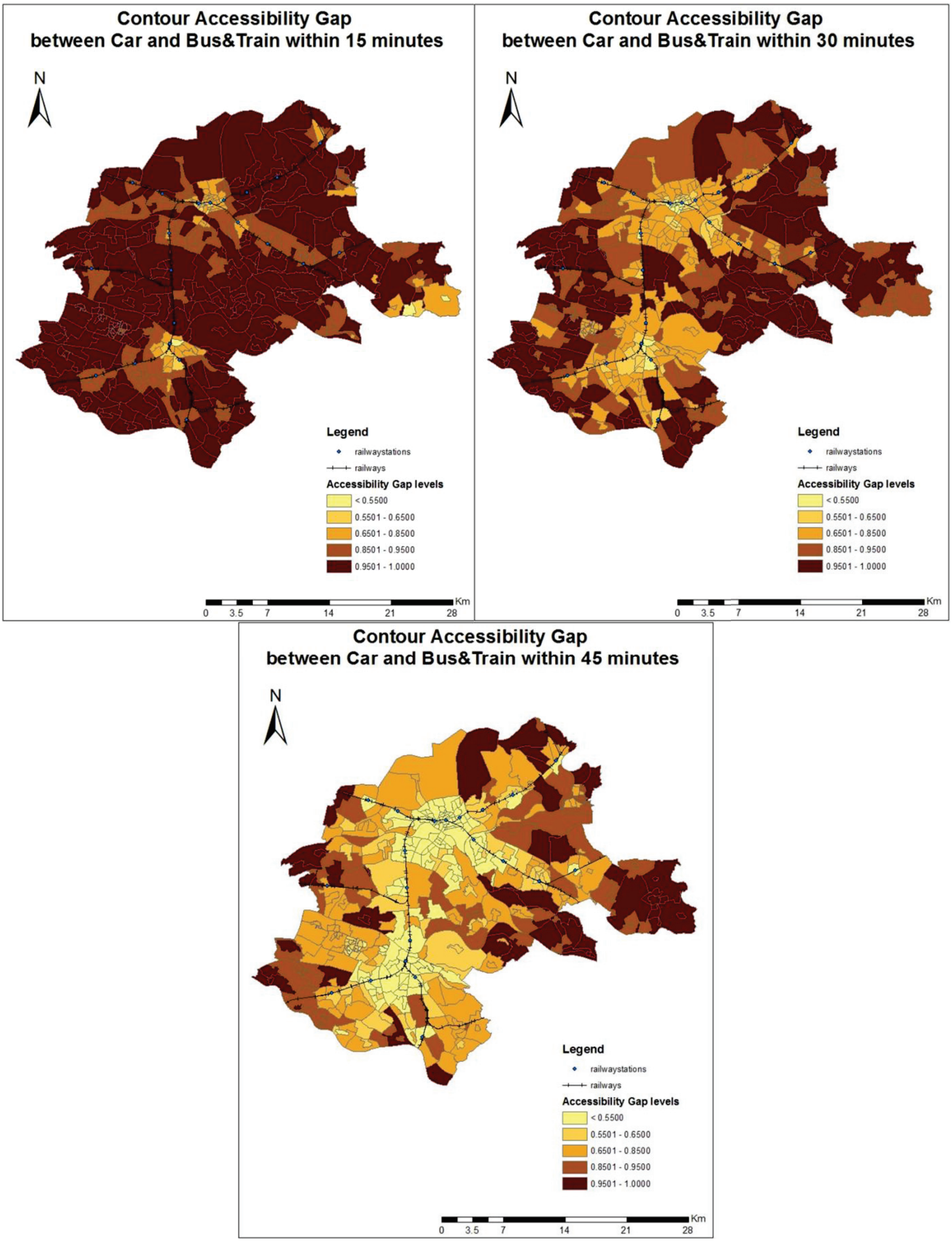



Figure 22: MAG between car and “bus&train” based on the contour accessibility measure

The Figure 22 above shows the MAG between car and bus&train based on the contour accessibility measure. It can be observed from the Figure 22 that the spatial distribution of train infrastructure has influence on the MAG value spatial distribution but the effect is not so much as the MAG between car and “bike+train” in Figure 20 above. The more influence may come from the spatial distribution of land use, the lighter color area most concentrates in the area with abundant job opportunity where industrial and commercial locates and with a large number of population where also with abundant bus infrastructures in common.

And take the East part of the study area, the Montferland municipality area for example; the MAG value is getting bigger as the travel time threshold increasing. The relative low MAG value when the travel time threshold is 15-minute indicates that the bus infrastructures keep high service quality in this area, but as the travel time threshold increasing, people traveled by car can find job opportunities located in relative distant Arnhem municipality much more easy than by bus&train. Therefore, to improve this situation, one important way is to improve the bus&train links between the Montferland municipality and the Arnhem municipality.

The Figure 23 gives the population distribution by the MAG value with different travel time threshold. As the figures (Figure 17, Figure 19 and Figure 21) shown above, the blue bar and the red bar have concentration within 0.9-1.0. The crest decays as the travel time threshold increases. And this result shows that the travel time threshold value has a remarkable influence on the value of MAG between car and bus&train when it is calculate based on the contour accessibility measure.

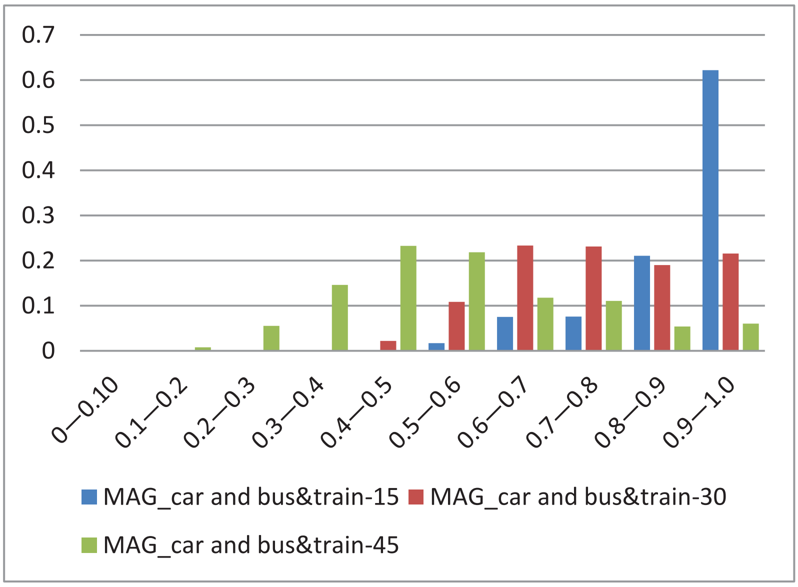


Figure 23: Population distribution of MAG value (between car and bus&train)

The average value of MAG declines about 0.0915 when the travel time threshold moving from 15-minute to 30-minute, which is shown in Table 13. Although the data is different from the other previous travel mode, this table reflects similar situation with the previous MAG statistical feature between car and other travel modes. From the Table 7, Table 9, Table 11, and Table 13 we can see that the average value of MAG decreases when the travel time threshold increases.

| Time threshold | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| 15 minutes | 0.4198 | 1 | 0.9238 | 0.1003 | 0.1085 |
| 30 minutes | 0.3709 | 1 | 0.8323 | 0.1463 | 0.1758 |
| 45 minutes | 0.1104 | 1 | 0.6607 | 0.2191 | 0.3316 |

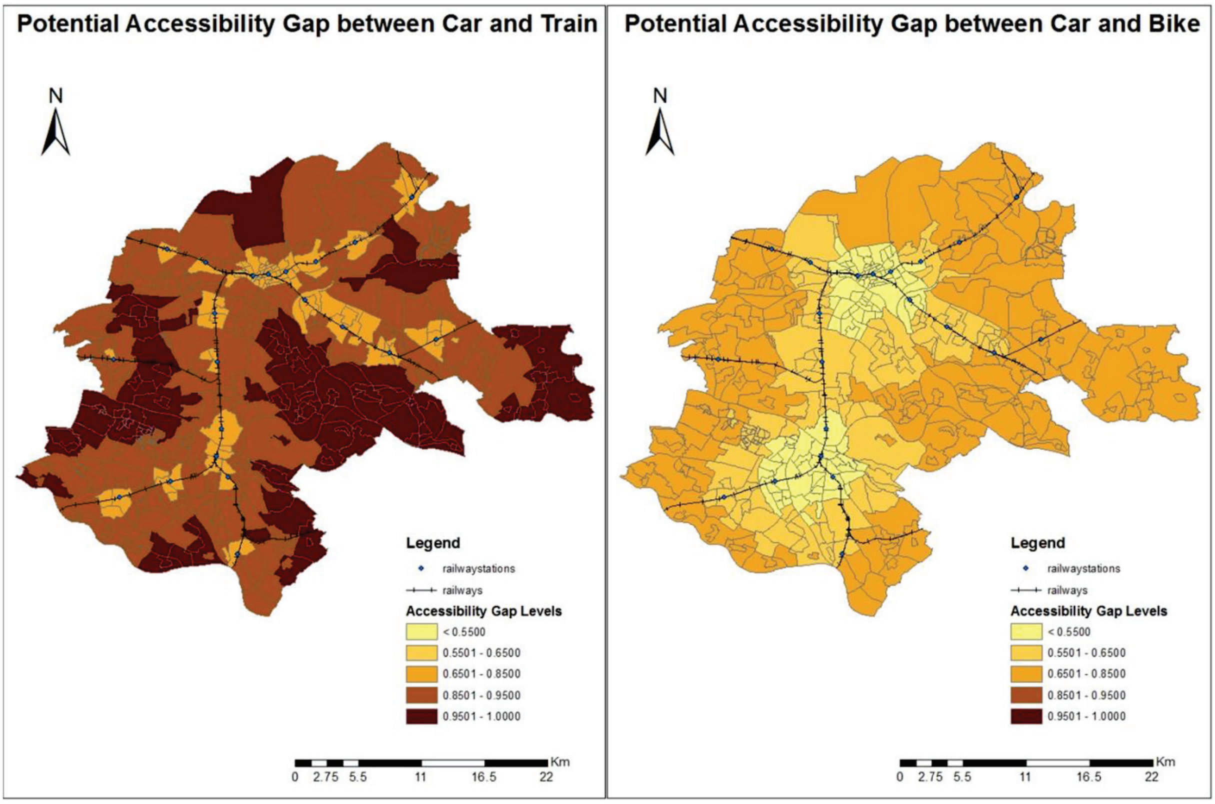
Table 13: MAG statistical feature between car and bus&train in contour measure

Similar as above, the Table 14 below shows the statistical feature about the variation value of the MAG as the travel time threshold increases. And similar like the Table 8 and Table 10, most of the neighbourhoods have a smaller MAG value and only a few of neighbourhoods have a bigger MAG value as the travel time threshold increases. It shows that when individuals go for work using a longer travel time, they would prefer to choose the public transport (train, bike+train, and bus&train). It thus concludes that the public transport has advantage on a long travel distance.

| | MAG-up | MAG-down | MAG-equal | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|---|---|---|
| From 15 to 30 | 49 | 383 | 16 | -0.3923 | 0.5083 | -0.0915 | 0.1050 | -1.1483 |
| From 30 to 45 | 11 | 436 | 1 | -0.4594 | 0.0369 | -0.1716 | 0.0998 | -0.5816 |
| From 15 to 45 | 18 | 429 | 1 | -0.7717 | 0.5452 | -0.2631 | 0.1821 | -0.6921 |

Table 14: MAG variation statistical feature between car and bus&train in contour measure as travel time

### 3.3.2. Potential Accessibility Gap



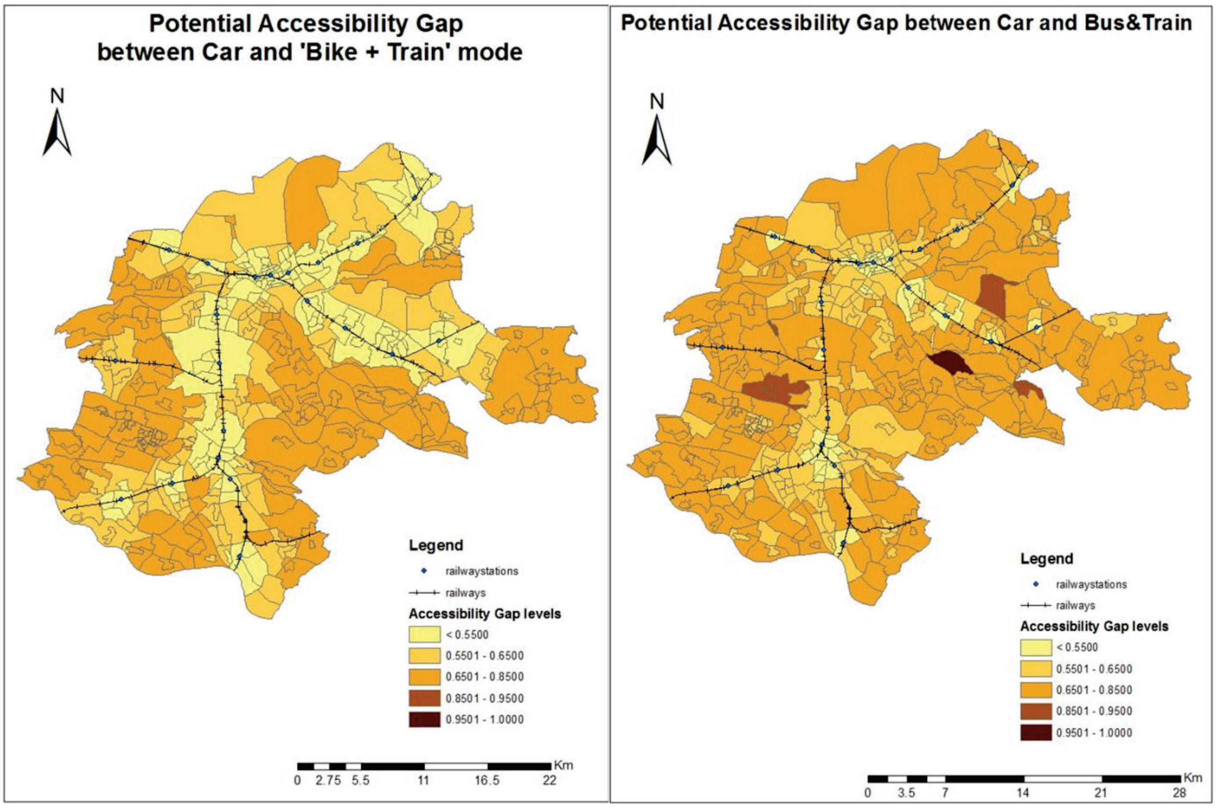



Figure 24: MAG between car and other travel modes based on the potential accessibility measure

The Figure 24 above shows the MAG between car and other travel modes based on the potential accessibility measure. The figure of MAG between car and train shows dark in most of the area and only the area around the stations and railway show some relatively light color. Compared to Figure 16 which shows the MAG between car and train based on the contour accessibility measure, the MAG between car and train based on potential accessibility measure shows much improvement.

The figure of MAG between car and bicycle and the figure of MAG between car and "bike+train" are similar in most of the area except that the station around area show weak color in the figure of MAG between car and "bike+train" than in the figure of MAG between car and bicycle.

The MAG between car and bus&train in Figure 24 shows no concentration around the railway stations or lines as the MAG between car and train or car and "bike+train" shows, or the abundant job opportunity area as the MAG between car and bicycle shows. On the contrary, it is obviously that several neighborhoods show much higher MAG value with relatively darker color. This is because that the bus network covers most of the area, and the travel speed of bus is much bigger than bicycle, so the neighborhoods away from the abundant job opportunity area can also be reached within a tolerable travel time. So the dark area in Figure 24 for the MAG between car and bus&train indicates a poor bus facility.

The Table 15 below shows the statistical feature of the MAG value based on the potential accessibility measure. The MAG between car and train shows the biggest average value of 0.8994 and the smallest coefficient of variation value of 0.0768, while the MAG between car and "bike+train" shows the smallest average value of 0.5979. And the average MAG value between car and bus&train is lower than between car and bicycle and between car and "bike+train", this inflects the Dutch transport feature of encouraging bicycle on the one hand, and also implies the improvement for bus supply.

| MAG type | Minimum value | Maximum value | Average value | Standard deviation | Coefficient of variation |
|---|---|---|---|---|---|
| Car and train | 0.6475 | 0.9921 | 0.8994 | 0.06908 | 0.0768 |
| Car and bicycle | 0.4061 | 0.7967 | 0.6213 | 0.1056 | 0.1699 |
| Car and “bike+train” | 0.2664 | 0.8102 | 0.5979 | 0.1170 | 0.1958 |
| Car and bus&train | 0.3568 | 0.9963 | 0.6520 | 0.0975 | 0.1496 |

Table 15: MAG statistical feature between car and other travel modes in potential accessibility measure

### 3.4. Discussion

From the analysis about the accessibility and MAG above, some results can be concluded. The first is that the effect of travel time threshold on the contour accessibility and MAG based on the contour accessibility measure. The average MAG value is decreasing as the travel time threshold increasing for all the MAG types. It means that when the distance for job becomes longer, car would lose some advantage and the public transport may be popular among people. This is obvious from the Figure 25 below.

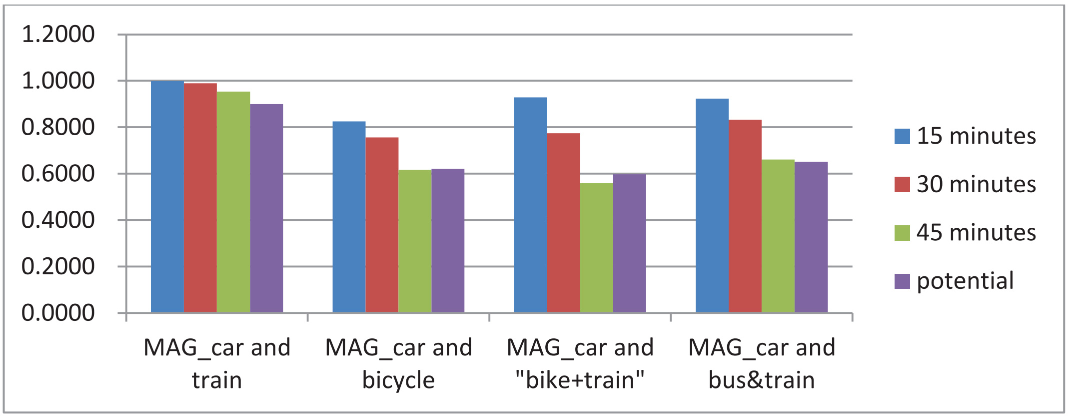



Figure 25: Average MAG value based on the contour and potential accessibility measure

This trend is consisted with the results of Kawabata (2007), who calculated the MAG between cars and public transit based on the job accessibility for the Boston metropolitan area and the San Francisco Bay Area in 1990 and 2000, though these areas are not really comparable to the study area. The trave time threshold of 30-minute, 45-minute and 60-minute are tested and their results show that the MAG between cars and public transit decreases as the travel time threshold increasing in the both study areas and both periods.

The mathematical explanation about this situation has been given in Kwok et al. (2004). Kwok et al. (2004) proved that the increase or decrease of MAG value is determined by the change of accessibility of different travel modes. If the growth rate of the cars accessibility is higher than the growth rate of public transit, then the MAG value will decrease and vice versa. Considering that the sign of numerator is opposite in this paper to Kwok et al. (2004). Therefore, since the accessibility growth rate of train, bicycle, “bike+train” and bus&train is higher compared that of car as the travel time threshold is increasing in this paper and Kawabata (2007), the decreases of MAG as the travel time threshold increasing is rightly so.

While further on, there is no explanation about why the accessibility growth rate of train, bicycle, “bike+train” and bus&train in this paper or public transit in Kawabata (2007) is higher compared that of car. As to this research, this can be explained as that the base of the car accessibility value within 15-minute is quite big so the improvement is limited as the travel time threshold increasing, and low accessibility value within 15-minute of other travel modes allows much more improvement than car. It has already been verified in Table 6 in the section 4.1.

Another feature in the Figure 25 is that the MAG based on the potential accessibility measure is roughly equal to the MAG based on the contour accessibility measure with 45-minute travel time threshold.

There are two patterns can be observed from the analysis about the spatial distribution of MAG in general. The first pattern is that the MAG between car and other travel modes is relatively low in the two job opportunity abundant area, the Arnhem municipality and the Nijmegen municipality. This reflects the effect of land use type or job opportunity distribution on the MAG value. The second pattern is that the MAG between car and other travel modes is relatively low in the transportation abundant areas, such as the area around the railway stations, along the railway lines or with abundant bus infrastructures. This presents the effects of the resource of transportation on the MAG value.

So in the next chapter the effects of two aspects on the MAG value are tested by constructing scenarios from the two perspectives, the transportation perspective and the land use perspective (or job distribution perspective).

# 4. SCENARIO DEVELOPMENT

This study constructs the scenario from two aspects: land use and transportation. And three scenarios are conducted in this study for the Stadsregio Arnhem Nijmegen in 2020. The first scenario considers decreased car speed caused by the increasing number of cars on road especially during the peak hour in the morning. The second scenario distributes the new job opportunity around some railway stations to improve the public transit accessibility. The third one is the combination of the scenario 1 and 2.

## 4.1. Scenario 1: Increased number of cars used on road

As the convenience, more and more people choose car as their main travel mode to work. And as the number of car increases, the travel speed of car decreases during the peak hours. The table below shows the car number increases in the recent years in Arnhem Nijmegen City Region area.

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|
| Number of cars | 309888 | 314680 | 321068 | 307086 | 312273 | 317021 | 322741 | 327214 | 329675 |

Table 16: Number of car in the study area[4]

In this scenario, the travel speed of car is assumed to be **decreased by 30 percent** for each kind of road in terms of increased number of cars on the road during the morning peak hours. The number and distribution of job opportunities remain the same. And the result speed shows below in Table 17 according to Table 5.

| Average speed during peak hours (km/h) / Type of road | **Scenario 1** | **Baseline scenario** |
|---|---|---|
| Auto road | 52.5 | 75 |
| Regional road | 45.5 | 65 |
| Local road | 38.5 | 55 |
| Street | 28 | 40 |
| Others | 28 | 40 |

Table 17: Compare the average speed for each kind of road between scenario 1 and the baseline scenario

While the speeds of other travel modes remain the same. The actual change in this scenario is that the travel time to job opportunities by car increase to 1.43 times as the baseline scenario performs. The car accessibilities based on the contour and potential accessibility measure are recomputed according to the new travel time. Then, the new MAG values between car and other travel modes are calculated and shown below.

[4] The data is gathered from (CBS, 2013c), and the data for the Mook en Middelaar municipality is not included in the table.

### 4.1.1. MAG variation based on contour accessibility measure

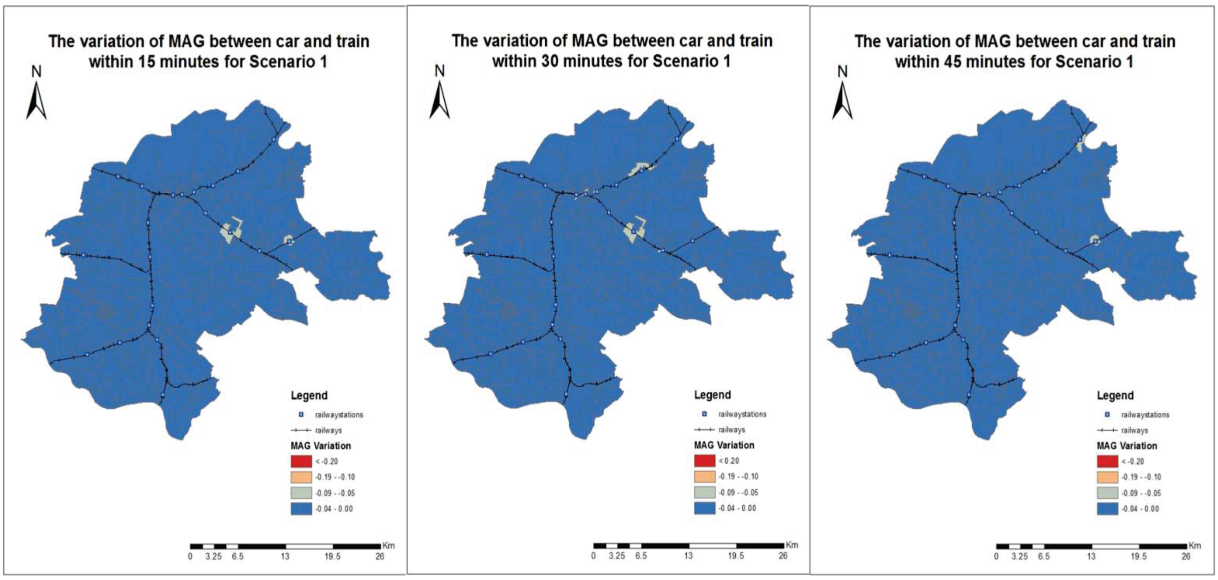



Figure 26: MAG variation between car and train based on the contour accessibility measure in scenario 1

The Figure 26 above shows that most parts of the study area have no dramatic change. For most of the place away from the railway stations, the accessibility value by 'walking+train' is zero. Although the car speed has been reduced in this scenario, those neighborhoods still remain stable. It means that 'walk+train' is not suitable for people who live far away from the rail station. Only the neighborhoods around the railway stations show some MAG decrease and the number of such neighborhoods increases as the travel time threshold becomes longer. This means that the location inequity among the different neighborhoods for the MAG decreases. Thus the more attention should be paid to avoid the enlargement of the location inequity, especially in the scenario 2 and 3 that will be discussed below, where the MAG increase situation appears.

To sum up, to improve the MAG value cannot just dependent on one aspect. The influence of reducing car speed is so miniscule that other measurements must be explored to improve the public transit and decrease the MAG.

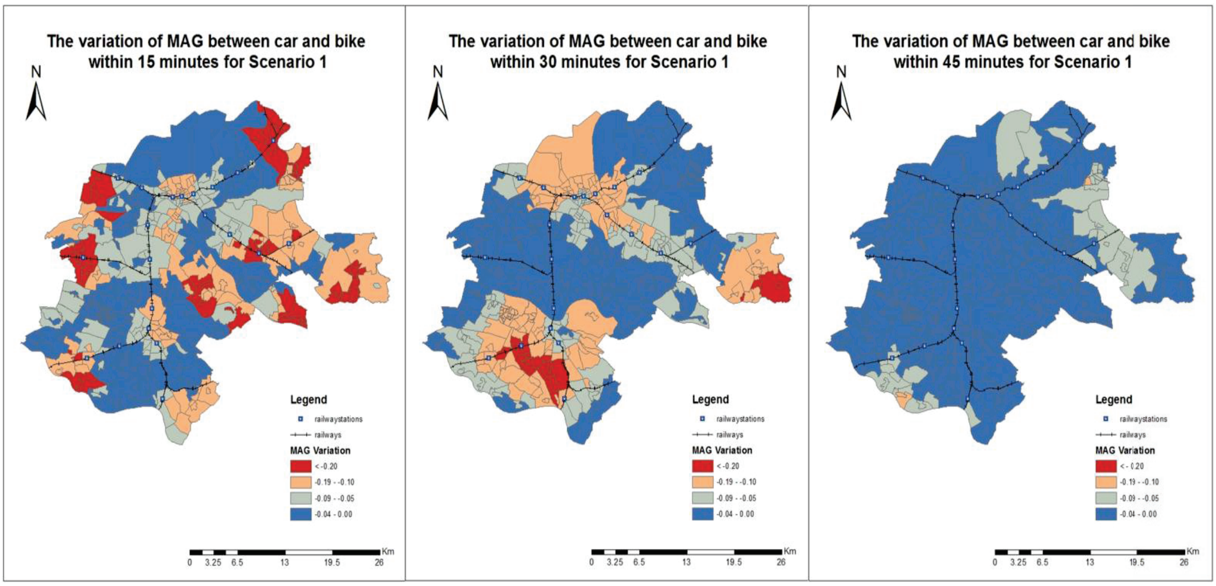



Figure 27: MAG variation between car and bicycle based on the contour accessibility measure in scenario 1

The MAG between car and bicycle has much more significant decrease than the MAG variation between car and train, especially for 15-minute and 30-minute travel time threshold, which could be illustrated by the color change in the Figure 27 above. It can also be observed from Figure 27 that the middle part of the study area shows higher MAG decrease when the travel time threshold is 15-minute than 30-minute. Meanwhile the neighborhoods around the Arnhem municipality, the Nijmegen municipality and the Montferland municipality show relatively high magnitude of MAG decrease compared to the neighborhoods in the middle part of the study area. This is consistent with the fact that the travel time by car from the neighborhoods in the middle part of the study area to the job opportunity cluster place, the Arnhem and Nijmegen municipalities, is around 15 minutes. It is thus the middle part are the sensitive place and easily to be influenced.

And the travel time by car between the Arnhem and Nijmegen municipalities is around 30 minutes. When the time increases in terms of lower car speed, the decreased number of jobs can be reached in these two municipalities within the same threshold. Furthermore, since the job opportunity distributed around the Arnhem municipality is more than that around the Nijmegen municipality, the decrease rate of car accessibility for the neighborhoods around the Nijmegen municipality is higher than that around the Arnhem municipality, which makes the neighborhoods around Nijmegen municipality emerge higher magnitude of MAG decrease than that around the Arnhem municipality. And the red color in the Montferland municipality is resulted from the similar reason to the Nijmegen municipality.

This manifests clearly how the travel time threshold influence the accessibility and MAG value based on the contour accessibility measure. As the car speed is decreased, the neighborhoods are sensitive to the MAG change if their travel time to the abundant job opportunities become out of the travel time threshold. On the contrary, when the travel time threshold is 45-minute, which the range can tolerate a larger change than 15-minute threshold, the MAG variation becomes unobvious at the whole scale. It reflects that the measurement of lower car speed does not have much influence on the accessibility and MAG when people can accept the relative long travel time to work.

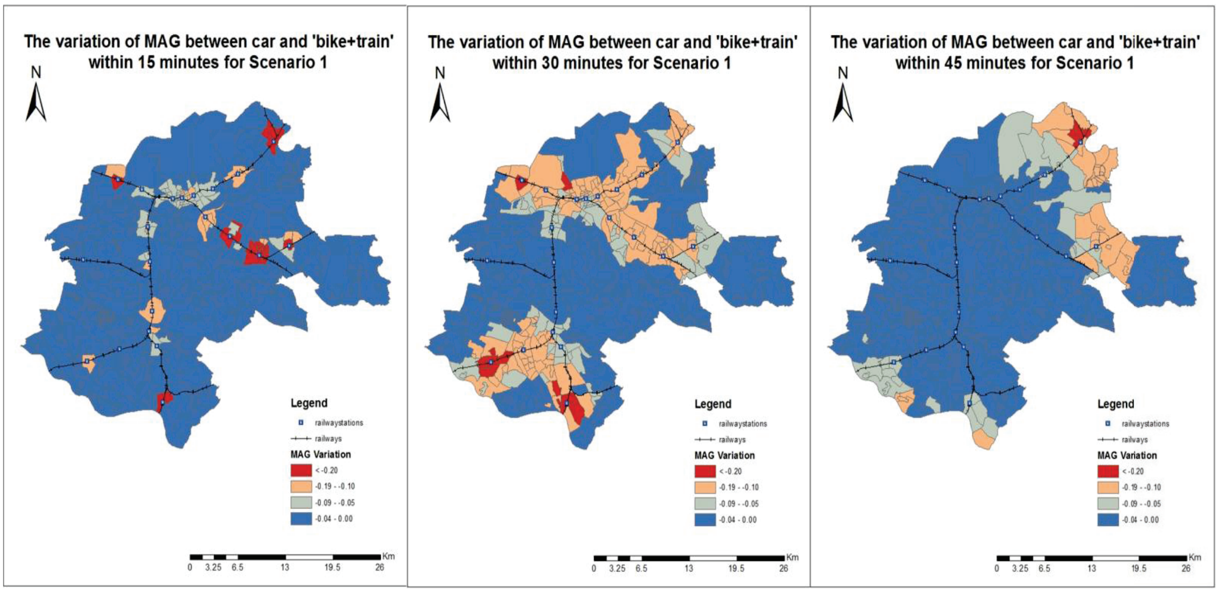


Figure 28: MAG variation between car and “bike+train” based on the contour accessibility measure in scenario 1

Figure 28 shows that most neighborhoods show no substantial change excepted for those around the railway stations within 15-minute. When the travel time threshold is 30-minute, it is obvious that the relative high MAG decrease happens in the North part and South part of the study area respectively, and along the railway lines. Meanwhile the neighborhoods in the middle part of the study area along the railway lines do show MAG decrease. Furthermore, when the travel time threshold is 45-minute, the MAG variation remained stable in most part of the study area like in Figure 27 expect for the Northern study area where still shows a relative high MAG decrease, especially around the Dieren station.

Compared with the MAG variation between car and train in scenario 1, the influence of lower car speed for the MAG decrease is much evident. This demonstrates the advantage of multimodal travel mode of the "bike+train" and its important role in the transportation improvement in this study area. This opinion is consistent to the fact that the modal share of bicycle as the access mode to the train station is increasing in recent years, from 35% (Rietveld, 2000) to 39% (Givoni et al., 2007), and up to 42% (Spoorbouwmeester, 2012).

The Population distribution of MAG variation in Figure 29 below also shows the same situation as in Figure 28 above. When the travel time threshold is 30-minute, almost 40 percent of population is covered by the variation range of -0.1 and -0.2 and 5 percent of population is covered by the variation range of -0.2 and -0.3. This may means that the advantage of travel mode "bike+train" is most obvious when travel time is about 30 minutes.

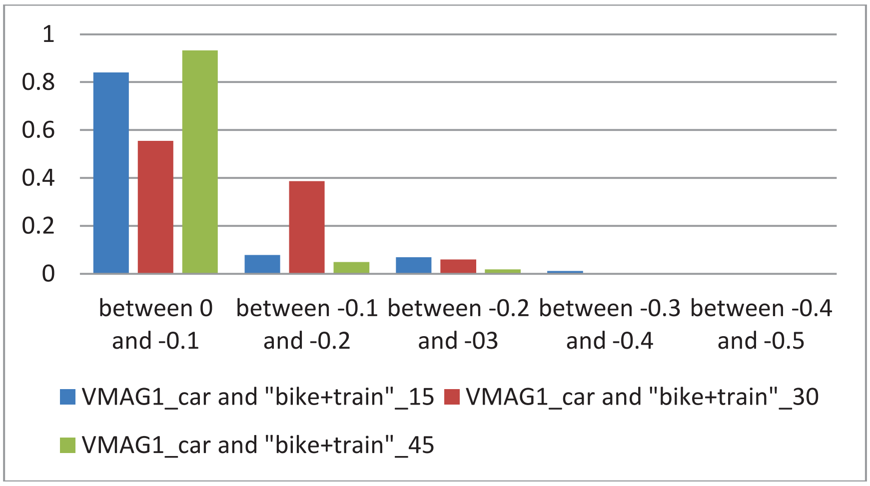



Figure 29: Population distribution of MAG variation value between scenario 1 and the baseline scenario (between car and "bike+train")

The MAG variation is not concentrating at some area or around the station in the Figure 30 below when the travel time threshold is 15-minute comparing to Figure 27 and 35. The neighborhoods with no MAG variation scatter in the study area. Compared with the Figure 22 in the section 4.3.1 it turns out that those neighborhoods are all with the relatively high MAG value (in fact they are all with the highest value +1) in the baseline scenario. This implies that for those neighborhoods the insufficient transport supply (bus) that even the car accessibility makes a reduction, there is yet little relative advantage compared to car. Thus, there still has a large space for bus improvement.

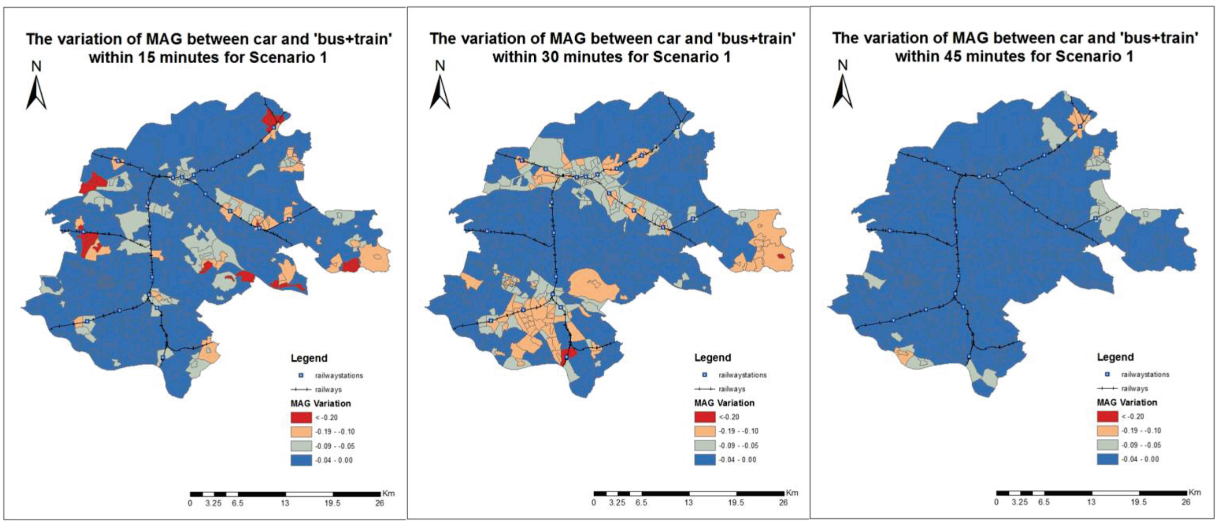



Figure 30: MAG variation between car and bus&train based on the contour accessibility measure in scenario 1

When the travel time threshold is 45-minute, there are still some neighborhoods with no MAG variation. However, except for the neighborhood Verspreide huizen Imbosch en Terlet in the Rozendaal municipality, north of the Arnhem municipality, the other neighborhoods has a significant advantage for their location in the sense that people there can reach any job opportunities in the whole Arnhem Nijmegen City Region. To decrease the MAG in such neighborhoods, it should resort to other measurements. One proper suggestion is to take the bus infrastructure improvement into account in those neighborhoods, especially their connection with the Arnhem and Nijmegen municipalities. And the neighborhood Verspreide huizen Imbosch en Terlet, though it shows poorest bus transportation, there is no need to focus on this part unless the government has the urbanization plan in there considering the little population and full of forest there.

When the travel time threshold is 30-minute the MAG decrease concentrates around the Nijmegen municipality, the Montferland municipality and along the railway lines of the North part of study area. And the magnitude of MAG decrease in the first two parts is relatively higher than in the last one out of the similar reason discussed above in the MAG variation between car and bicycle in scenario 1.

#### 4.1.2. MAG variation based on potential accessibility measure

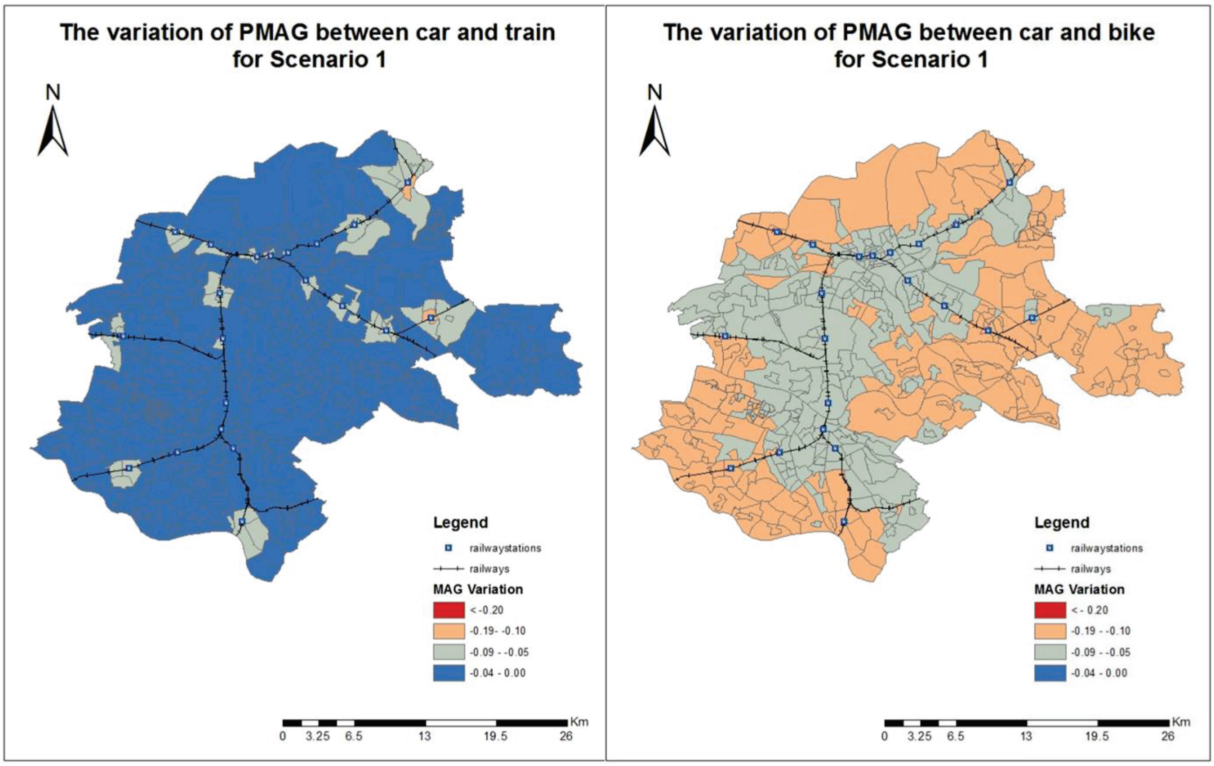



Figure 31: MAG variation between car and other travel modes based on the potential accessibility measure in scenario 1

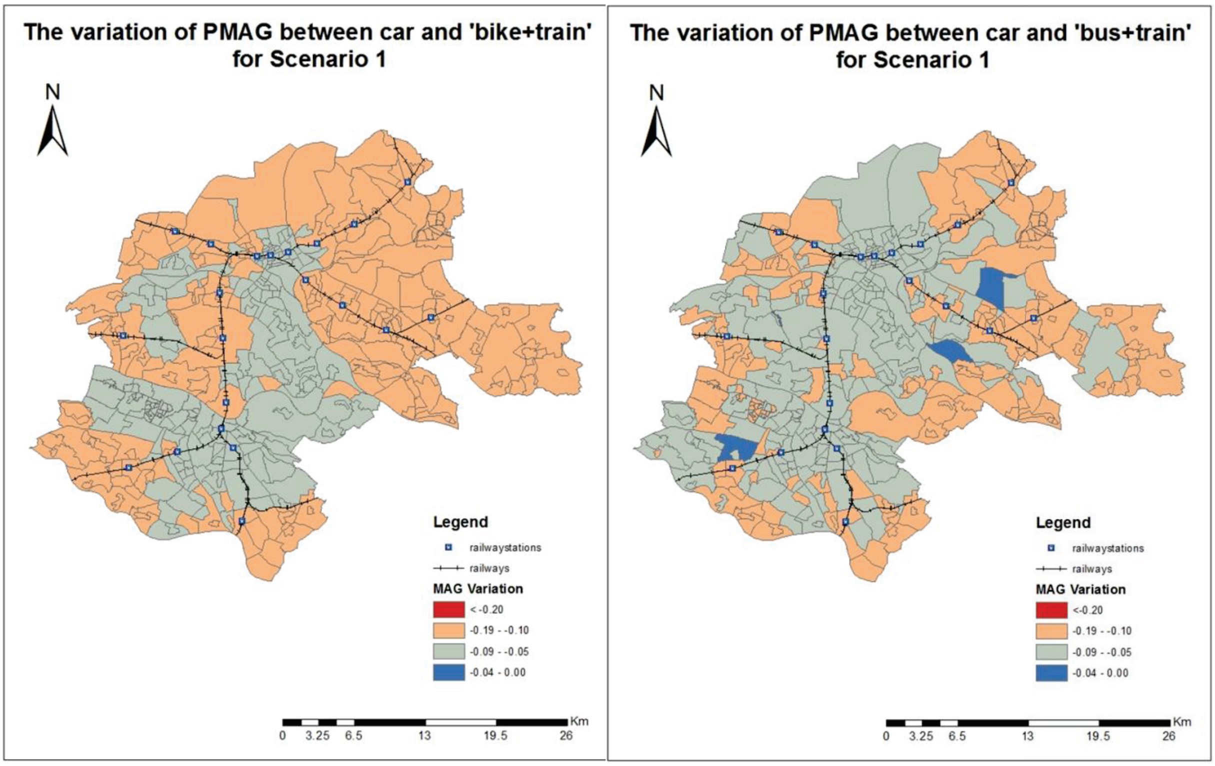



Figure 31: continued

The PMAG (the MAG based on the potential accessibility measure) between car and train decrease in the whole SAN and the magnitude is relatively high especially in the neighborhoods around the railway stations. While for other three types of PMAG, there exists a trend that the magnitude of PMAG decrease around the Arnhem municipality, the Nijmegen municipality and the middle part of the study area is smaller than the border of the study area. This is opposite to the situation based on the counter accessibility measure to some extent.

The population distribution in Figure 32 below shows that the MAG variation between car and train concentrates within the range of 0 and -0.1, while the variation range of -0.1 and -0.2 covers about 30-45 percent of population for other three MAG types. It means that the effect of lowering car speed on MAG decrease between car and train is smallest.

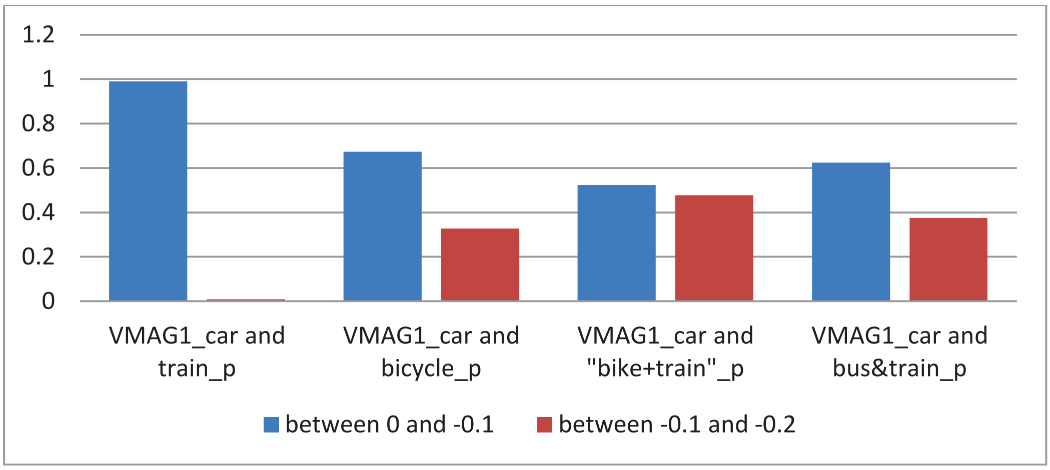



Figure 32: Population distribution of MAG variation value between scenario 1 and the baseline scenario (based on potential accessibility)

## 4.2. Scenario 2: The new job distribution

In scenario 2, the new job opportunity distribution is considered based on the prediction of the increasing job opportunity in the study area. The growth job opportunities are distributed into the 50 neighborhoods in the Arnhem municipality and Nijmegen municipality around the railway stations. And the growth rate of the job opportunity in 2020 is assumed as the same with the growth rate during the past decade in the Arnhem Nijmegen City Region, 11 percent according to “Stadsregio Arnhem-Nijmegen: uitdagingen voor de toekomst” (Rabobank, 2012). Based on the new job opportunity distribution, the MAG between car and other travel modes are recomputed and the MAG variation compared with the baseline scenario situation is shown and discussed as below.

### 4.2.1. MAG variation based on contour accessibility measure

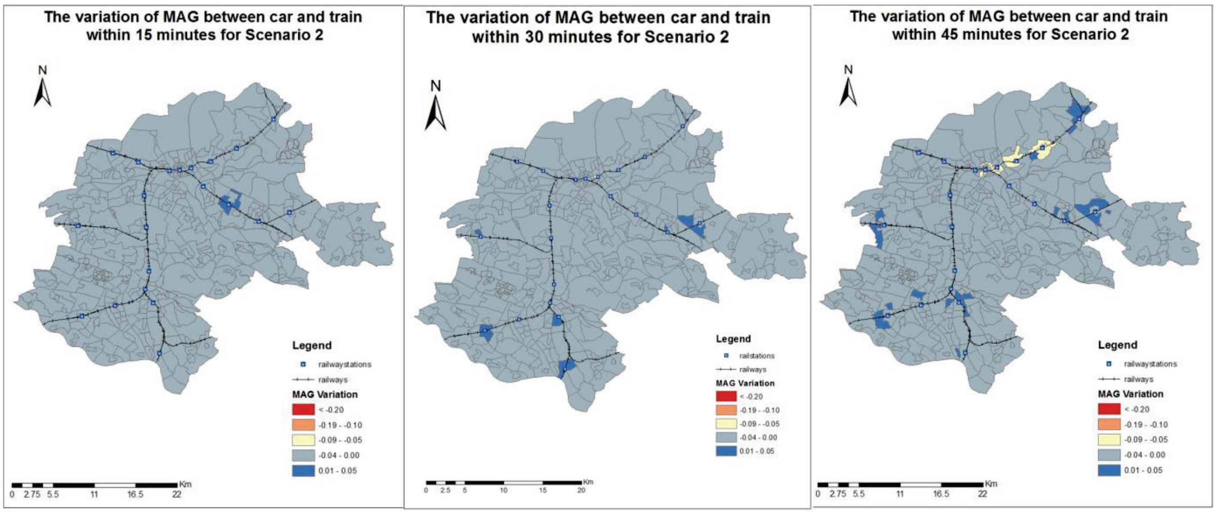



Figure 33: MAG variation between car and train based on the contour accessibility measure in scenario 2

Similar with scenario 1, the MAG value between car and train in scenario 2 shows little difference compared with the baseline scenario. For the neighborhoods away from the railway stations, the MAG values show no variation.

When it comes to the neighborhoods around the railway stations, the situations are somewhat complicated. The first situation is that those neighborhoods cannot reach the new job opportunities within the travel time threshold by walking+train, while the new job opportunities are available for them by car, then their MAG value will increase. Take the neighborhood Duiven randbebouwing around the Duiven station for example, no new job opportunity in the Arnhem municipality can be reached within 15-minute by walking+train from there. On the contrary, most of the new job opportunities in the Arnhem municipality can be reached within 15-minute by car. So it is shown as dark color (blue) in the Figure 33 when the travel time threshold is 15-minute.

If the neighborhoods could reach the new job opportunities distributed in the station area of the Arnhem municipality and Nijmegen municipality within the travel time threshold by walking+train and their accessibility improvement rate of train is higher than car, then according to section 4.4, the MAG value would decrease. Also take the neighborhood Duiven randbebouwing as an example, when the travel time threshold is 30-minute, some of the new job opportunities could be reached for neighborhood Duiven randbebouwing by walking+train and the accessibility improvement rate of train is higher than car. So the neighborhood Duiven randbebouwing is shown as light color in Figure 33 when the travel time threshold is 30-minute.

If the neighborhoods can reach the new job opportunities within the travel time threshold by walking+train, while their accessibility increase rate of train lower than car, their MAG value would show increase as well. This is obvious from the Figure 33 when the travel time threshold is 45-minute.

From the whole scale perspective, the effect of the scenario 2 on the MAG decrease between car and train is quite limited. This is mostly caused by the relatively long travel time and spatial limitation by the walking+train travel mode that even the new job opportunities are distributed around the railway stations, the accessibility improvement of train is little optimistic compared to car.

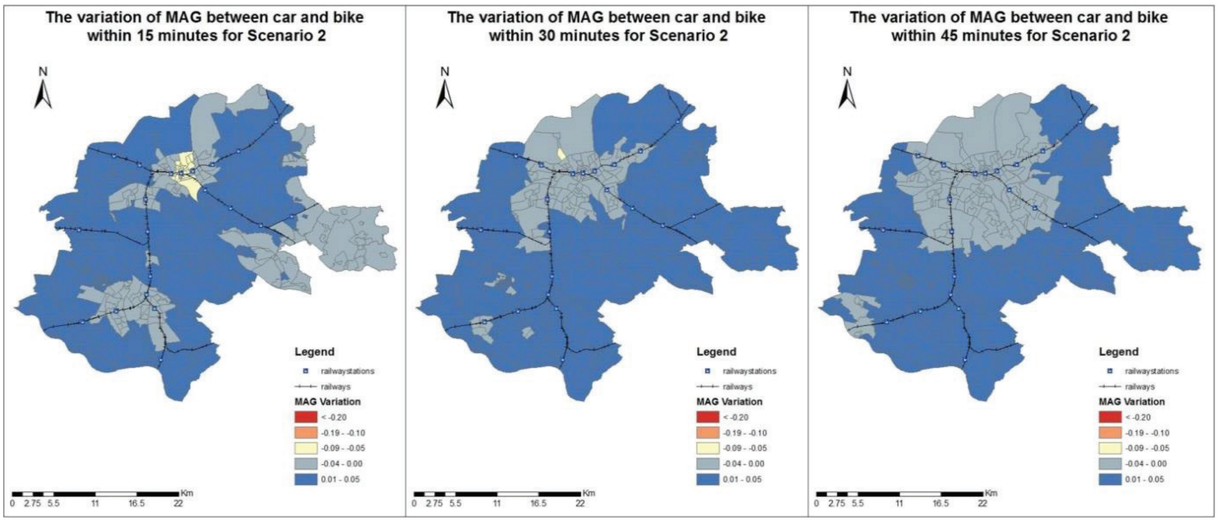



Figure 34: MAG variation between car and bicycle based on the contour accessibility measure in scenario 2

For the neighborhoods in the Nijmegen municipality, the travel time to the Arnhem municipality is mostly between 15 and 30 minutes by car, and larger than 45 minutes by bicycle. When the travel time threshold is 15-minute, the increased job opportunities in the Nijmegen municipality can be reached by both car and bicycle, while those in the Arnhem municipality cannot be achieved neither by bicycle nor car. So it is possible that the bicycle accessibility improvement rate is larger than car for those neighborhoods. The light color around the Nijmegen municipality in Figure 34 when the travel time threshold is 15-minute reflects this situation. When the travel time threshold is 30 and 45 minutes, the new job opportunities distributed in the Arnhem municipality could be reached by car for the neighborhoods around the Nijmegen municipality. It thus results that the MAG increase for most of the neighborhoods around the Nijmegen municipality.

For the neighborhoods in the East of the study area, take the neighborhoods in the Montferland municipality as an example, the travel time to Arnhem municipality is all between 15 and 30 minutes by car and out of 45 minutes by bicycle. When the travel time threshold is 15-minute, there is no accessibility improvement for car and bicycle. So there is no MAG variation in those areas. When the travel time threshold is 30 and 45-minute, the MAG values increase as the car accessibility improving in those neighborhoods.

Different to the situation above, the light color area expands around the Arnhem municipality as the travel time threshold increasing. This happens as that there are more job opportunities distributed in the Arnhem municipality than the Nijmegen municipality, and the accessibility improvement rate of bicycle around the Arnhem municipality is higher than around the Nijmegen municipality.

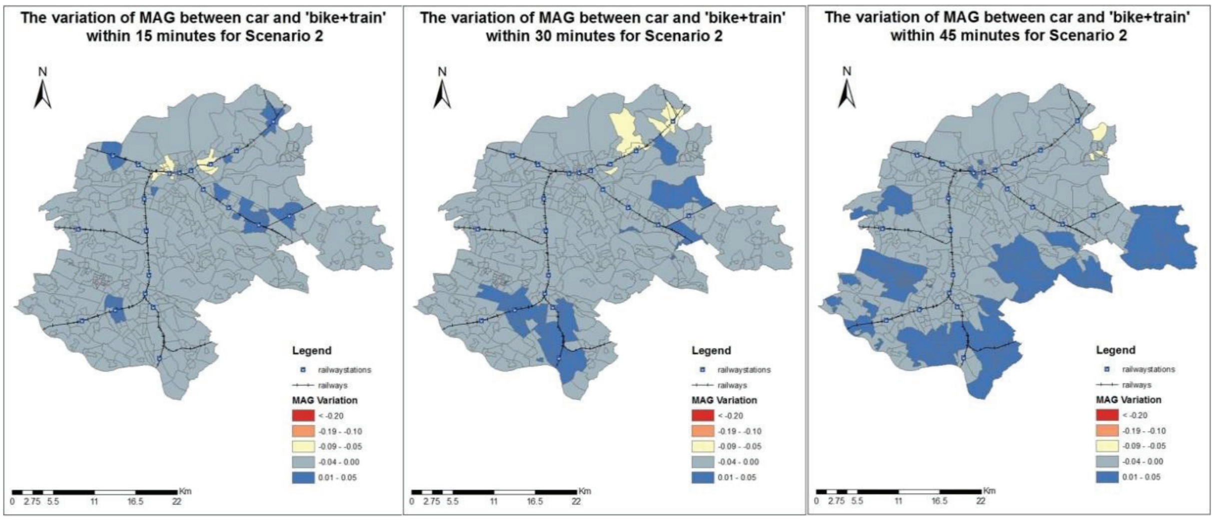



Figure 35: MAG variation between car and "bike+train" based on the contour accessibility measure in scenario 2

When the travel time threshold is 15-minute, the MAG variation area concentrates around the railway stations. Except to the Arnhem municipality and the Nijmegen municipality where the new job opportunities distributed, the middle part of the study area also show MAG decrease.

When the travel time threshold is 30-minute, the MAG decrease area expands to more large scale, especially for the middle part and the North part of the study area. And the relatively high MAG decrease neighborhoods located along the railway lines. While the South part of the study area shows more MAG increase compared with when the travel time threshold is 15-minute. As the travel time threshold increasing to 45-minute, the MAG increase area are back to the border of the study area where the travel time to the new job opportunities is quite large.

Compared with the MAG variation between car and bicycle in scenario 2, the effect on the MAG decrease is more significant. More importantly, the number of neighborhoods for MAG increase is much less. This indicates that the combination of train and bicycle performs better in the MAG decrease compared to bicycle.

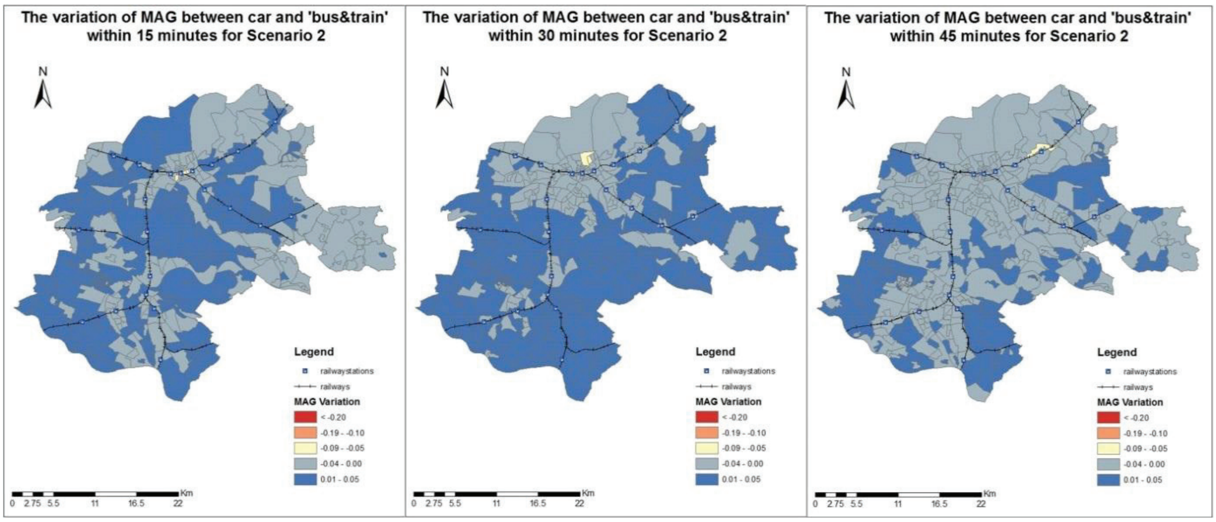



Figure 36: MAG variation between car and bus&train based on the contour accessibility measure in scenario 2

As all the situations shown above, the area of MAG decrease between car and bus&train expands as the travel time threshold increasing, and the area with no MAG variation shrinks at the same time. When the travel time threshold is 15-minute, it illustrates that only the neighborhoods around the new job opportunities show MAG decrease. The neighborhoods with MAG increase, MAG decrease and no MAG variation are interlaced. For example, the neighborhood Molenhoek around the railway station Molenhoek-Mook could reach the neighborhood Heijendaal in the Nijmegen municipality within 15-minute travel time threshold. And there are new job opportunities distributed in the neighborhood Heijendaal so the MAG value shows decrease in the neighborhood Molenhoek. While the nearby neighborhood Verspreide huizen bosgebied ten oosten kanaal in the Heumen municipality cannot reach the new job opportunities within 15-minute, so the MAG value remains the same.

When the travel time threshold is 30-minute, there are more neighborhoods show MAG decrease around of the Arnhem municipality. The neighborhoods Westelijk van Schaarsbergen and Noordoostelijk van Schaarsbergen located in the north of the Arnhem municipality are full of forest and little population, so the actual influence area concentrates the center and south part of the Arnhem municipality. And when the travel time threshold increases to 45-minute, the area with MAG decrease shows obvious expansion taking the Arnhem municipality as center. The effect of scenario 2 on MAG decrease is more significant around the Arnhem municipality than around the Nijmegen municipality.

#### 4.2.2. MAG variation based on potential accessibility measure

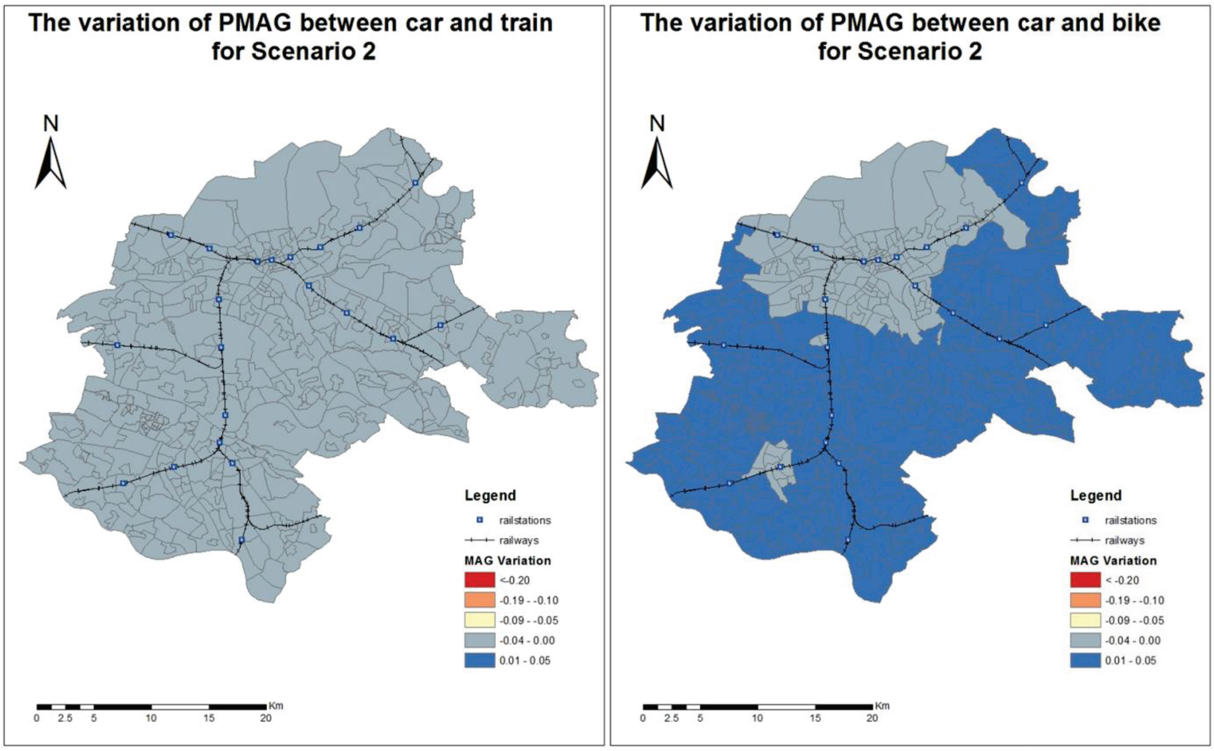



Figure 37: MAG variation between car and other travel modes based on the potential accessibility measure in scenario 2

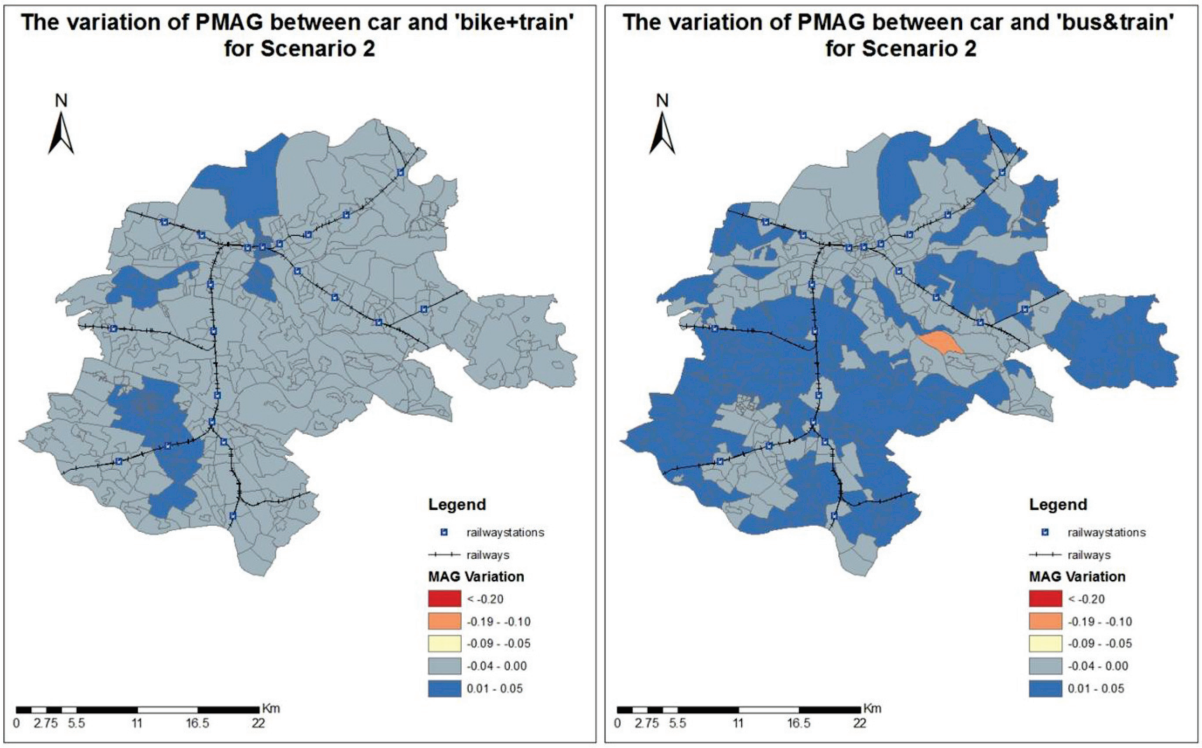



Figure 37: continued

The MAG variation based on the potential accessibility measure shown above is quite different with that based on the contour accessibility measure. The most obvious feature of PMAG between car and train is that the MAG decrease area distributes mostly along the railway lines.

The MAG decrease between car and bicycle concentrates around the Arnhem municipality, and the Nijmegen municipality shows little improvement. In the Nijmegen municipality only the neighborhoods around the railway station Nijmegen Dukenburg show MAG decrease. The neighborhoods around the railway station Nijmegen Heyendaal in the Nijmegen municipality show MAG increase. This may be caused that the travel time by car from those neighborhoods to the Arnhem municipality, is shorter than that from the neighborhoods around the station Nijmegen Dukenburg. So the accessibility improvement rate of car is higher than bicycle in those neighborhoods.

The most areas in Arnhem Nijmegen City Region show MAG decrease between car and "bike+train", which is more satisfactory than the MAG decrease between car and bicycle. The conclusion could be drawn that the effect of scenario 2 on the MAG decrease between car and "bike+train" is more significant than that between car and bicycle. And this is constant no matter what accessibility measure is based on in this study.

The above provides the analysis mostly from the perspective of how the MAG varies in different locations, different travel time thresholds and based on different accessibility measure in scenario 2. While from a statistic point, the general patterns of MAG variation in scenario 2 could be concluded and the compare with the effects of scenario 1 will be clearer than the figures shown.

### 4.3. Scenario 3: Combine new job distribution (scenario 2) and car speed limitation (scenario 1)

The scenario 1 examines the transport effects on the MAG decrease, and the scenario 2 examines the land use effects on the MAG decrease. While the transport and land use are interacted, their impacts to each other are hardly to be isolated in fact (Wegener, 2004), so the more reasonable approach maybe the hybrid of transport and land use. Moreover, the accessibility measure is mostly related to transport and land use, as well the MAG, thus make hybrid scenario more suitable than the first two, which only consider one aspect of the MAG.

#### 4.3.1. MAG variation based on contour accessibility measure

The MAG variation between car and train in scenario 3 shown in the Figure 38 below is similar to the scenario 1 and scenario 2. Most of the neighborhoods have no marked change. The neighborhoods with MAG decrease all concentrate around the railway stations.

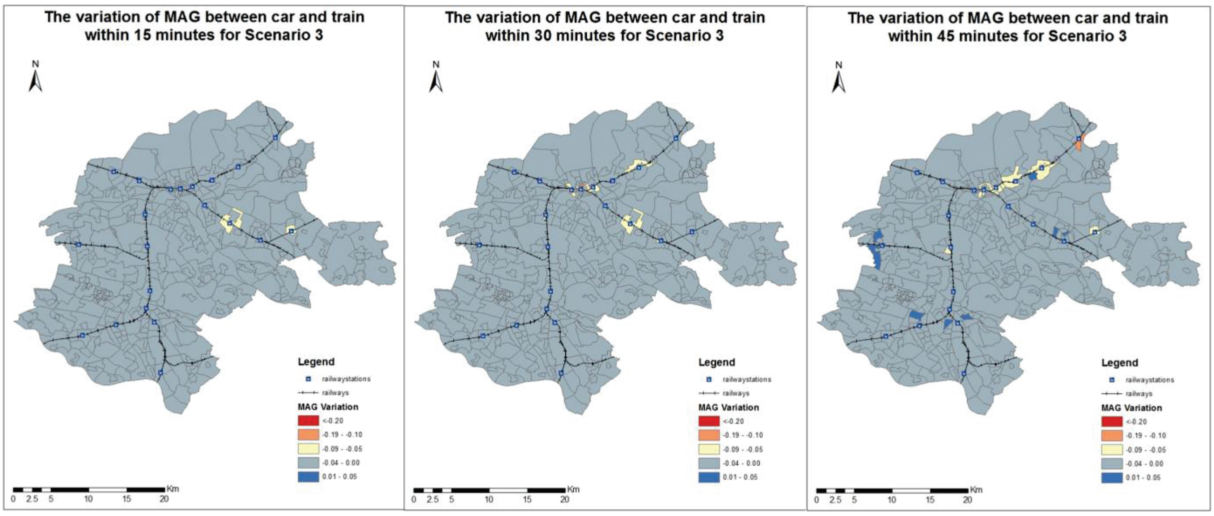



Figure 38: MAG variation between car and train based on the contour accessibility measure in scenario 3

It indicates the accessibility gap between car and train is so huge that little effect of decrease MAG can be achieved from no matter the way of lower car speed or the new job opportunity concentration around the railway station. So the proper approach to improve the current situation is to consider the combination of train and other travel modes as discussed in Chapter 4.

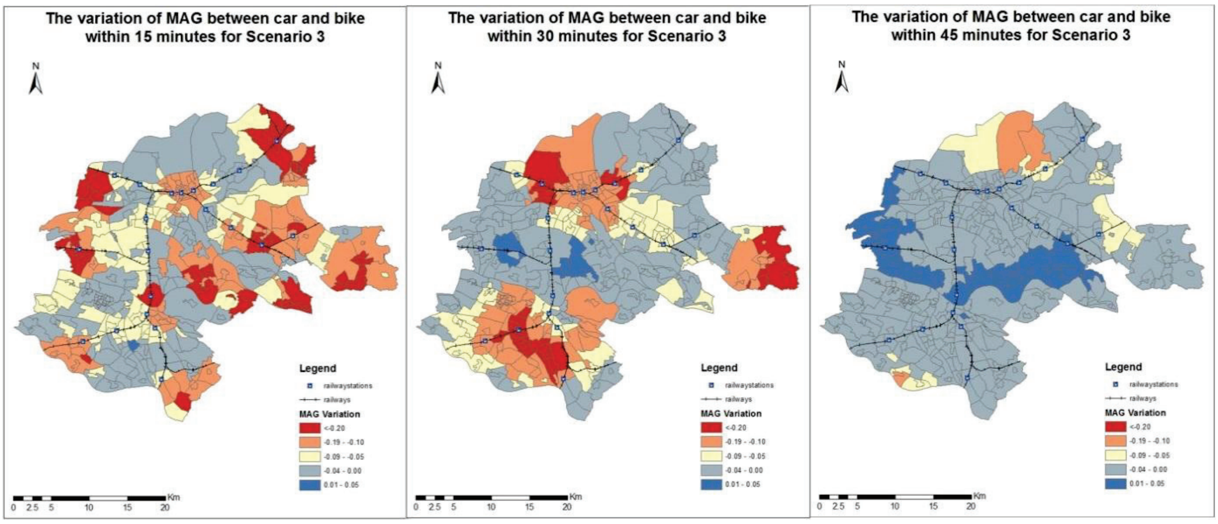



Figure 39: MAG variation between car and bicycle based on the contour accessibility measure in scenario 3

In this scenario, there displays more MAG decreases in Figure 39 compared with the Figure 27 about the MAG variation between car and bicycle in scenario 1. The neighborhoods with MAG increase are quite little in the Figure 39.

When the travel time threshold is 30-minute, the MAG decrease area mostly concentrates around the Arnhem municipality and Nijmegen municipality. The travel time from the neighborhood like Verspreide huizen Azewijn in the Montferland municipality to the Arnhem municipality is around 30 minutes in scenario 2 while about 45 minutes in scenario 3. That is why the East part of the study area also shows relatively high MAG decrease. There are neighborhoods in the middle part of the study area show MAG increase and those areas expand as the travel time threshold increasing to 45-minute. The similar situation will be discussed in the following about the MAG variation between car and bus&train.

Another obvious feature in the Figure 39 is that the neighborhoods with relatively high MAG decrease are less when the travel time threshold takes a drop. This implies that when the travel time threshold goes up, the influence on the MAG decrease of car speed limitation is less.

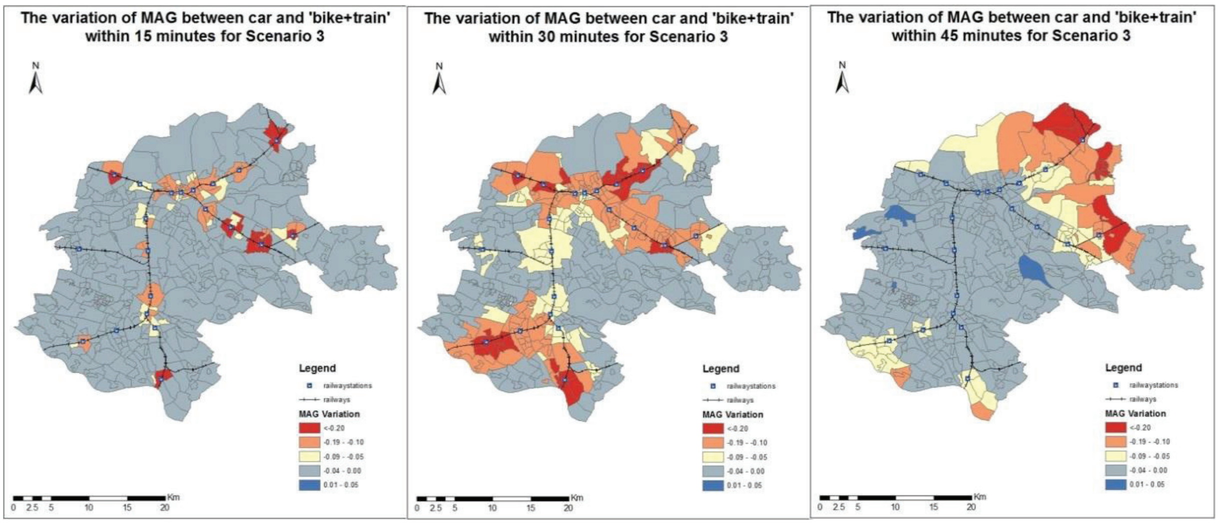



Figure 40: MAG variation between car and "bike+train" based on the contour accessibility measure in scenario 3

When the travel time threshold is 15-minute, most of the neighborhoods show no MAG change as expected. Only the neighborhoods around the railway stations show MAG decrease, which indicates that the accessibility improvement of "bike+train" is higher than that of car in those neighborhoods. The neighborhoods around the railway station Zetten-Andelst in the Overbetuwe municipality located in the West of the study area show no MAG variation. This happens by cause of the travel time by "bike+train" from those neighborhoods to the job opportunity is out of 15-minute that the MAG value remains +1 in the scenario 3.

When the travel time threshold is 30-minute, the neighborhoods around the railway station Zetten-Andelst also show MAG decrease. And not only the neighborhoods around the railway stations, but also the neighborhoods along the railway lines show a decline of MAG, especially the North and South part of the study area show relatively high MAG decrease.

In the opposite, when the travel time threshold is 45-minute, most parts of the study area show MAG decrease and the relatively high MAG decrease only located several neighborhoods in the North part of the study area, not concentrates the railway stations as 30-minute travel time threshold shown. Moreover, several neighborhoods show MAG increase when the travel time threshold is 45-minute. This indicates that the influence magnitude of lower travel speed of car is reduced; the influence area of this measurement enlarges at the same time.

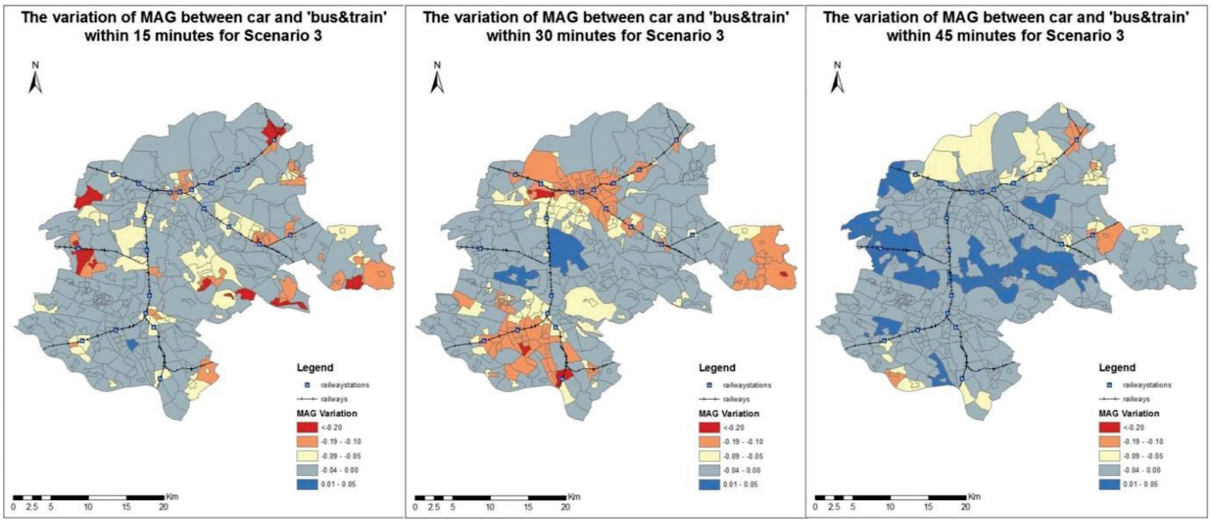



Figure 41: MAG variation between car and bus&train based on the contour accessibility measure in scenario 3

Similar as the MAG variation situation in the scenario 1, when the travel time threshold is 15-minute, the MAG decrease area scatters in the study area in the scenario 3. While when the travel time threshold is 30-minute, the MAG decrease area is cluster around the Arnhem municipality, the Nijmegen municipality and the Montferland municipality. At the same time some neighborhoods in the middle part of the study area can reach the new job opportunity located in the Arnhem municipality and the Nijmegen municipality within the travel time threshold that they show MAG increase. And when the travel time threshold is 45-minute, there are more neighborhoods in the middle part of the study area showing MAG increase, which indicates that the influence of lower car speed become weaker as the travel time threshold increasing.

While compared with the scenario 2, the MAG increase area reduces in large scale. This shows that the lower travel speed of car has a remarked influence on the MAG variation. And the east neighborhoods in the Montferland municipality explain the effect evidently. In scenario 2 the MAG decrease is not obvious in those neighborhoods while in scenario 1 and 3 which the MAG decrease is shown apparently. This indicates that the reducing car speed is more efficient than new job opportunity distribution for the Montferland municipality to decrease the MAG value.

#### 4.3.2. MAG variation based on contour accessibility measure

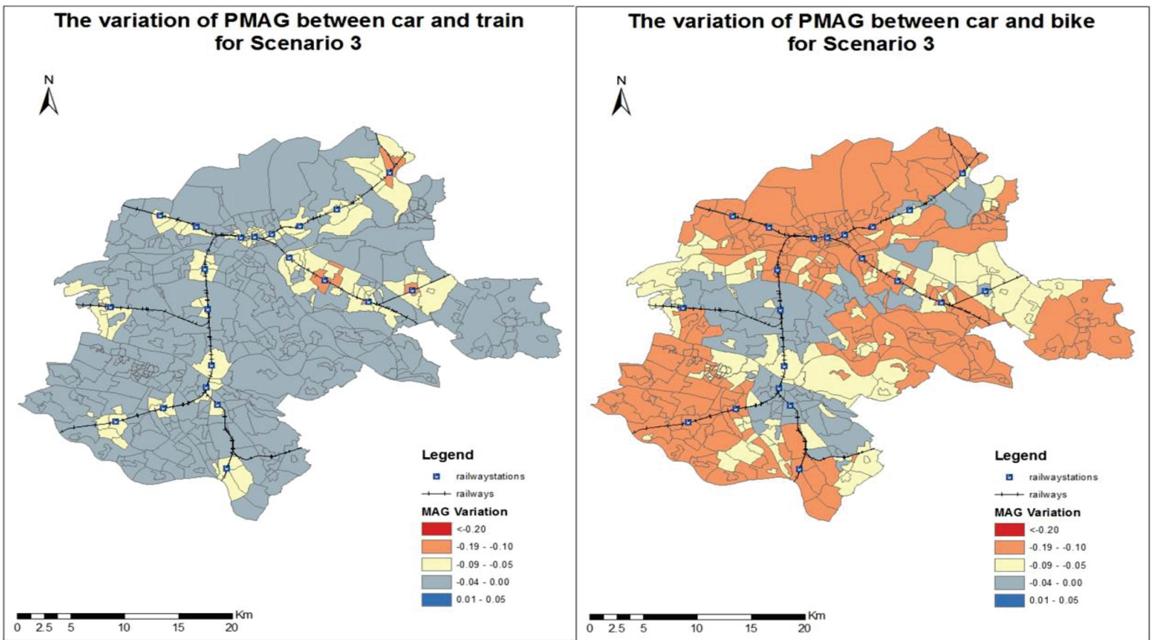



Figure 42: MAG variation between car and other travel modes based on the potential accessibility measure in scenario 3

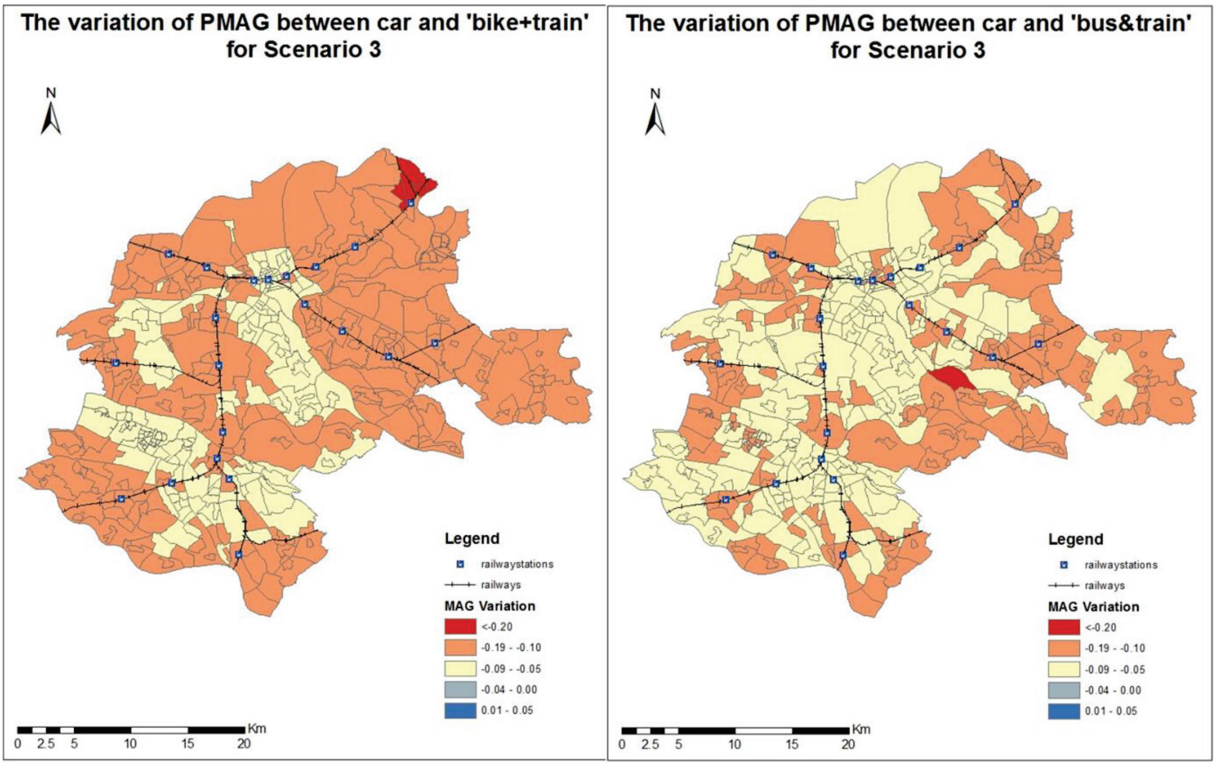



Figure 42: continued

Most parts of the study area show relatively low MAG decrease between car and train, only the neighborhoods around the railway stations show relatively a large MAG decrease. Compared with scenario 1, the neighborhoods around the Arnhem municipality show higher MAG decrease in the scenario 3. This indicates the influence of the increased job opportunity in the Arnhem municipality, which can also be seen in the scenario 2.

The MAG variation between car and “bike+train” in scenario 3 is similar to scenario 1 to some extent except for the neighborhoods around the railway station Dieren, the most northern railway station in Arnhem Nijmegen City Region. The neighborhoods around the railway station Dieren show higher MAG decrease. And the MAG variation based on the counter accessibility in the three scenarios also shows relative high MAG decrease in those neighborhoods. This may offer an advice that the “bike+train” travel mode is quite suitable in those neighborhoods and should be paid more attention in the future.

There are not much difference about the MAG variation between the car and bus&train in scenario 1 and scenario 3 based on the potential accessibility measure. The increased job opportunity only makes several neighborhoods in the Arnhem municipality show higher MAG decrease. It seems little influence of the new job opportunity distribution on the MAG variation based on the lower car speed situation. And compared with the situation in scenario 2, the MAG increase area disappear, the dark color becomes light on the whole, which reveals the remarkable effect of the lower travel speed of car on the MAG decrease. This indicates that the lower car speed is more important to decrease the MAG value in the study area, and the hybrid of transportation (lower car speed) and land use (new job opportunity distribution) makes the goal a little easier to achieve.

Furthermore, take a statistic comparison of the effects on MAG decrease between scenario 1 and 2, this scenario shows more MAG decrease, which implies the advantage of hybrid policies to some degree.

| MAG | Accessibility measure | Average value **Scenario 1** | Average value **Scenario 2** | Average value **Scenario 3** | **The Baseline Scenario** |
|---|---|---|---|---|---|
| Train | 15 minutes | -0.0004 | -0.0002 | -0.0006 | 0.9992 |
| | 30 minutes | -0.0027 | -0.0019 | -0.0049 | 0.9902 |
| | 45 minutes | -0.0013 | -0.0061 | -0.0074 | 0.9533 |
| | Potential | -0.0312 | -0.0043 | -0.0363 | 0.8994 |
| Bike | 15 minutes | -0.1003 | -0.0027 | -0.1087 | 0.8255 |
| | 30 minutes | -0.0853 | -0.0025 | -0.0893 | 0.7566 |
| | 45 minutes | -0.0225 | -0.0024 | -0.0226 | 0.6172 |
| | Potential | -0.1004 | -0.0017 | -0.1022 | 0.6213 |
| Bike+Train | 15 minutes | -0.0291 | -0.0054 | -0.0349 | 0.9290 |
| | 30 minutes | -0.0677 | -0.0093 | -0.0781 | 0.7749 |
| | 45 minutes | -0.0291 | -0.0141 | -0.0424 | 0.5597 |
| | Potential | -0.1064 | -0.0075 | -0.1147 | 0.5979 |
| Bus&Train | 15 minutes | -0.0516 | -0.0022 | -0.0528 | 0.9238 |
| | 30 minutes | -0.0606 | -0.0047 | -0.0661 | 0.8323 |
| | 45 minutes | -0.0199 | -0.0090 | -0.0274 | 0.6607 |
| | Potential | -0.0958 | -0.0045 | -0.1006 | 0.6520 |

Table 18: the statistic of MAG variation between each scenario and the baseline scenario of 448 neighbourhoods

The negative MAG variation means the lower MAG value in scenario 1 than in the baseline scenario, and this decrease in MAG value is considered as an improvement in this study. The column of percentage of improvement is calculated based on the average accessibility value. Obviously, as the lower car speed only induces lower car accessibility, there is no MAG increase in this scenario. From the Table 18 above, it shows that the average MAG variations are bigger when the accessibility measure is based on potential accessibility measure than which is based on the contour accessibility measure. This situation may be resulted from the difference between the two kinds of accessibility measure. For example, if the travel time from neighbourhood $i$ to neighbourhood $j$ is increased from 14 minutes to 20.02 minutes, then it has an opposite effect on the contour accessibility value within 15-minute travel time threshold, exclude the other travel time threshold. On the other hand, as long as the travel time increases, the potential accessibility value would be decreased.

The statistic of MAG variation in scenario 2 shows that the MAG decrease is smaller than in scenario 1. The limited effects on MAG decrease may be due to that only the growth part of job opportunities are distributed around some railway stations, which are relative little compared to the total job opportunities. And the variation patterns are also different from scenario 1. Firstly, the MAG decrease rate is increasing as the travel time threshold increasing based on the counter accessibility measure. Secondly, the MAG decrease based on the potential accessibility measure does not bigger than based on the counter accessibility measure. And finally, there are some neighbourhoods show MAG increase.

By integrating scenario 1 and 2 into the scenario 3, it can also help to evaluate land use and transport interaction and see how to get a more sustainable urban development. The average value of MAG decrease in scenario 3 shows a relatively high advantage over the other two scenarios. The more sustainable urban development can be achieved by using scenario 3.

# 5. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study is to evaluate the current Modal Accessibility Gap (MAG) for the study area, based on two different accessibility measures—contour measure and potential accessibility measure—to explore approaches to decrease the MAG in form of three different scenarios, and to exam the effectiveness of the three scenarios. The results of this study are generally concluded in the first part of this chapter. Then recommendations about the further studies are provided. They include the further detail data, a discussion about MAG based on some new accessibility measurements and the more policies to develop.

## 5.1. Conclusions

The main objective in this research is to evaluate the Modal Accessibility Gap (MAG) based on two different accessibility measures—contour measure and potential accessibility measure; then construct accessibility scenarios to analyze the accessibility gap between car and other travel modes in order to to reduce the gap for achieving more sustainable development in the transport planning. The study has been achieved the main objective with the following sub-objectives.

Firstly, the contour accessibility measure and potential accessibility measure are applied to represent the job accessibility in this study. In the Netherlands, 80 percent of the working population travels less than 30 min per single journey to work (van Ham et al., 2001). Thus the travel time thresholds in contour measure have been set as 15-, 30-, and 45-minute for measuring the job accessibility. When travel time limits increases, more number of jobs could be reached. In this research, different transport modes were used for comparing with car aimed at promoting sustainable transport mode and thus encouraging the use of alternative to the car. The contour measure was easy to operationalize and get clearly results but lack of theoretical soundness. In order to improve the accuracy of job accessibility measurement, the potential accessibility was applied because it included the decay function which made a more reasonable theory, the longer distance the more difficult to reach the job opportunities. And both of the measurements are easier to understand as well as interpret among the other measures in the literatures.

The CBS provides the job opportunity data and the ArcGIS calculates the travel time data for different travel modes as input, except for bus, which is obtained from Google Direction API through some programming. Compared with other travel modes, car shows the absolute advantage in both contour accessibility and potential accessibility. In adverse, “walk+train” displays the lowest value of accessibility for both of two kinds of measures. Furthermore, the job accessibility with multiple modes of transport (“train+bike”) ranked the second highest value of accessibility, which was followed by “bike” travel mode.

Following, the MAG between car and other travel modes is calculated based on the two accessibility measurements according the method of (Kwok et al. (2004)). MAG in this research provides a way to evaluate the level of accessibility for different transport modes and help the city enjoy a more sustainable urban development. The results show that the MAG value is quite large in the study area. The travel time threshold shows remarkable influence on the MAG value. From this research we can see that the MAG value decreases as the travel time threshold increasing based on the contour accessibility measure generally. And the decrease magnitude is significant in the MAG between car and “bike+train”, which indicates the advantage of multiple modes of transport in the urban transport service. Furthermore, based on both accessibility measurements, the land use and transport factors show significant influence on the MAG value distribution in spatial dimension. In reality, transport and land use interaction is complex and dynamic. For instance, the centre region of Arnhern and Nijmegen are dominated by both relatively high opportunity and high population density values. The neighbourhoods around the job opportunity centres and public transport always show relatively low MAG value. Accordingly, their spatial distribution affect the MAG since if the energy efficient travel modes (public transport, bike) infrastructures are located near to the jobs, this will improve the sustainable development and decrease the value of MAG. Therefore, residential development should thus be encouraged in the surrounding areas.

Finally, the effects of different scenarios on going down MAG are examined, from the perspective of transport, land use and the combination of both of them. In scenario 1, it is important to note that all the study area for the car speed is decreased by 30 percent which has the same assumption in terms of the general purpose for the research. Compared to the situation in the baseline scenario, the MAG decrease is acceptable except the MAG between car and train, which shows little improvement. In scenario 2, the new job opportunities are distributed in the neighbourhoods around the train stations in Arnhem and Nijmegen municipalities. The location of jobs has an impact on MAG value. If the job opportunities are located near to the public transport, this will show the advantage of decreasing the MAG. Some neighbourhoods show MAG increase in this scenario. Besides the location of job opportunities, the development of public transport is equally important. Therefore, scenario 3 is the combination of scenario 1 and 2, which shows the most significant effects. As a result, MAG improvement (decrease) is more obvious based on the potential accessibility measure than contour accessibility measure in scenario 1 and 3.

While the detail situation of MAG variation is even more complicate, influenced not only by the distribution of job opportunity and transport infrastructure, but also by the travel time to abundant job opportunities, and the travel time threshold. The difference in job opportunity distribution in the Arnhem and Nijmegen municipalities leads to relative high MAG decrease in the Nijmegen municipality in the MAG variation between car and bike within 30-minute in scenario1 and similar with decreased MAG value in 45-minute travel time threshold. The neighbourhoods which are near to the job opportunities or with high quality transport infrastructure show the decreased value of MAG, such as the MAG variation between car and "bike+train" in scenario 3. Consequently, the proposed scenarios have to be suggested with respect to improve the accessibility by energy efficient travel modes (public transport, bike), especially by public transport and finally encourage the sustainability. These include the land use and transport facilities.

## 5.2. Recommendations

The research evaluated the current Modal Accessibility Gap (MAG) for Arnhem Nijmegen City Region based on two different accessibility measures, and constructed three scenarios to decrease the MAG value. However, there are some limitations during the data collection process, methodology and scenario planning analysis, shown as following.

Most of data are obtained from CBS, ESRI Netherland, and ITC former projects and are secondary data. In order to measure the MAG, it is better to build a transport network to make it more easy and effective to calculate the travel time of different travel modes in the ArcGIS environment. This is important especially for the bus network; the travel time is gained by Google Direction API through programming in this study and taken lots of time to get the data. However, the data source difference may influence the results to some extent. Most importantly, it is easily to estimate the travel time variation in the ArcGIS environment with network analyst when the transport infrastructures change. This makes it possible for the planner to evaluate various and detailed transport policies.

This research measured the Modal Accessibility Gap (MAG) for different travel modes and developed accessibility scenarios to decrease the MAG for the study area. However, accessibility measures are always confronted with contradiction between more accurate and more interpretations (Bertolini et al., 2005). In this study, the contour accessibility measure and potential accessibility measure are chosen for their fundamental role in the accessibility measure, and easy to compute and understand but less accurate. Thus, a further research could be implemented by calculating the MAG based on the other accessibility measure. For example, Geurs et al. (2003) made a conclusion that match the job with education level would obtain more accurate accessibility computation. However, other accessibility measure, like potential accessibility with travel time threshold and competition-based accessibility measure are applied more and more in the resent researches since these measures are more practical and operational. Furthermore, as noted earlier, the further questions should be focused on whether the different components can be added in the accessibility measures; how the MAG performs based on those accessibility measures; what policies could be carried out and how they may perform in the next study.

Accessibility impacts of land-use and transport changes and policies are evaluated using accessibility measures (Geurs et al., 2004). From above mentioned, a planning policy of job location which near to the public transport, especially near the transit interchange will favor sustainable transport development (Kwok et al., 2004). Another improvement could be achieved by examining more policies which combine transport and land use. Such as built more bus lines and stops, investment on the combination of bicycle and train or bicycle and bus, distribute more job opportunities in the middle or East part of the study area rather than the job opportunity centers. Furthermore, the job accessibility with multiple modes of transport would promote sustainable development and thus encourage the use of alternatives to the car(Cheng et al., 2013). If the transport problem is so serious that government and planners should take into cutting down parking facilities, or closing up roads for public transport only or provide the public subsidies for the individuals to encourage them to shift the car user to transit riders. Particularly, the government can consider the youth education which can give the teenager the knowledge that the more public transport we use, the more health and sustainable world we have. Therefore, how those polices influence the MAG of the SAN area will provide important information to the planners and policy-makers in deciding the future transport and land use development of this area.

As to the future transport policies of the study area, based on the effects of three scenarios on the MAG decrease, the following suggestions are provide:

- Considering the absolute accessibility advantage of car, actions must be taken to decrease the MAG value in the SAN area for sustainable development. The TOD project is useful in MAG decreasing, but the effect is feeble when only consider increasing the job opportunities around the railway stations. The proper combination with other travel modes (bicycle, bus) will make it easier to achieve the goal.
- Different transport policies suit different places. Such as the Montferland municipality should improve its bus connection with the Arnhem municipality, while most neighborhoods around the railway stations should improve the facilities for the combination of different travel modes.
- The transport policies and land use policies are mutual related, and their combination will achieve more effectiveness on MAG decrease.

# LIST OF REFERENCES


Bartholomew. (2007). Land use-transportation scenario planning: promise and reality. *Transportation, 34*(4), 397-412.

Benenson, Martens, & Rofé. (2010). Measuring the Gap Between Car and Transit Accessibility. *Transportation Research Record: Journal of the Transportation Research Board, 2144*(1), 28-35.

Berechman. (1981). Transportation, Temporal, and Spatial Components of Accessibility, by Lawrence D. Burns. *Geographical Analysis, 13*(2), 185-187.

Bertolini, le Clercq, & Kapoen. (2005). Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport policy, 12*(3), 207-220.

Bhat, Handy, Kockelman, Mahmassani, Chen, & Weston. (2000). Urban accessibility index: literature review. *Austin: Texas Department of Transportation*.

Blumenberg. (2004). En-gendering effective planning: spatial mismatch, low-income women, and transportation policy. *Journal of the American Planning Association, 70*(3), 269-281.

Blumenberg, & Hess. (2003). Measuring the role of transportation in facilitating welfare-to-work transition: evidence from three California counties. *Transportation Research Record: Journal of the Transportation Research Board, 1859*(1), 93-101.

Bodegraven, Boekema, & Parie. (2009). Advies over de verstedelijkingsopgave 2010-2020 van de Stadsregio Arnhem Nijmegen.

Bradfield, Wright, Burt, Cairns, & Van Der Heijden. (2005). The origins and evolution of scenario techniques in long range business planning. *Futures, 37*(8), 795-812.

CBS. (2012). De mobiliteit van de Nederlandse bevolking in 2012 [Mobility of the Dutch population in 2012]. *Statistics Netherlands, Voorburg*.

CBS. (2013a). Bevolkingsontwikkeling; regio per maand.

CBS. (2013b). The fastest driver in place destination.

CBS. (2013c). Motorvoertuigen; per postcode naar regio-indelingen (Motor vehicles, by postal code by region formats).

Cheng, & Bertolini. (2013). Measuring urban job accessibility with distance decay, competition and diversity. *Journal of Transport Geography, 30*, 100-109.

Cheng, Bertolini, & le Clercq. (2007). Measuring sustainable accessibility. *Transportation Research Record: Journal of the Transportation Research Board, 2017*(1), 16-25.

Couclelis. (2000). From sustainable transportation to sustainable accessibility: Can we avoid a new tragedy of the commons? *Information, Place, and Cyberspace* (pp. 341-356): Springer.

Curtis, & Scheurer. (2010). Planning for sustainable accessibility: Developing tools to aid discussion and decision-making. *Progress in Planning, 74*(2), 53-106.

El-Geneidy, & Levinson. (2006). Access to destinations: Development of accessibility measures.

Engelen. (2000). The wadbos policy support system: information technology to bridge knowledge and choice. *Technical paper prepared for the National Institude for Coastal and Marine Management/ RIKZ*.

Farrington, & Farrington. (2005). Rural accessibility, social inclusion and social justice: towards conceptualisation. *Journal of Transport Geography, 13*(1), 1-12.

Geertman, & Stillwell. (2003). *Planning support systems in practice*: Springer.

Geurs. (2006). *Accessibility, land use and transport*: Eburon Uitgeverij BV.

Geurs, & Ritsema van Eck. (2001). Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use transportation scenarios, and related social and economic impact.

Geurs, & van Eck. (2003). Evaluation of accessibility impacts of land-use scenarios: the implications of job competition, land-use, and infrastructure developments for the Netherlands. *Environment and Planning B, 30*(1), 69-88.

Geurs, & VAn Wee. (2004). Accessibility evaluation of land-use and transport strategies: review and

research directions. *Journal of Transport Geography, 12*(2), 127-140.
Givoni, & Rietveld. (2007). The access journey to the railway station and its role in passengers' satisfaction with rail travel. *Transport policy, 14*(5), 357-365.
Google. (2013). The Google Directions API.
Greeuw, van Asselt, Grosskurth, Storms, Rijkens-Klomp, Rothman, . . . Ribeiro. (2000). *Cloudy crystal balls*: Amt f. Amtl. Veröff. d. Europ. Gemeinschaften.
Handy, & Niemeier. (1997). Measuring accessibility: an exploration of issues and alternatives. *Environment and planning A, 29*(7), 1175-1194.
Hansen. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*(2), 73-76.
Hendricks, Fleury, Flynn, & Goodwill. (2005). Impacts of transit oriented development on Public Transportation Ridership: National Center for Transit Research, University of South Florida.
Hess. (2005). Access to employment for adults in poverty in the Buffalo-Niagara region. *Urban Studies, 42*(7), 1177-1200.
Hickman, Saxena, Banister, & Ashiru. (2012). Examining transport futures with scenario analysis and MCA. *Transportation Research Part A: Policy and Practice, 46*(3), 560-575. doi: 10.1016/j.tra.2011.11.006
Hilbers, & Verroen. (1993). *Measuring accessibility, a key factor for successful transport and land-use planning strategies.* Paper presented at the PTRC Summer Annual Meeting, 21st, 1993, University of Manchester, United Kingdom.
Ingram. (1971). The concept of accessibility: a search for an operational form. *Regional studies, 5*(2), 101-107.
Kahn, & Wiener. (1967). The next thirty-three years: a framework for speculation. *Daedalus, 96*(3), 705-732.
Kawabata. (2007). Spatio-Temporal Dimensions of Modal Accessibility Disparity: The Cases of Boston and San Francisco, 1990-2000.
Kenworthy, & Laube. (2001). THE MILLENNIUM CITIES DATABASE FOR SUSTAINABLE TRANSPORT. DATABASE.
Kwok, & Yeh. (2004). The use of modal accessibility gap as an indicator for sustainable transport development. *Environment and planning A, 36*(5), 921-936.
Le Clercq, & Bertolini. (2003). Achieving sustainable accessibility: An evaluation of policy measures in the Amsterdam area. *Built Environment (1978-)*, 36-47.
Ludin, Nazri, & Yaakup. (2006). Scenario-based spatial modelling for land use planning and evaluation.
Lutter, Pütz, Spangenberg, & Communities. (1992). *Accessibility and Peripherality of Community Regions: The Role of Road-, Long-distance Railway- and Airport Networks*: CEC.
Mahmoud, Liu, Hartmann, Stewart, Wagener, Semmens, . . . Dominguez. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling & Software, 24*(7), 798-808.
Murray, Davis, Stimson, & Ferreira. (1998). Public transportation access. *Transportation Research Part D: Transport and Environment, 3*(5), 319-328.
Newman, & Kenworthy. (2006). Urban design to reduce automobile dependence. *Opolis, 2*(1).
Nijmegen. (2006). Regionaal Plan 2005-2020.
City Region Arnhem Nijmegen. (2013). Stadstregio Arnhem-Nijmegen (SAN) projects.
De Stadsnegio Arnhem Nijmegen. (2013). Transport and Accessibility.
De Stadsnegio Arnhem Nijmegen (Ed.). (2012). *About Arnhem Nijmegen City Region Retrieved August 2012*.
NTTP. (2001). National Traffic and Transport Plan 2001-2020. *Tweede Kamer, Vergaderjaar 2000-2001, 27 455*, no. 1-5.
Porter. (1985). Competitive advantage: creating and sustaining superior performance: New York: The Free Press.
Rabobank. (2012). Stadsregio Arnhem-Nijmegen: uitdagingen voor de toekomst.
Rietveld. (2000). The accessibility of railway stations: the role of the bicycle in The Netherlands. *Transportation Research Part D: Transport and Environment, 5*(1), 71-75.
Saliba. (2009). Windows for the mind: The use of scenario planning for enhancing decision-making and managing uncertainty. *Journal of Futures Studies, 13*(3), 123-129.
Shen. (1998). Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environment and planning B: Planning and Design, 25*(3), 345-365.
Shen. (2001). A Spatial Analysis of Job Openings and Access in a U.S. Metropolitan Area. *Journal of the*

*American Planning Association, 67*(1), 53-68. doi: 10.1080/01944360108976355
Spoorbouwmeester. (2012). De reiziger centraal: Bureau Spoorbouwmeester.
Steen, Dreborg, & Åkerman. (1998). Policy Scenarios for Sustainable Mobility in Europe–the POSSUM Project. *Environmental Strategies Research Group/FOA*.
Vale. Sustainable urban form, accessibility disparity and spatial inequalities: a case-study from Lisbon.
Van der Heijden. (1996). Scenarios: the art of strategic conversation.
van Ham, Mulder, & Hooimeijer. (2001). Spatial flexibility in job mobility: macro-level opportunities and micro-level restrictions. *Environment and planning A, 33*, 921-940.
Wachs, & Kumagai. (1973). Physical accessibility as a social indicator. *Socio-Economic Planning Sciences, 7*(5), 437-456.
Wegener. (2004). Overview of land-use transport models. *Handbook of transport geography and spatial systems, 5*, 127-146.
Zegras, Sussman, & Conklin. (2004). Scenario planning for strategic regional transportation planning. *Journal of urban planning and development, 130*(1), 2-13.

# APPENDIX I

Travel behavior survey for different travel modes, 2012 (Afgelegde afstand naar reis duur en vervoerwijze)

| | Auto (bestuurder) | Auto (passagier) | Trein | Bus/tram /metro | Brom-/ snorfiets | Fiets | Lopen | Overige vervoerwijzen | Total |
|---|---|---|---|---|---|---|---|---|---|
| 0 tot 5 min | 0.04 | 0.01 | . | . | . | 0.06 | 0.08 | . | 0.19 |
| 5 tot 10 min | 0.16 | 0.08 | . | . | . | 0.22 | 0.14 | 0.01 | 0.6 |
| 10 tot 15 min | 0.16 | 0.07 | . | . | 0.01 | 0.17 | 0.08 | 0.01 | 0.49 |
| 15 tot 20 min | 0.16 | 0.08 | . | 0.01 | 0.01 | 0.13 | 0.06 | 0.01 | 0.46 |
| 20 tot 25 min | 0.08 | 0.03 | . | . | . | 0.05 | 0.02 | . | 0.2 |
| 25 tot 30 min | 0.04 | 0.01 | . | . | . | 0.02 | 0.01 | . | 0.09 |
| 30 tot 45 min | 0.13 | 0.05 | 0.01 | 0.02 | . | 0.06 | 0.04 | 0.01 | 0.32 |
| 45 tot 60 min | 0.05 | 0.02 | 0.01 | 0.01 | . | 0.02 | 0.01 | . | 0.12 |
| 60 tot 90 min | 0.04 | 0.02 | 0.02 | 0.01 | . | 0.01 | 0.02 | . | 0.12 |
| 90 tot 120 min | 0.01 | 0.01 | 0.01 | . | . | . | 0.01 | . | 0.04 |
| 120 min of meer | 0.01 | 0.01 | 0.01 | . | . | 0.01 | 0.01 | . | 0.05 |
| Totaal mobiliteitskenmerken | 0.88 | 0.38 | 0.05 | 0.06 | 0.03 | 0.74 | 0.49 | 0.04 | 2.68 |

Table 1 : Verplaatsingen per persoon per dag (source: CBS 2012 )

APPENDIX II

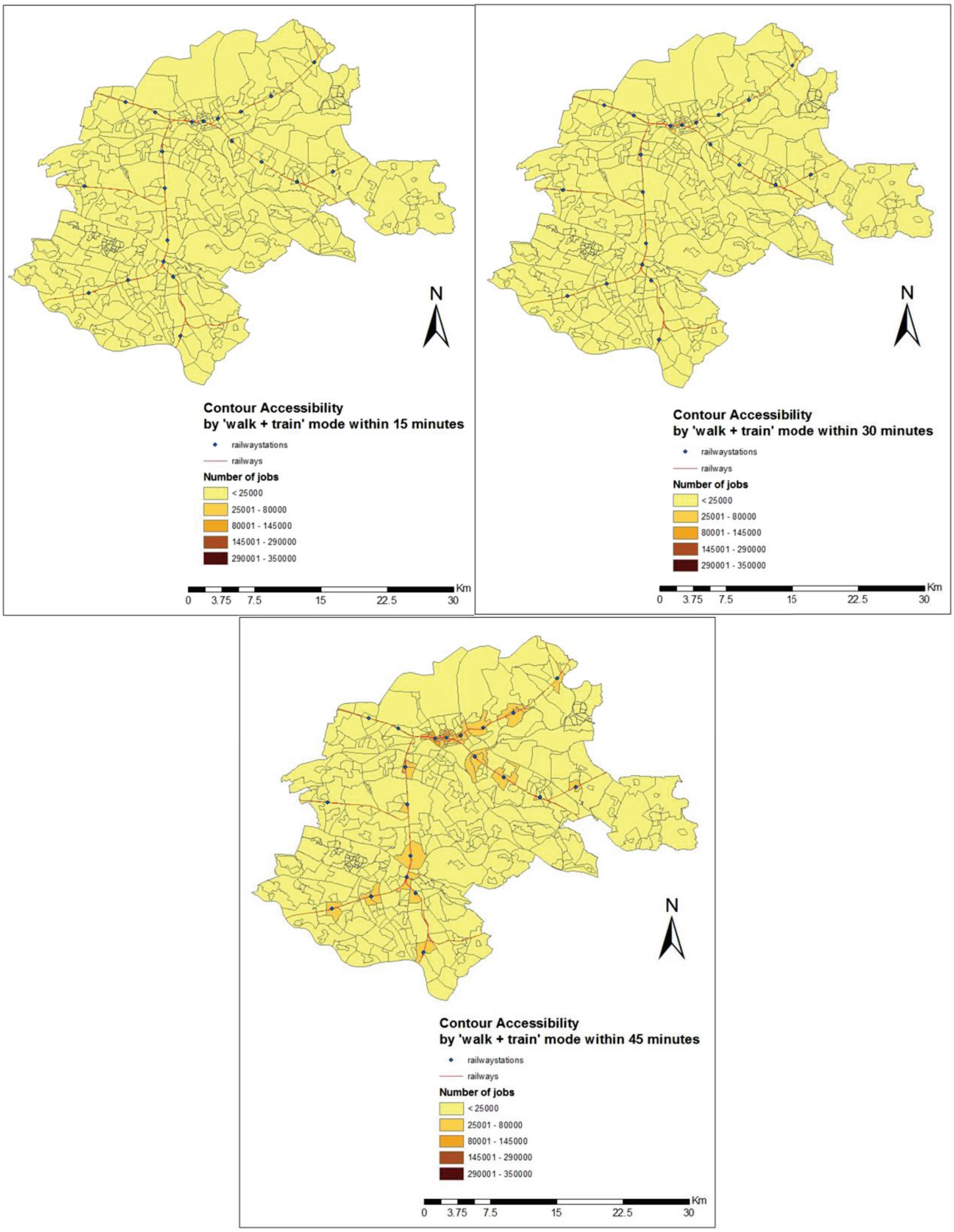



Figure 1: Contour accessibility value by train within 15-, 30-, 45-minute travel time threshold

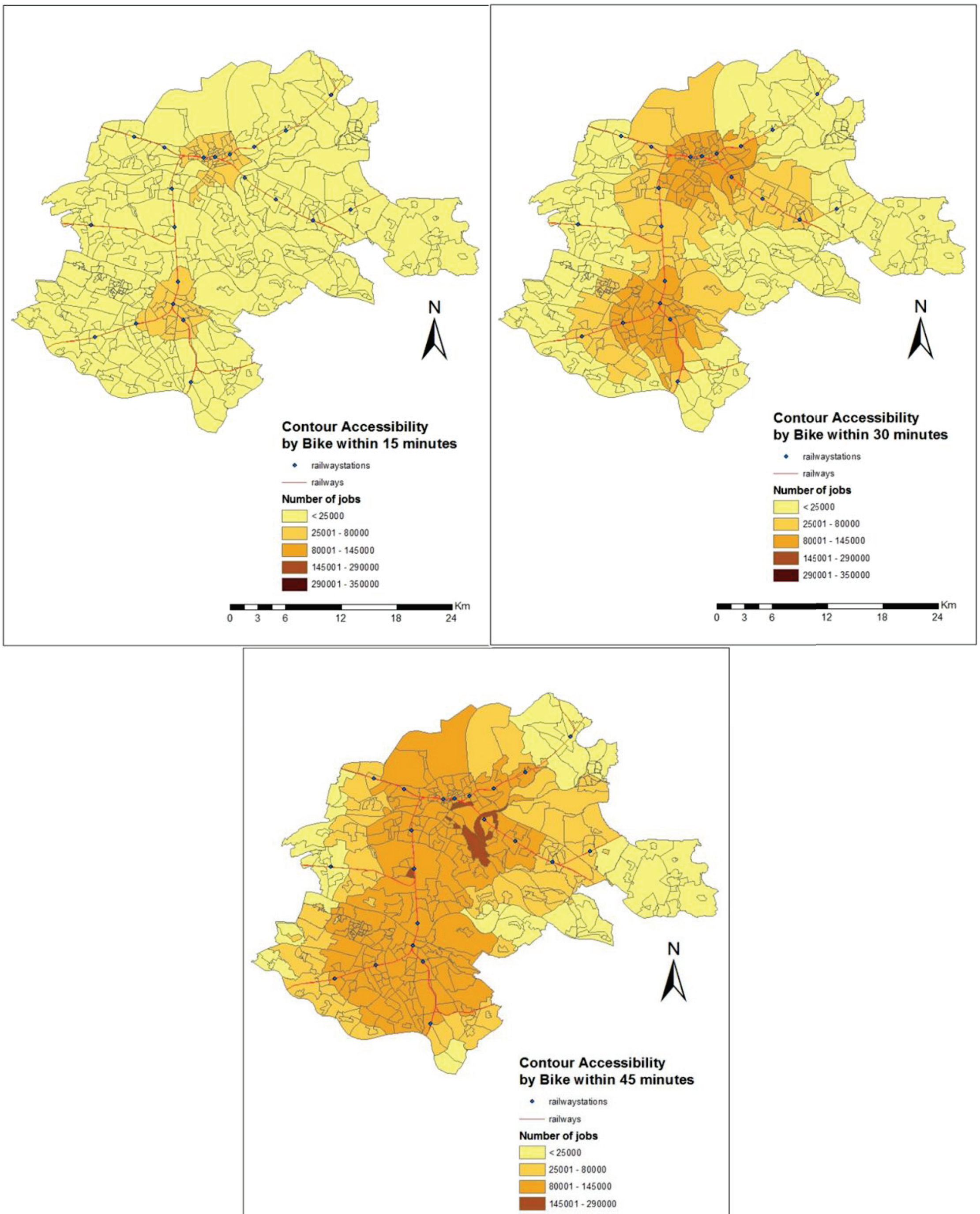



Figure 2: Contour accessibility value by bicycle within 15-, 30-, 45-minute travel time threshold

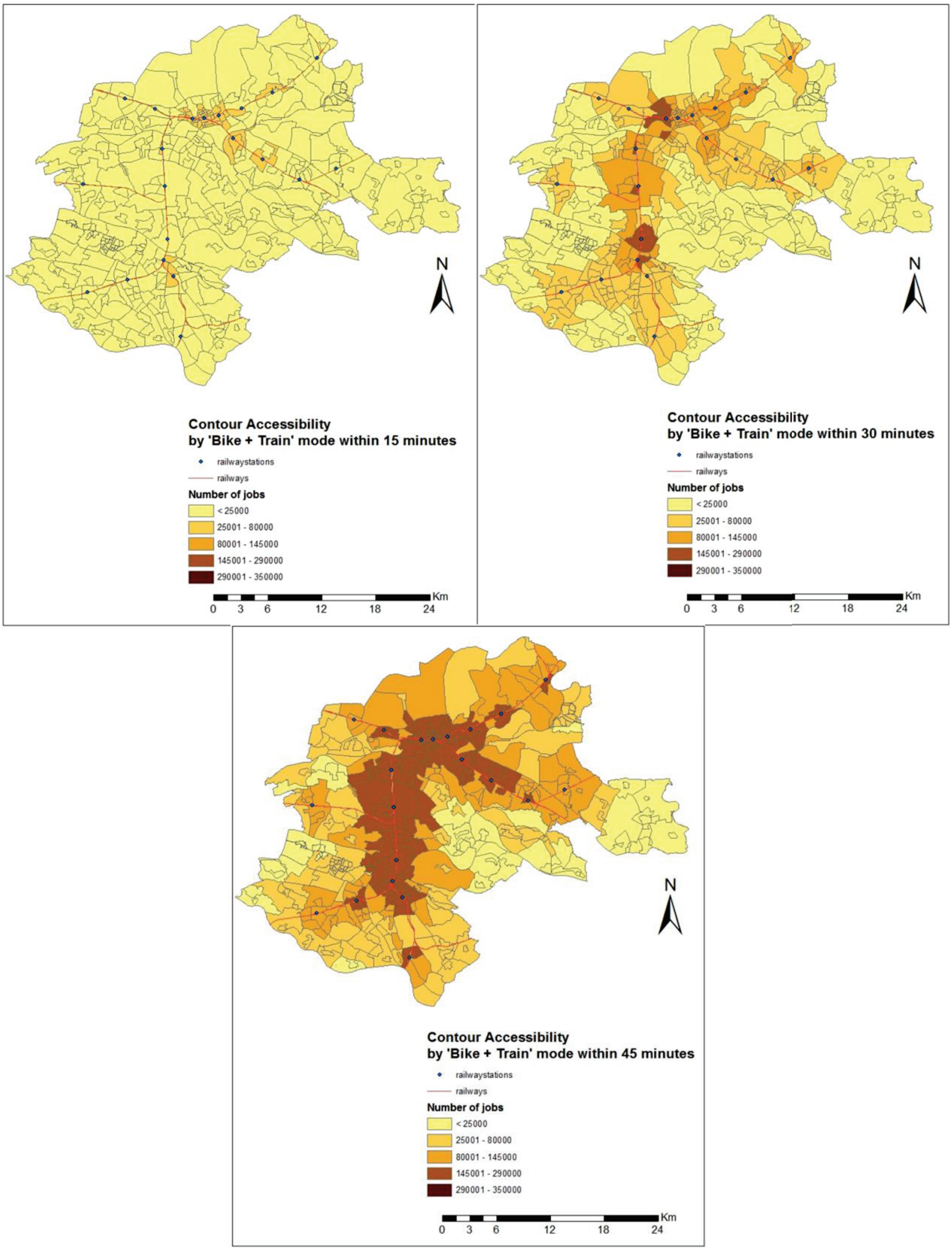



Figure 3: Contour accessibility value by "bike+train" within 15-, 30-, 45-minute travel time threshold

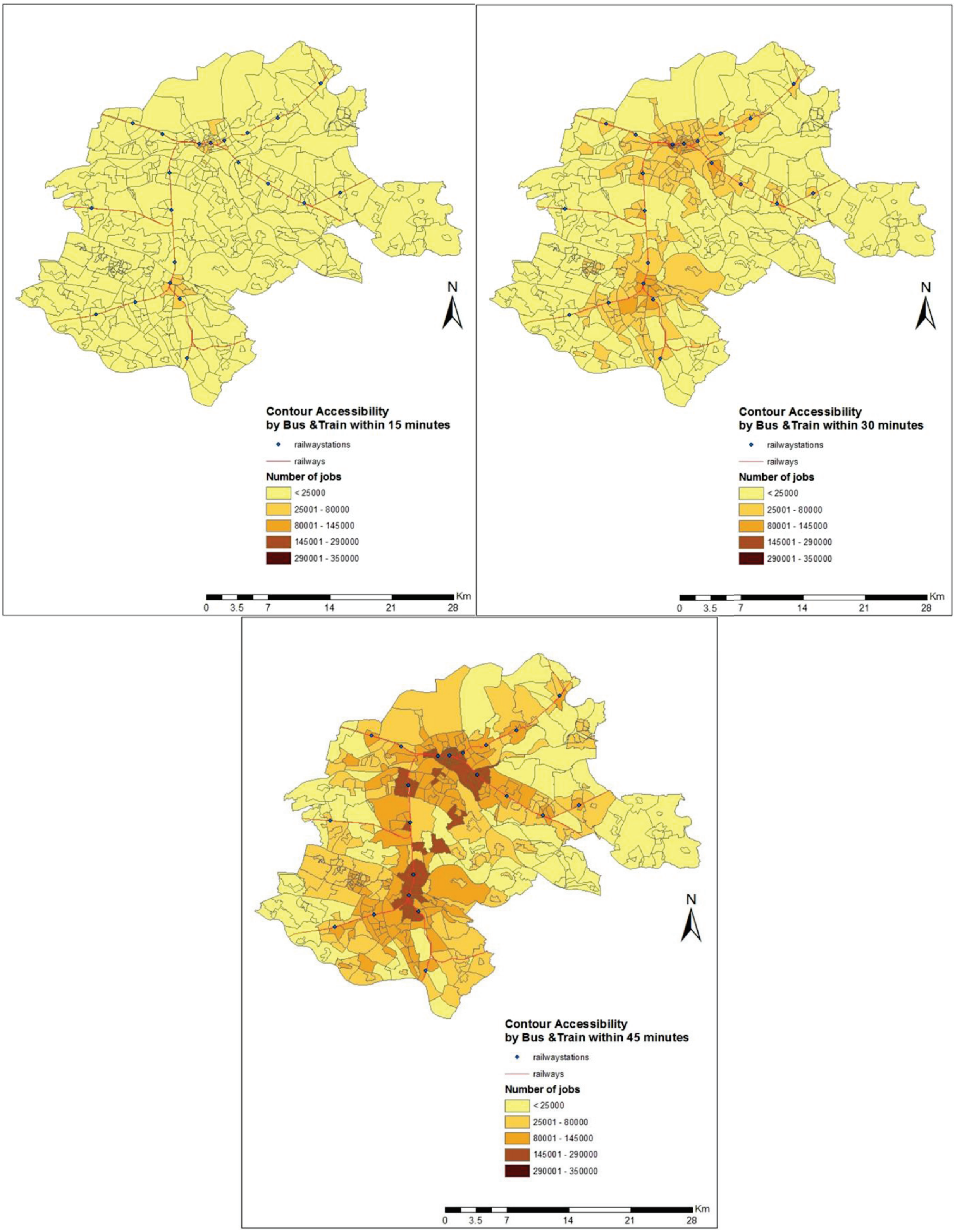



Figure 4: Contour accessibility value by bus&train within 15-, 30-, 45-minute travel time threshold

# APPENDIX III

```
#include "stdafx.h"
#include <tchar.h>
#include <string>
#include <iostream>
 #include<fstream>
#include "stdio.h"
#include <vector>
#include<Windows.h>
#include "stdlib.h"
#include "time.h"
#using <mscorlib.dll>
#using <System.Xml.dll>

using namespace System;
using namespace System::Xml;
using namespace std;
fstream con("config.txt");
ofstream out("output.txt",ios::trunc);
ifstream fin("Input.txt");
inline bool isNumber(const std::string &s)
{
  if(s.empty()||((!isdigit(s[0]))&&(s[0]!='-')&&(s[0]!='+')))return false;

  char*p ;
  strtod(s.c_str(),&p);

  return(*p ==0);
}

void MarshalString ( String * s, string& os ) {
  using namespace Runtime::InteropServices;
  const char* chars =
    (const char*)(Marshal::StringToHGlobalAnsi(s)).ToPointer();
  os = chars;
  Marshal::FreeHGlobal(IntPtr((void*)chars));
}

void MarshalString ( String *s, wstring& os ) {
  using namespace Runtime::InteropServices;
  const wchar_t* chars =
    (const wchar_t*)(Marshal::StringToHGlobalUni(s)).ToPointer();
  os = chars;
  Marshal::FreeHGlobal(IntPtr((void*)chars));
}

int search(String *URLString,string saddr,string daddr)
{
        XmlTextReader *reader = new XmlTextReader (URLString);
        int flag=0;
        int alrt=0;
```

```
        string duration,start_address,end_address;
        string tem;
while (reader->Read())
{
   switch (reader->NodeType)
   {
                        case XmlNodeType::Element: // The node is an element.
                                MarshalString(reader->Name, tem);
                                if(tem=="duration")
                                {
                                        flag=1;
                                //      cout<<duration<<"  "<<":";
                                        tem="null";
                                }

                                if(tem=="vehicle")
                                {
                                        flag=4;
                                //      cout<<duration<<"  "<<":";
                                        tem="null";
                                }
                                if(tem=="start_address")
                                {
                                        flag=2;
                                //      cout<<duration<<"  "<<":";
                                        tem="null";
                                }
                                if(tem=="end_address")
                                {
                                        flag=3;
                                //      cout<<duration<<"  "<<":";
                                        tem="null";
                                }

                                if(tem=="status")
                                {
                                        flag=5;
                                //      cout<<duration<<"  "<<":";
                                        tem="null";
                                }


                                //Console::Write(s);
                                //Console::Write("<{0}", reader->Name);
                                while (reader->MoveToNextAttribute()) // Read the attributes.
                                Console::Write(" {0}='{1}'", reader->Name, reader->Value);
                                /*Console::WriteLine(">");*/
          break;
                        case XmlNodeType::Text: //Display the text in each element.
                                //Console::WriteLine (reader->Value);
                                if(flag==1)
                                {
                                flag=0;
                                MarshalString(reader->Value, tem);
                                if(isNumber(tem))
```

```
        {
        duration=tem;
    }
    }

    if(flag==2)
    {
    flag=0;
    MarshalString(reader->Value, tem);

        start_address=tem;
    }
    if(flag==3)
    {
    flag=0;
    MarshalString(reader->Value, tem);

        end_address=tem;
    }

    if(flag==4)
    {
    flag=0;
    MarshalString(reader->Value, tem);
    if(!alrt)
    {
    if(tem=="Train")
        {
            alrt=1;
            cout<<"-------------------this route includes train----------
-------------"<<endl;
            out<<"-------------------this route includes train-----------
------------"<<endl;
            out<<"can search by hand："<<endl;

out<<"https://maps.google.de/maps?saddr="<<saddr<<"&daddr="<<daddr<<"&hl=de&geocode=F
WDeGAMdzLhXAA%3BFR7fGAMdXsZdAA&dirflg=rB"<<endl;
    }
    }
    }

    if(flag==5)
    {
    flag=0;
    MarshalString(reader->Value, tem);
    if(tem=="OVER_QUERY_LIMIT")
        {
            cout<<"-------------------reach the upper limit-------------
----------"<<endl;
          out<<"-------------------reach the upper limit---------------------
-"<<endl;
            return 2;
    }
    if(tem=="ZERO_RESULTS")
        {
```

```
                                        out<<"can search by hand："<<endl;

out<<"https://maps.google.de/maps?saddr="<<saddr<<"&daddr="<<daddr<<"&hl=de&geocode=F
WDeGAMdzLhXAA%3BFR7fGAMdXsZdAA&dirflg=rB&date=05%2F11%2F13&time=08:00"<<endl;
                                        }
                                }
        break;
                        case XmlNodeType::EndElement: //Display the end of the element.
                        //      Console::Write("</{0}", reader->Name);
                                //Console::WriteLine(">");
        break;
    }

  }

        //out<<"duration"<<"  "<<":"<<duration;
        cout<<"duration"<<"  "<<":"<<duration<<"  start_address"<<"  "<<":"<<start_address<<"
end_address"<<"  "<<":"<<end_address<<endl;
        out<<"duration"<<"          :          "<<duration<<endl<<"start_address"<<"       :
"<<start_address<<endl<<"end_address   :  "<<end_address<<endl;
  // Console::ReadLine();
        alrt=0;
        return 1;
}
void changecon(int k,vector<string> config)
{
        con.close();
        ofstream fing("temp.dat",ios::out);
        for (int i=0;i<7;++i)
                {
                        if(i==6)
                        {
                        fing<<k<<endl;
                        continue;
                        }
                        if(i==5)
                        {
                        fing<<1<<endl;
                        continue;
                        }
                fing<<config[i]<<endl;

                }
        remove("config.txt");
        fing.close();
        rename("temp.dat", "config.txt");

}
void _tmain(void)
{
        string time="15407152";
        string startOrt,zielOrt;
        startOrt="Tolkamer";
        zielOrt="Janssingel";
        string Ort;
```

```
            string con2;
            int i=0;
            vector<string> Orts;
            vector<string> config;
            while(!con.eof() )
{
            getline(con,con2);
  config.push_back(con2);
            }
            int j=0;
            int bis=0;
            bool lastrun=0;

            while(!fin.eof() )
{
            getline(fin,Ort);
  Orts.push_back(Ort);
  i++;
            }
            if(config[5]=="1")
            {
            string xuanze="1";
            cout<<"continue the previous or not？  1 Y. 2 N"<<endl;
            cin>>xuanze;
            if  (xuanze=="1")
                        {
                                    lastrun=1;
                                    j=atoi(config[6].c_str());
                                    bis=atoi(config[3].c_str());
                  }
            }

if(!lastrun)
{
            j=atoi(config[1].c_str());
            bis=atoi(config[3].c_str());
            cout<<"in  "<<i<<"  place！！！！！！！ "<<endl;
}

cout<<"from  <<"<< j <<">>  to  <<"<<bis<<">>   end"<<endl;
//cout<<"in  "<<i<<"  place"<<"cannot input the number larger than this！！！！！！！ "<<endl;
//cout<<"please input the start number and press the Enter: ";
//cin>>j;
//cout<<"please input the end number and press the Enter: ";
//cin>>bis;
if(bis>i)
            bis=i;
int jishu=0;

  for(j;j<bis;j++)
            {
                        changecon(j,config);
                        startOrt=Orts[j];
                        for(int k=j+1;k<i;k++)
```

```
                {
                        zielOrt=Orts[k];
        string A="http://maps.googleapis.com/maps/api/directions/xml?origin=";
        A=A+startOrt;
        A=A+"&destination=";
        A=A+zielOrt;
        A=A+"&sensor=false&mode=transit&departure_time=";
        A=A+time;
        String *URLString=new String(A.c_str());
        //for(int i=0;i<2;++i)
          cout<<"----------------------------"<<jishu++<<"---------------------------------"<<endl;
          out<<"----------------------------"<<j<<"---------------------------------"<<endl;
                out<<A<<endl;
                if(search( URLString,startOrt,zielOrt )!=1)
                {
                cout<<endl<<"unfinished";
                out.close();
                system("pause");
                return;
                }
                out<<"InputStart     :   "<<startOrt<<endl;
                out<<"InputEnd       :   "<<zielOrt<<endl<<endl<<endl;
                        Sleep(5000);
                }
         }
                cout<<endl<<"finished";
                out.close();
                system("pause");
}
```