MULTIMODAL ACCESSIBILITY INDICATORS IN GIS

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March, 2011

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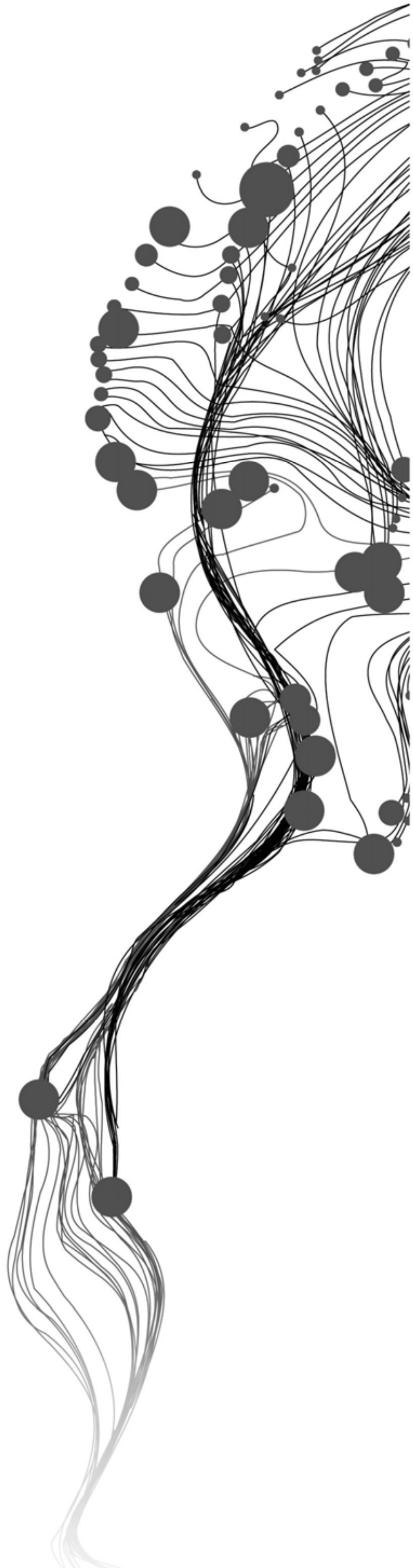

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Enschede, The Netherlands, March, 2011

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.
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ABSTRACT

An urban area is a web of various activities and people, wherein the transport system connects the two in space. The ease, with which people are able to access facilities and transfer goods from one place to other, depends upon the effectiveness of the transportation system in the urban areas. A paradigm shift is occurring in conventional transport planning practices. Modern transportation planning practices are based upon accessibility concept, which not only helps to improve transport infrastructure but also improves the travel behaviour and accessibility to various land uses.

Due to the shift from mobility oriented solution to accessibility based solution in transport service, there is a remarkable change is shaping in service provided by the transport system. Due to increased mobility, urban areas are facing various problems like traffic congestion, increasing number of automobiles , lack of a good public transport system and lack of integration between transport infrastructure and land use. These issues have led various organizations and public policy makers to adapt that solution which integrates various transport infrastructures as well as land use, and this has lead to adopt the concept of multimodal transport system. The concept of multimodal transport system is influencing the overall transport network structure and activities on space. But one of the problems realised by the policy makers is that once the multimodal transport system comes on ground then how can one evaluate and assess it on the basis of desired goal of increased accessibility. For this, accessibility based measures are found to be more accurate in evaluating the multimodal transport system against its desired goals.

Accessibility is one of the important performance measures which provides information with regards to functionality and effectiveness of existing and newly planned transport systems. It thereby provides necessary information for designing as well as monitoring the transportation system in integration with land use system of urban area.

This research seeks to investigate accessibility of a multimodal transport system in an urbanised area. From literature and current practices various factors influencing multimodality in transport are interpreted. The research aims to identify various accessibility indicators, which critically evaluate the system and identify key factors which influence multimodality by comparison of accessibility between automobile-only based and multimodal based system.

The method used to conduct accessibility analysis follow the work of Liu and Zhu , at two levels; city level and regional level. The first requirement was to develop multimodal transport network and unimodal network in GIS environment, which help to generate the cost factors to conduct accessibility measure and selection of distance decay function But Logsum cost method applied to calculate cost for multimodal transport system. This study only focuses on job accessibility experienced by various zones in the study area.

It was found from the study that choosing the appropriate accessibility measure for conducting accessibility measure depend upon the assumptions chosen for the accessibility analysis and results will differ with different socio-economic structures and modes(of what) used.

The findings of this research will hopefully help the planners and decision makers to efficiently invest in transport infrastructure and monitor them

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1. INTRODUCTION

1.1. Background

An urban area is a web of various activities and people, wherein the transport system connect these two in space. The ease, with which people are able to access facilities and transfer goods from one place to other, depends upon the effectiveness of the transportation system in the urban areas. Therefore, a good transportation infrastructure is a precondition for physical and economical growth of any urban area. Thus to achieve this goal, national and local governments are making enormous investments in transport infrastructure.

The basic goal behind conventional transport policies in many big cities is movement of people but not access to facilities. This lack of integration is the missing link between land use and transport system. The demand for transport is a derived demand, arising out of travellers' needs for accessing different services distributed in an urban area. Therefore, there is a growing requirement of an efficient transport system in urban cities, which links different land uses and delivers accessibility. The efficiency of a transport system to link various land uses in an urban areas is assessed through performance measures. Accessibility measures are performance measures which determines the ease with which an individual or group can access activities or opportunities from a source location using the offered modes of transport system in an urban area. Accessibility measures have multiple purposes and help to reflect the land-use and transport component of any integrated land use-transport development in an urban area.

1.1.1. Function of transport infrastructure

Transport modes are primarily distinguished by their functioning patterns and costs. Public transport modes are public transport services (bus, trams, metro and rail etc.) that carry passengers between predefined public transport points (Horn, 2002) . Transportation can be viewed as a system which include transport modes (private and public), consumers and operators (service providers and local government), how it operates at different scales (different scales means hierarchy of area served by system) and how various transport services are integrated in an urban area (Potter & Skinner, 2000). Multimodal transport system is intended to make travel easier by providing different mode choices during the journey.

Most cities contain two types of transport systems, network based and services based. The network based transport is consist of road networks and common modes include cars, bikes, buses whereas services based transport systems include service networks like trains, trams and metro. Most cities today have a combination of both systems. In the modern era, road networks suffer from congestion, poor accessibility to important centres and negative impact on environment. Similarly, transport service systems are unable to cope up with ever-growing populations, new developments and lack efficient management strategies. It is still unclear how to deal with negative developments and improve the scenario of transport systems as a whole in urban cities.

As a solution, a multimodal transport system offers opportunities to exploit the strengths of network based and service based transport while avoiding their weaknesses. This might involve combining different modes of private and public transport.

1.1.2. Accessibility

The concept of accessibility is not new, it has been utilised in many other fields and traditionally it has been discussed with reference to movement of people from one place to other by an automobiles. In general, accessibility is often a misunderstood, poorly defined and poorly measured construct (Karst T. Geurs & van Wee, 2004). It can be used in many fields and takes many forms; it can be applied to an individual or entire population and can be found at different spatial scales. Different authors have defined accessibility differently ("Accessibility," 2010; Black & Conroy, 1977; Koenig, 1980; T. Litman, 2010; Morris, Dumble, & Wigan, 1979; Weibull, 1976). Ross (2000) defines accessibility as "the ease of reaching some destination', and may include real or perceived costs in terms of time or money, distance travelled, level of comfort, availability and reliability of public transport, or any combination of these ". Accessibility can be viewed as the "ability to access" and its possible benefits. T. Litman (2010) stated that in any transport system, mode is one of the key aspects of accessibility. From figure 1, it can be clearly seen that the different modes have different levels of accessibility. A higher mode frequency and faster travel increases accessibility, whereas congestion can decrease the accessibility by some modes.

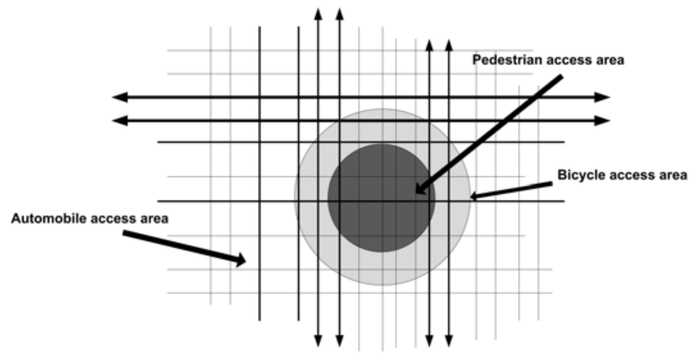


Figure 1: Accessibility by different modes (T. Litman, 2010)

1.1.3. How to evaluate a transport system

Measuring accessibility is important as it provides information on the functionality of existing transport systems and developing an improved or a new transport system. It provides necessary information for developing as well as monitoring the transportation system. According to Morris, et al.,(1979) accessibility reflects the performance of a transport system and its links with various land-uses . Accessibility measures are powerful tools to evaluate the service provided by a transport system to different sections of people in an urban area, and the ease with which a commuter can reach a desired activity/place with desired modes.

1.1.4. Accessibility measures

As stated above, accessibility measures can be used as performance measures to assess transport systems in urban areas. Weir (2008) stated in his report that accessibility is typically measured against desired goals set by the transport organization with the help of accessibility measures or indicators. Such indicators may be considered individually or collectively and can be used to create an accessibility index to allow comparison and ranking of population groups or geographical areas, or mapped to provide a visual tool to aid the planning process.

1.1.5. Types of accessibility indicators

There are wide-ranging accessibility indicators which have been developed and applied to evaluate the transport system by many authors (Black & Conroy, 1977; Karst T. Geurs & van Wee, 2004; Javier Gutiérrez, Condeço-Melhorado, & Martín, 2010; S. L. Handy & Niemeier, 1997; Koenig, 1980; T. Litman, 2010; G. Miller, 2001; Morris, et al., 1979; Wachs & Kumagai, 1973; Weibull, 1976; Weir, 2008). Every author takes a different perspective and outlook towards defining accessibility. Some of the accessibility indicators are based upon human behavioural, others on the basis of infrastructure, equity and spatial scale and some on the basis of transport, activity and utility. However, accessibility indicators are not appreciated because they bring out only a limited amount of information. According to Koenig (1980), "they are often appreciated as providing some interesting information; but their formulation usually confines their practical use to a minor role" . A key reason could be that every accessibility measure has its performance goal, assumption and urban setting. Therefore, there is a need to come up with a well developed assumption and goal before applying accessibility indicators - which are not only suitable but also act as a sound tool to evaluate the performance of a transport system and its impacts.

1.2. Justification

1.2.1. Types of transportation

The focus of this study is the evaluation of a multimodal transport system. Multimodal transport system is defined as a transport system in which two or more different modes are used for a single trip to reach a destination by user. According to Rodrigue (2010), a multimodal transport system integrates different geographical scales from the global to the local. If it is so, cities having a multimodal transport system should not experience any of the before mentioned transport problems and if cities has these problems then there is need to identify the problems in the transport system and try to solve them. According to Nes (2002), the two important components of a multimodal transport system are modes and multimodal platform. Contrary to the multimodal transport system is a unimodal transport system, in which only a single mode is used, as can be seen in figure 2.

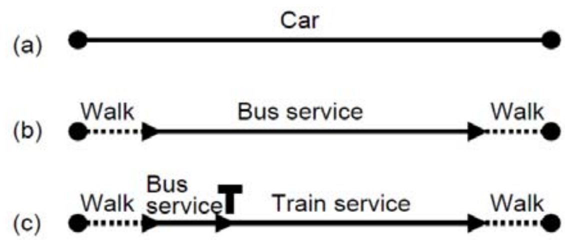


Figure 2: Example of a & b) Unimodal trip c) and multimodal trip

For the understanding of a transport system there is a need to understand few more factors of multimodal such as transfer, modes and transport services, cost (time and cost etc.), trip and role of walking etc which are explained in detail in chapter 2.

1.2.2. Relation with accessibility

Transport system helps the user to make a trip from an origin to a destination using certain modes and this determines the quality of that trip and transport service. The effectiveness of the transport system can be seen from the point of view of commuters as well as transport operator. A commuter is generally concerned with the service regularity, efficiency, travel costs (time and fare) and safety. The transport system operator, on the other hand, is generally concerned about the system's patronage, its operation & management costs, revenues, equity and environment impact etc. It shows that accessibility is strongly related to transport service provided by various networks. Better accessibility is the combination of good facility in terms of mode speed, less travel time, transfer and less trip cost. Nes (2002) compared public transport in combination with cycle and walking against car as shown in figure 3 and explained that multimodal transport requires fast and cheap transport service , so that it can save money (in terms of trip cost) and provide fast service to the commuter (save travel time) so commuter using car can shift to public transport.

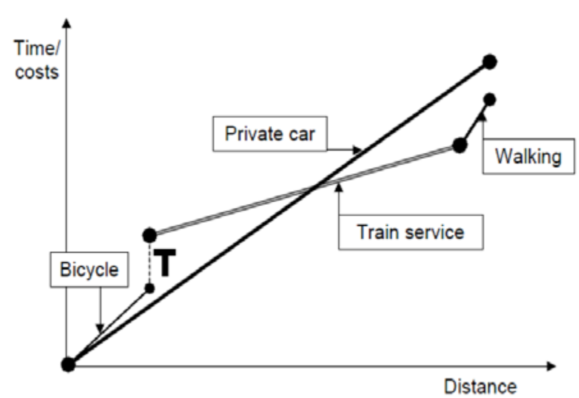


Figure 3: Time/ cost-distance diagram of a unimodal and a multimodal trip

1.2.3. Drawbacks of presently available accessibility indicators for multimodal transport system

The main question of this study is how to evaluate the performance of multimodal transport in an urban area. Thus, on one hand there are set of decision variables that determine the characteristics of such a system, while on the other side, there are objectives against which the performance of the multimodal system is evaluated. However, all above mentioned criteria are transport operator perspectives. Hence, there is a need to evaluate multimodal transport system from the perspective of the commuter. Commuters are the main consumers of transport services and it is essential to understand the level of ease with which they access opportunities at various locations. Accessibility measures have been applied by many researchers to evaluate automobile based and public transport system performance. However, a comparative study of the usability of these measures for multimodal transport system reveals that none of above mentioned measures are modeled and tested for assessment of the multimodal system against its performance objectives and hence do not provide a good fit. Therefore, there is a need to check the assumption, usability and objectives behind various accessibility indicators, and if necessary modify them to assess the performance of a multimodal transport system. Accessibility measures would aid policy makers to improve or develop multimodal transport system and also help them to monitor the performance of the transport system as whole.

1.3. Research Problem

A paradigm shift is occurring in conventional transport planning practices. There is a shift from extensive traffic flow (mobility) oriented approach to accessibility oriented strategies, which has led to a visible change from the perspective of transportation planning practice. Accessibility oriented transport policies look in to various other factors and favour different solutions like improvements to alternative modes, incentives to change travel behavior, and more accessible land use patterns, thereby helping to develop efficient transport systems which links various land uses and leads to more accessible urban cities (T. Litman, 2010).

Due to the shift from transport market to transport service, there is a remarkable change in service provided by the transport system. Cities like Manila, Cairo, Lagos, Macau, Seoul, Dhaka, Jakarta and Delhi are facing the typical urban transport problems and accessing opportunities might be the ultimate challenge for commuters in these cities. These issues have led to a variety of organizations and public policy makers to adopt the concept of multimodal transport system. From the last decade, the concept of multimodal transport system is influencing the transport network structure and transport market. According to Nes (2002), multimodal transport systems have been developed in different periods and by different actors in the transportation field. A look in to the multimodal system in the current scenarios of the cities reveals that most are not truly multimodal transport systems, but a set of different unimodal transport systems, which are poorly linked. There is no real strategy for a truly coherent multimodal transport system. These loosely connected unimodal systems have their separate schedules, frequency of modes and serve a particular target group like bus commuters, long distance train commuters and commuters using trams and metro services inside the cities.

One of the challenges in planning multimodal transportation systems is the development of measures of performance that properly reflect the level of service provided by the conceived systems. In thinking about performance measure for multimodal transport services, we face conceptual and analytical challenges. This is especially the case when performance measures are categorical, or non-additive, which complicates their integration into evaluation models. But these measures can be easily applied to each mode separately. Whereas in multimodal transport system, it is difficult to measure the level of service provided at different scales by different modes. The result of performance measure is inadequate to assess the overall performance multimodal transport. If performance of each unimodal assessed and sum them and compare with the desired objective of multimodal transport system will not be a sound basis for evaluating overall performance. Looking at the average of the entire picture performance measure may leave important facts which might be important for development of multimodal or monitoring purpose. With inadequate integration methodology, the problem may be underestimated or even overlooked. Multimodal systems work only if the modes are integrated well at the interface, and it is this integration that suffers the most from inadequate level of service definition and measurement.

Conventional transport network are based on unimodal transport networks only. Multimodal transport, however, implies combinations of different unimodal transport networks or transport services, and implies different network levels. One of the key objectives of this research study is to evaluate the impact of multimodal transport system over unimodal transport system and accessibility in the urban area. Does it lead to better accessibility level? In order to answer these questions, well structured assumptions behind accessibility measures are required. These assumptions will clearly evaluate the relationships between accessibility and service provided by multimodal transport system.

Literature on accessibility indicators is widely available, but the focuses of these accessibility indicators are on unimodal transport system or public transport system. Most appraisal practices tend to measure mobility over accessibility. Comparing the characteristics and attributes of multimodal transport, one need to rethink the concept behind accessibility indicators for multimodal systems. If one looks into the components of the presently available accessibility indicators and the components of multimodal system, accessibility indicators lack in many aspects. **Hence, there is not only the need to reevaluate the concept behind accessibility measure for multimodal systems, but also a challenge to model them in a GIS environment .**To understand the relationships between accessibility and multimodal transport systems, this research also reflects on the various factors that influence both and selects important factors which can be considered in accessibility measures. Further will also identified the gaps in currently available accessibility measures, and thereafter select accessibility indicators which can reflect the performance of multimodal transport systems and modeled them in a GIS environment. One of the other challenges of this study is to develop well structured multimodal transport systems in GIS environment, which includes important components of multimodal transport system.

1.4. Research Objective and Question

1.4.1. Main Objective

The main objective of this research is to determine a set of suitable accessibility indicators for evaluation of a multimodal transport system, which can be modeled and analyzed in GIS.

1.4.2. Sub Objectives

1. To understand the concept of multimodal transport system and describe how it differs from a unimodal system.
2. To understand the concept of accessibility from different stakeholder perspectives
3. To analyze the various factors affecting accessibility
4. To review the various accessibility indicators, particularly with respect to their suitability in multimodal system.
5. To select/adopt desired accessibility indicators that can be used to evaluate and compare a multimodal and unimodal transport system
6. To model and analyze the set of accessibility indicators in GIS

1.4.3. Research Question

To help achieve these objectives, the following questions have been framed. Through answering these questions, the objective of the research will be accomplished:

Table 1: Research questions

S.No.	Objectives	Research question
1	To understand the concept of multimodal transport system and describe how it differs from a unimodal transport system.	1. What is meant by transport system and when do we call a transport system a multimodal transport system and how does it operate differently from a unimodal transport system? 2. What are the factors which influence the multimodality in urban area?

2	To understand the concept of accessibility from different stakeholder perspectives	1. How is accessibility defined? or What are the various definitions of accessibility from different perspectives? 2. What are the different components of accessibility?
3	To analyse the various factors affecting accessibility	1. What are the factors spatial, social, economic etc. that affect accessibility? 2. How do these factors affect accessibility and to what extent?
4	To review the various accessibility indicators in particular with respect to their suitability in multimodal systems.	1. What are the various accessibility indicators? 2. How accurate/ useful are accessibility indicators in evaluation of accessibility?
5	To select/adopt those accessibility indicators that can be used to evaluate and compare a multimodal and unimodal transport system	1. What are the gaps in the current accessibility indicators which enable precise evaluation of multimodal transport system? 2. Which accessibility indicators can be adopted/ adapted for multimodal transport system and what will be the focus of this accessibility measure? 3. What will be the accessibility measure framework for the multimodal transport system? 4. What are the factors differentiating performance of multimodal transport from unimodal transport system?
6	To model and analyze the set of accessibility indicators in GIS	1. How to operationalise accessibility indicators for multimodal transport system in GIS and find out the usability and complexity? 2. Compare the accessibility measure evaluation for multimodal transport system and unimodal system and identify the scope for the development of multimodal transport system.

1.5. Research Methods

Methodology for conducting this study is adapted from the work of Liu and Zhu (2004) and can be structured in four phases (Figure 4).

1. Accessibility concept development,
2. Accessibility measures selection and specification,
3. Accessibility measurement, and
4. Interpretation and evaluation

The first phase of the methodology is accessibility concept development, which involves defining the purpose of accessibility analysis, understanding the planning context within which the accessibility analysis is to be conducted, and formulating the concept of accessibility. The concept of accessibility should be defined according to the purpose of the analysis, the nature of the transport system, and the relevance of the accessibility indicators to examine and evaluate the need for or the effectiveness of particular transportation and land use polices.

The second phase is selection of accessibility measures and specifications involved or developing appropriate type of accessibility measure for multimodal transport system and describe the selected accessibility measures. It is generally assumed that in the measurement of accessibility, the accessibility between origins and destinations shall be directly proportional to the associated demand and attraction, and inversely proportional to the distance, time or cost for traveling between them (Liu & Zhu, 2004; Morris, et al., 1979). But in the case of multimodal system, there are various other factors needed to be considered including the above. Compared to unimodal transport system multimodal system is more complex. For selecting accessibility indicators for a multimodal system, we are first required to understand the complexity of the system and its attributes, based upon which, we need to select or develop appropriate measures.

The third phase of accessibility measurement is to model the accessibility measures within a GIS environment (ArcMap10). As mentioned before, there are many accessibility indicators within contemporary literature, but they are based upon unimodal transport system. In this phase, we aim to model the concepts of multimodal accessibility indicators and try to evaluate different parameters of selected indicators. Later on, accessibility measures shall be calculated in multimodal network and land use pattern. It will measure different factors of accessibility for multimodal system and enhance our knowledge with regards to the important factors needed to measure the accessibility of system and reflect the emerging gaps. The second step in this phase is to calculate the overall accessibility index based on the specifications defined/ emerged in the second phase, so as to reflect the performance of the transport system.

The final phase of accessibility analysis focuses on presentation, interpretation and evaluation of the results of accessibility measurement. It may include the definition of spatial unit used for analysis, the definition of socio-economic samples, the type of opportunities, the choice of mode of travel, the definition of origin and destination and measurement of attractiveness and travel impedances for selected city or traffic analysis zones (TAZ). It will show us the performance of multimodal transport system and gaps and further improvements in accessibility indicators. It aims to interpret the results and translate them into useful information for policy making.

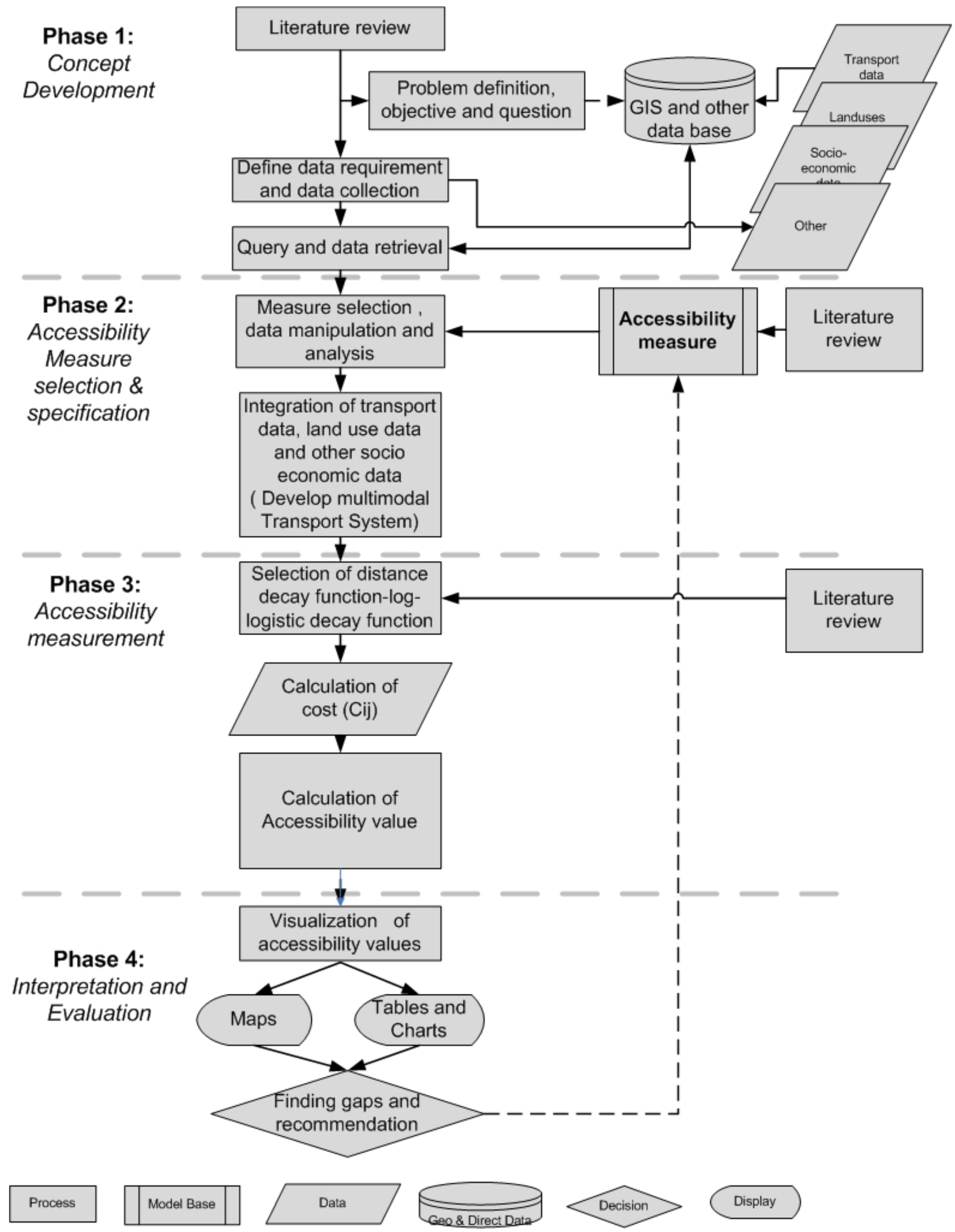


Figure 4: Operational Methodology: Approach to multimodal accessibility analysis

1.6. Limitation of research

The main limitation is the reliance on secondary data. Since it was not possible to conduct a extensive survey required for this study, it was necessary to rely on secondary data. Since, the integrity of data for this study was difficult to ascertain, this might have some repercussions on accuracy of the analysis.

Second limitation of this study lies in defining the Traffic analysis zones (TAZs) for the selected case study. The Size of TAZs was large which was not suitable for conducting accessibility analysis for this study. New TAZs had to be delineated keeping in mind various factors like highway network compatibility, boundary compatibility, socioeconomic data and size and broad land use. The new TAZs contain different socio-economic data and land use compared to the obtained TAZ from different sources. However, effort has been made to keep them as similar to their original shapes so as to keep the data accurate.

The third limitation was the lack of time and knowledge of requisite software, which may have an effect on the development of multimodal transport network. The fourth and the last limitation was the cost selected for conducting accessibility assessment for multimodal transport. Generalized cost has been calculated from travel time behaviour data and fare between origin and destination for combination of modes which might not be the true cost for calculation.

1.7. Thesis Structure

This being the first chapter, Chapter 2 introduces the subject of urban transport systems, multimodal transport, accessibility and accessibility measures. It discusses the concept of accessibility as whole, numerous factors which influence accessibility, the various accessibility indicators in literature, the concepts of multimodal transport and the characteristics of multimodal mobility today.

The overview of selected measures is given in Chapter 3. It presents various accessibility measures selected for this study from literature. It also looks in to the distance decay function and procedure of cost calculation adapted for this study.

The case study and accessibility measurement framework is introduced in chapter 4. Accessibility performance of multimodal transport system is the core issue in this study. This is evaluated through the accessibility measure framework, discussed in the chapter. This chapter also focuses on the development of multimodal transport network, calculation of cost for multimodal transport network and methodology framework to conduct accessibility analysis for multimodal transport system.

The output of accessibility measure is dealt in Chapter 5. It describes the application of various accessibility measures for multimodal transport system and also for unimodal transport system against various assumptions set for this study.

Chapter 6 and 7 returns to the main subject of this thesis: accessibility measure for multimodal transport system. The findings of chapters 5 are integrated in chapter 6 from multimodal transport perception, and the remaining questions are discussed and recommendations for further study are given.

2. LITERATURE REVIEW

This chapter gives the overview of transport system in urban area, accessibility measure and their application as found in literature. The first section of this study tries to identify the types of transport system in an urban area and emphasise on multimodal transport system and also look in to various factors that influence multimodal transport system. The second section of this chapter gives the overview of accessibility measures, short introduction to different components of accessibility and different perspectives. The third section reviews various accessibility definitions in literature and in planning practices and defines accessibility for this study. The last section describes various accessibility measures in literature and reviews them and tries to understand their application and usability for multimodal transport system and also tries to identify various criteria which can help to select accessibility measures for this study.

2.1. Urban transport system

Rapid urbanization has been one of the prevailing contemporary processes as cities grow due to economic factors and population growth. Considering these trends, transport issues are a concern to all because transport links each one. Transport system in urban areas is highly complex because of the modes involved, the multitude of origins and destinations, and the amount and variety of traffic. Traditionally, the focus of urban transportation has been on mobility, as cities were viewed as locations of people interacting with complex traffic patterns linked to commuting, economic development and cultural activities. However, cities are also locations of production, consumption and distribution where activities are linked to movements of freight. Conceptually, the urban transport system is intricately linked with urban form and spatial structure(Force & Rogers, 1999). Urban transportation is an important dimension of mobility, notably in high density areas. Barter (Barter, 1999)has compared different city structures based upon type of transport system. He has categorized cities in walking cities, transit cities and automobile cities. Various researches try to understand the complex relationships between transportation and land use through urban and transport models. However, this study tries to understand only transport system from the aspects of modes in the urban cities like unimodal transport and multimodal transport system. The focus of this study will be on multimodal transport in urban area.

2.1.1. Unimodal transport system

Unimodal transport system has different network levels and can be distinguished by specific trip types and having its own network characteristics in terms of space accessibility, network density, and network speed. Each unimodal transport has its own transport function and provides access to higher network levels. In unimodal transport system generally people travel between origin and destination through one mode only like car network, tram network , metro and rail network and there is no transfer between one to other modes network.

2.1.2. Multimodal transport system

In the past decade transport planning has broadened its horizons and also considered other aspects like mobility, accessibility, economic and land use. The concept behind the conventional transport planning is shifting from vehicle movement to people movements. In an urban area there are many transport modes; network and integration in between these networks and each mode perform its role in the overall framework. Contemporary transport practices are adapting to the concept of multimodal transport planning. According to (T. A. Litman, 2009) Multi-modal planning refers to decision making that considers various modes (walking, cycling, automobile, public transit, etc.) and connections among modes so each can fill its optimal role in the overall transport system.

For this study the concept of multimodal transport system has been studied from the work of Schmöcker (2002). The layer model of Schmöcker is a framework to analyze the transportation system and relationships between its components. The basic model of Schmöcker (2002) consists of three layers, Activities, Transport services and Traffic services, and two markets between them (Figure 5):

1. Transport market between activities and transport services;
2. Traffic market between transport services and traffic services.

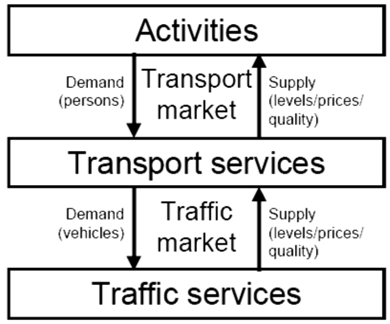


Figure 5: Layer model of the transportation system

Analyzing the model, multimodal transport system is related to the second layer which is transport services, where transport services determine the quality of the whole journey from door to door and it is influenced by various modes, various network and various attributes related to transport service. According to Schmöcker and M.G.H (2002) transport services include private transport as well as public transport. The differences between the various transport services depend on the characteristics of the transport networks like road based services or public transport based services.

According to multimodal transport system for any trip more than one mode or network combination services can be chosen. But there are very important elements concerned the transport services related to multimodal transport system and these are transport service integrators, providing transport means, and operating transport means.

The definition of multimodal transport in this thesis is adapted from (Nes, 2002) work , He defined multimodal system as a system where two or more different modes are used for a single trip between origin and destination (OD). A mode might be defined by vehicle type or by transport function. The part of the trip where a single mode is used is called a leg and there are some other components of multimodal transport like transfer, waiting time, travel time, access and egress time to the OD which will be discussed in brief in next section.

2.1.2.1. Components of multimodal transport

Accessing a bus at a stop may require walking to the stop. Traveler spends some time in bus to reach final destination and get down at transfer station from where he walks to office. Multimodal transport system has various components, these are:

- **Access:** The concept of access is usually mode specific. It is possible to consider that each mode is providing access to the next, but for the purpose of this analysis we reserve the term "access" to represent the first link connecting the a trip origin and the first mode to be used in the multimodal system. From a door-to-door perspective this begins from the moment the user gets out of the door to the point when he/she enters the system of the mode. This process may include composite links (walking, bicycling etc.) but they are all consolidated together as an access link. If any of these links is itself the subject of analysis, then it would have to be modeled as a separate mode.
- **Waiting time:** This is defined as the duration between the user's arrival to a transport nodes/terminal and the actual entry into the vehicle of the mode in question.
- **In-vehicle travel:** This is the duration of time spent in the vehicle.
- **Transfer:** This is defined as the duration between one getting out of the previous mode and arriving at the entrance point of the next mode/higher mode.

2.1.2.2. Factors that influence multimodal transport

In an urban area there are many factors which have an influence on the transport system. These factor rise from other aspects of urban area like economic growth of area and people, social structure of people, activity distribution and land use combinations etc. For Multimodal transport system in urban area these are variables related to traveler, such as age, education, and vehicle availability, and variables related to the trip itself, type of origin and destination area, trip purpose, and trip length. According to Nes's (Nes, 2002) three factors proved to be dominant in discriminating between unimodal and multimodal trips (in order of importance):

- Trip length: longer travel distances have more multimodal trips;
- Type of destination area: multimodal trips are oriented to the main cities and especially the city centers;
- Trip purpose: the main trip purposes for multimodal trips are work and education.

2.1.2.3. Multimodality in practices

Through literature, it is already confirmed that multimodal transport already exists in most urban areas, but what are the characteristics of multimodal mobility today? Characteristics such as the share of multimodal transport compared to unimodal transport and what are the various factors that determine multimodal transport usage. In order to answer these questions many researchers has done study on public transport (Bertolini & Le Clercq, 2003; Keijer & Rietveld, 1999; T. A. Litman, 2009; Nes, 2002). One of the example of multimodality in practices can be seen from the work of Nes on multimodal transport system, the data used for his study from National Travel Survey (NTS) 1995-1997 for Netherlands from. Table 4, shows the modal split for all trips with a distinction between unimodal and multimodal trips taken from the study of . According to Nes (Nes, 2002) the share of multimodal trips is small that is 2.9% of all trips are multimodal. Most multimodal trips (72%) consist of two legs, that is, two vehicle mode are used. 26% of multimodal trips contain three legs, and only 2% of multimodal trips consist of four or more legs. When looking at the main mode, that is, the mode used to cover the largest distance, train is the most important mode accounting for 59.2% of all multimodal trips. The second mode is bus, having 14.5%, followed by a group having a share of 6 to 7%: car passenger (7.3%), tram/metro (6.4%), and car driver (6.2%). Above seen analysis is one example and there are many other cases with different variables and characteristics.

Table 2: Modal split with distinction between unimodal and multimodal trips (NTS 1995-1997 for Netherlands)

Main mode	All trips (%)	Unimodal (%)	Multimodal (%)	Percentage multimodal
Car driver	36.2	36	0.2	0.5
Car passenger	13.1	12.9	0.2	1.6
Train	2.1	0.4	1.7	80.5
Tram/Metro	0.9	0.7	0.2	20.4
Bus	2	1.6	0.4	21.2
Bicycle	27.6	27.5	0	0.1
Walking	16	15.9	0.1	0.7
Other	2.1	2.1	0	1.7
All modes	100	97.1	2.9	2.9

2.2. Perspective

Multimodal performance measures can be defined from two perspectives: the user's perspective and the supplier's perspective. User's perspective can be gained by the individual's response on perceived utility based upon the assessment of costs and benefits from travelling. This study will focus only on user perspective. The supplier perspective reflects a producer's optimization process or a public agency's process of evaluating global impacts. The supplier can also be the government or private company. If government is the supplier, their concern is most likely the overall social welfare rather than final profit. The user's assessment of benefit is part of the supplier's optimization objective. But the supplier is also concerned with other attributes such as investment cost; agency cost, externalities, and with weights all these aspects as part of a planning, policy making process.

2.2.1. User's Perspective

Users' perception about multimodal transport system is usually captured by the utility function. From the users' perspective depend upon travel time, cost, safety, reliability and travel flexibility etc. and these factors can be categorized in two broad categories like: disaggregates and aggregate. This study will deal with the user perspective at disaggregates level.

Table 3: User's perspective

Category	Various factors
Disaggregates	Time(s)
	Money
Aggregate	Safety
	Reliability
	Flexibility etc

2.2.2. Agency's Perspective

Perspective of an agency should usually be based upon the profit out of total system. It should be able to maintain the balance of its income and expense. The government is responsible to provide the subsidy covering the gap between revenue and agency cost. To simplify our analysis the supplier's perspective is represented by the government's perspective.

2.3. Performance measure

A good performance measure system is significant to the success of any transportation system design and the required performance should be identified at the very start of system design. Many national, local research studies have been putting remarkable effort on transportation performance measures in recent years. The very first step in shaping the performance measure of a transportation system is to identify goals and objectives for different modes and for the system. The selection of goals and objectives should directly reflect the consumer's needs and the economic costs associated with it. The basic goals for transportation can be summarized by the following factors: mobility, accessibility, safety, environmental and public Involvement.

In general, performance measures can be classified as either qualitative or quantitative. According to Barter (1999) quantitative performance measures can be valued with a number such as average time of a travel, cost per ton-mile, and so on. Qualitative performance measures are those hard to be quantified and are indicative measures for system efficiency. Barter (1999) also classified performance measures based on different levels and grouped into three type and these are:

1. Infrastructure performance measures in transportation involve connections to transportation systems, intermodal facilities, and principle markets;
2. Operational level performance measures can be used to evaluate environmental impacts and
3. Service level; total travel time, delays, costs, freedom of scheduling, mode choice flexibility, and route choice flexibility, mobility and accessibility performance measures are some user level performance measures.

This study only look in to service level performance measure and accessibility will be the main focus of this study.

2.4. Measuring accessibility

The measurement of accessibility is an important component of most integrated land use and transport planning as it provides evidence that guides the planning process as well as tracking progress once the plan is implemented. As per Koenig (1980) accessibility indicators provide a sound tool for evaluating transport policies, especially at disaggregated level. It is used to assess how comfortably with which an individual, particular group or community can access activities from a specified location (origin) using the available modes of transport. Accessibility is typically measured against standards known as accessibility measures or indicators. Such indicators may be considered individually or collectively and can be used make comparison and ranking of population groups , geographical areas, or mapped to provide a visual tool to aid the planning process.

There are a range of methodological approaches to accessibility measure. Various authors has identified different measure to access the accessibility of people ((Curtis & Scheurer, 2010; Karst T. Geurs & van Wee, 2004; Koenig, 1980; Morris, et al., 1979; van Wee, Hagoort, & Annema, 2001). Most of them are quantitative measures which are based upon transport system, threshold or opportunity, coverage, attraction and behavioural approach. The work of (C Bhat et al., 2002; Karst T. Geurs & van Wee, 2004) are particularly relevant.(Karst T. Geurs & van Wee, 2004) classify accessibility measures in three categories: infrastructure based accessibility measure, activity based and utility based measures.

- Infrastructure based accessibility measures use of congestion level, average travel speed on road and travel time models to analyze the performance of transport infrastructure.
- The activity based measure analyzes the range of available opportunities, their distribution in space and travel impendence between origin and destination points.
- Lastly, the utility-based measures use Logsum benefit measure, balancing factors and space-time measure used to analyze the benefit individuals derive from the land use-transport system.

There are also other categorise developed by Baradaran and Ramjerdi (2001) which are based upon travel cost approach, gravity or opportunities approach, constraints- based approach, utility-based surplus approach, composite approach etc. Bhat et al.(2005) has categorized accessibility measure on the same line of Geurs and van Wee , These are: graph theory and spatial separation as an accessibility measure, cumulative-opportunity accessibility measure, gravity measure, utility measure and time space measure. Most of above mentioned measures have been talked about by all the above mentioned authors but they have categorized measures as per their study situation. However, this study will try to consolidate the range of accessibility measure and try to identify which are the measures which can be applied and on what base for multimodal transport system in GIS.

2.5. Components of accessibility

This section describes the various components of accessibility in literature.

2.5.1. Transport components of accessibility

Geurs and van Wee (2004) has discussed three elements of transport system

1. Supply of infrastructure, its location and characteristics
2. Demand for passenger and freight travel and
3. The characteristics of resulting infrastructure use.

The conflict between infrastructure supply and travel demand, result in spatial distribution of road traffic, and the travel time, cost and effort to reach a destination. .These elements can be look in to three broad categories like travel time, travel cost and travel effort. These three factors become the generalized cost function in transport model and are normally used to estimate the level of spatial separation, level of service between the origin and destination. An example of generalized cost function is shown in equation (1).

$$C_{ij} = v_m\, t_{ijm} + c_m\, d_{ijm} + u_m\, k_{ijm} \quad (1)$$

Where t_{ijm}, d_{ijm} and k_{ijm} are travel time , travel distance and comfort of travel from location i to j by mode m, and respectively v_m , c_m and u_m are value of time, cost per km and disutility of inconvenience of mode m. The other factor is distance decay. If we look in the urban fabric of the city, the interaction between two location declines with the increasing generalized cost or disutility between them. In general there are many perspective and views which evaluate cost between an origin and destination and it is influence by these factors like transport mode, purpose of trip, socio-economic condition of people and land use characteristics .On the basic of these factors there are several distance decay function used in accessibility study. The choice of a specific distance decay function to be used is an accessibility measure depends upon the characteristics of the function, study area and availability of data, and choice of distance function and cost used in study as discussed below:

Distance decay

Distance decay describes the impedance of travel distance. The concept of distance-decay, used widely in geography and spatial interaction modeling, including many transportation forecasting models, can be interpreted as measuring either the impedance to travel through a network or the willingness of individuals to travel various distances to access opportunities. According to Geurs and van Eck (K. T. Geurs & van Eck, 2003) the perception and valuation of the distance between origin and a destination differs according to transport modes, purpose of trip , characteristics of the household and characteristics of the destination

There are many distance decay function in literature, some of them were also used in accessibility studies like:

- A negative power
- A negative exponential function
- Gaussion function
- Logistic function etc

The choice of distance decay function for accessibility measure depends upon the characteristics of distance decay function, study area and available traffic data. Some distance decay functions are less useful to describe the best fit of traffic behaviors. The selection of distance decay function for this study discussed in chapter 3.

Cost

Cost is important factor to conduct accessibility analysis for any urban area. Application of accessibility measure without cost is not possible. In reality there are two main components of the cost incurred by individual users during traveling are: time and money (fare). The measurement of travel time is easy, but it is difficult to quantify from user's perception as time varies between the different components of the total travel time. The cost incurred by individual by car and multimodal transport discussed in chapter 3.

2.5.2. Land use components

The distribution of opportunities in space influences the level of accessibility. In general the land use components of accessibility can be split up into two elements- the spatial distribution of supplied activities area and their characteristics and spatial distribution of demand of activities and their characteristics. Both the components of land use influence accessibility one way or other way. The interaction between demand and supply of various activities influences the level of accessibility.

2.5.3. Temporal components

Miller (1991) has introduced temporal components in accessibility. Temporal components of accessibility involve the availability of activities at different time of the day, week or year etc. and on the other hand time intervals in which individual participate in specific activities. The time component is dependent upon land use components of accessibility.

2.5.4. Individual component

The socio-economic characteristic of the user plays an important role in accessibility. The level of accessibility to opportunity depends upon the individual's socio-economic background. According to Steg, Steg and Gifford (Steg & Gifford, 2005) there are few characteristics related to people which influence accessibility and these are need, abilities and opportunity to any individual. Many researcher try to study the influence of above mentioned characteristics of individual on accessibility (Black & Conroy, 1977; Hansen, 1959; Preston & Rajé, 2007; Scheurer & Curtis, 2008).

2.5.5. Scale

In accessibility, scale is one of the important factors if we are dealing with the complex urban area and consisting of various neighbourhood, zones, districts or even regions. According to land use planning practices these area are connected by various transport networks and public transport services. These network and services can be functionally distinguished at different network levels. According to (Nes, 2002; Tahmasseby, Netherlands Research School for Transport, & Logistics, 2009) each network level is suited for specific trip type, especially with respects to trip length and also connecting to higher network level. Scale components of accessibility become relevant if we are dealing with the big urban area or region and when there are numbers of network levels and services which operate separately in the region. The next section will look in to different accessibility definitions from literature based upon above mentioned component and try to understand key factors which influence accessibility

2.6. Overview of accessibility definitions

The goal behind conventional transport policies is always mobility, which is related to the movement of people or freight and it can have different levels linked to the speed, capacity and efficiency of movements. In urban area good mobility is often considered as a basis for prosperity but it is also has negative impact on environment, waste of resources, damages communities, and contributes to pollution. The term 'mobility' is commonly used to describe the possibility to move and the actual movement of people and objects. It creates traffic in public space through various transport modes (road, rail, air space, and waterway). It can be measured by vehicle kilometres travelled, vehicle occupancy, passenger kilometres, and traffic speed or vehicle ownership. In transport, travelling is derived demand and the utility of that travelling depends upon the user, so it is difficult to say whether more or less travel is preferable, and whether more or fewer trips are better.

If we compare the time we spend daily travelling from home to desired destination, we realize that it is increasing. The travel time is continuously growing in the large as well as in the medium urban areas, even the situation is still better in the smaller areas (K. Geurs, Zondag, de Jong, & de Bok, 2010). Nuvolati (2009) study shows that mobility is only one aspect of personal well-being . But the mobility of people depends upon many factors and is not only dependent upon the quality of the transport system but also socio-economic condition of any individual , land use allocation , location and organization of services. According to Geurs and van Wee (2004) the land use is the component of transport system and mobility only deals with the transport system.

Accessibility, unlike mobility, tries to show the as a positive utility derived from transport-land use integration , regardless of how 'accessible' a city or region is, so that, unlike mobility, more is always seen as better. The concept of accessibility is not new, it has been used in many other fields and traditionally it has been discussed with reference to mobility. In general, accessibility is often a misunderstood, poorly defined and poorly measured construct (Karst T. Geurs & van Wee, 2004). It can be used in many fields and takes many forms; it can be applied to an individual or entire population and can be found at different spatial levels. According to van Wee et al. (2001) accessibility remains more difficult to define and measure than mobility. In urban geography, accessibility is used to explain the growth of region and it shows the relationship between the land use allocation , how facilities are distributed and how transport links them (Agarwal, 2007). Different authors have defined accessibility differently ("Accessibility," 2010; Black & Conroy, 1977; Koenig, 1980; T. Litman, 2010; Morris, et al., 1979; Weibull, 1976). Ross (2000) defines it as "the ease of reaching some destination', and may include real or perceived costs in terms of time or money, distance travelled, level of comfort, availability and reliability of public transport, or any combination of these ". Accessibility can be viewed as the "ability to access" and possible benefit of that. T. Litman (2010) stated that in a transport system, mode is one of the key aspect of accessibility.

If accessibility is to prove a useful concept in practice, a consistent terminology is needed. There are many definitions of accessibility in the literature, a selection of which are summarized in appendix 1 and also figure 6 show the overall reflection of performance measure, factors, and components which define accessibility.

Even though the basic elements of accessibility are therefore clear from above described definitions, there are also some differences which make a detailed comprehensive definition of accessibility problematical. In particular:

- How to segment the population in term of accessibility based upon abilities and perceptions.
- Ensuring a broad enough view and information of all transport modes which reflects all aspects of modal choice, and quality in terms of speed, cost, prestige, security, comfort etc.
- Clarifying when absolutes can be defined e.g. "ability" and when comparatives are needed e.g. "ease". Specifically, what is "reasonable", what is "need", and how much choice is needed?

2.6.1.1. Defining Accessibility

Definition of accessibility for this study has been study from Rose's definition of accessibility in combination into some other key factors. In this study accessibility is referred to the "**ability to reach desired opportunities at reasonable cost, in reasonable time and with reasonable ease with the help of available and reliable transport network and transport service, or any combination of these by all group of society".**

2.6.1.2. Factors that effects accessibility

Accessibility measures are very sensitive and they are sensitive to the following factors: Transport need and activities, land use factors, constraints, barriers, transportation options, affordability, spatial scale, integration, spatial scale, equity and dynamics. These factors are briefly discussed in table no 4.

Table 4: Key factors that influence accessibility measure

Key factors	**Description**	**Current consideration**
Transportation need and ability	Amount of mobility people would like under various conditions and the amount of mobility people actually experience.	Motorized travel demand is well studied, but non-motorized demand is not. Travel demand is often considered exogenous rather than affected by planning decisions.
Land Use Factors	Various land use factors like density, mix, connectivity and distribution of activities and services affects accessibility.	Considered in land use planning, but less in transport planning.
Constraints	It is relatively straightforward to take account of regulatory constraints and bye-laws.	Broad regulation considered in transport planning during development of infrastructure but mostly depend upon the people behaviors
Barriers	Spatial and non-spatial impedance, e.g. economic, legal, cultural or linguistic barriers between areas may be considered	Considered in land use planning but not really followed in transport planning practices
Transportation options	The quantity and quality of transport modes and services available in a particular situation.	Motor vehicle options and quality are usually considered, using indicators such as roadway level-of-service, but other modes lack such indicators and some important service quality factors are often overlooked.
Affordability	User affordability for the services and transport service particularly for basic access.	Automobile operating costs and transit fares are usually considered.
Spatial Scale	Activities are located in areas representing regions, cities or corridors. At what scale are we making our policies?	There is need to integrate which is missing in both land use and transport planning practices
Equity	Issues of spatial equity arise with respect to differences in accessibility both within and between areas	Land use planning tries to distribute resource equally among the people but transport planning practices ignored the fact of equity in most urban areas. Transport planning practices depend more upon the trip flow and congestion than equity factors.
Dynamics	Cities are dynamics in nature and cities are changing vary rapidly with the distribution of socio-economic variables.	Land use planning try to incorporate the current situation of cities and plan for coming year, whereas it lacks in transport planning practices. It requires better

		forecasting tool for new development and traffic requirement.
Integration	The degree of integration among transport systems links and modes, including terminals and parking facilities with land use activities.	It requires more integration at the stage of planning.

The quality of accessibility has direct and indirect impacts in an urban area. The above mentioned factors affect accessibility. Some of these factors tend to be overlooked or undervalued, particularly non-motorized travel demand, alternative mode service quality etc.

Our ability to evaluate accessibility is improving and becoming a powerful tool to policy maker as they try to understand these factors and incorporate in accessibility measures and it policy making to quantify accessibility impacts. However, an accessibility technique are still new and requires good data for application and sound interpretation to understand the results and practitioners are still learning how to apply them to specific decisions.

2.6.1.3. Overview of accessibility measures

This section describes the typology of accessibility indicators. There are hundreds of published accessibility measures with different names, source data, uses, and calculation methods (C Bhat, et al., 2005). As described earlier in this chapter, accessibility is the unit of measurement of either the opportunities being reached or the measure of separation of reaching opportunities. Generally transport policy is intended to improve the "ease of reaching" activities, and then the measure needs to mirror this. Accessibility measure can be categorized in three major categories and these are shown in table no 5 (C Bhat, et al., 2005; Karst T. Geurs & van Wee, 2004).

Table 5: Accessibility measure

Accessibility Measure	Example of accessibility indicators application used by various authors
Infrastructure Based Measure	(Linneker & Spence, 1992)
Location Based Measures	
Contour measure	(Black & Conroy, 1977; Eno Foundation for & Eno Foundation for Highway Traffic, 1947; Guy, 1983; Ingram, 1971; Wachs & Kumagai, 1973)
Potential measure	(S. Handy, 1993; Hansen, 1959; Stewart, 1947; Vickerman, 1974)
Adapted potential measures	(Knox, 1978; Shen, 1998; van Wee, et al., 2001; Weibull, 1976)
Balancing factors	(K. T. Geurs & van Eck, 2003)
Person Based Measures	(Harvey J. Miller, 1991; Recker, Chen, & McNally, 2001)
Utility Based Measures	
Logsum benefit measure	(S. L. Handy & Niemeier, 1997; Koenig, 1980; Niemeier, 1997; Sweet, 1997)
Space–time measure	(H.J. Miller, 1999)
Balancing factor benefit measure	(Martínez, 1995)

Source:(Karst T. Geurs & van Wee, 2004)

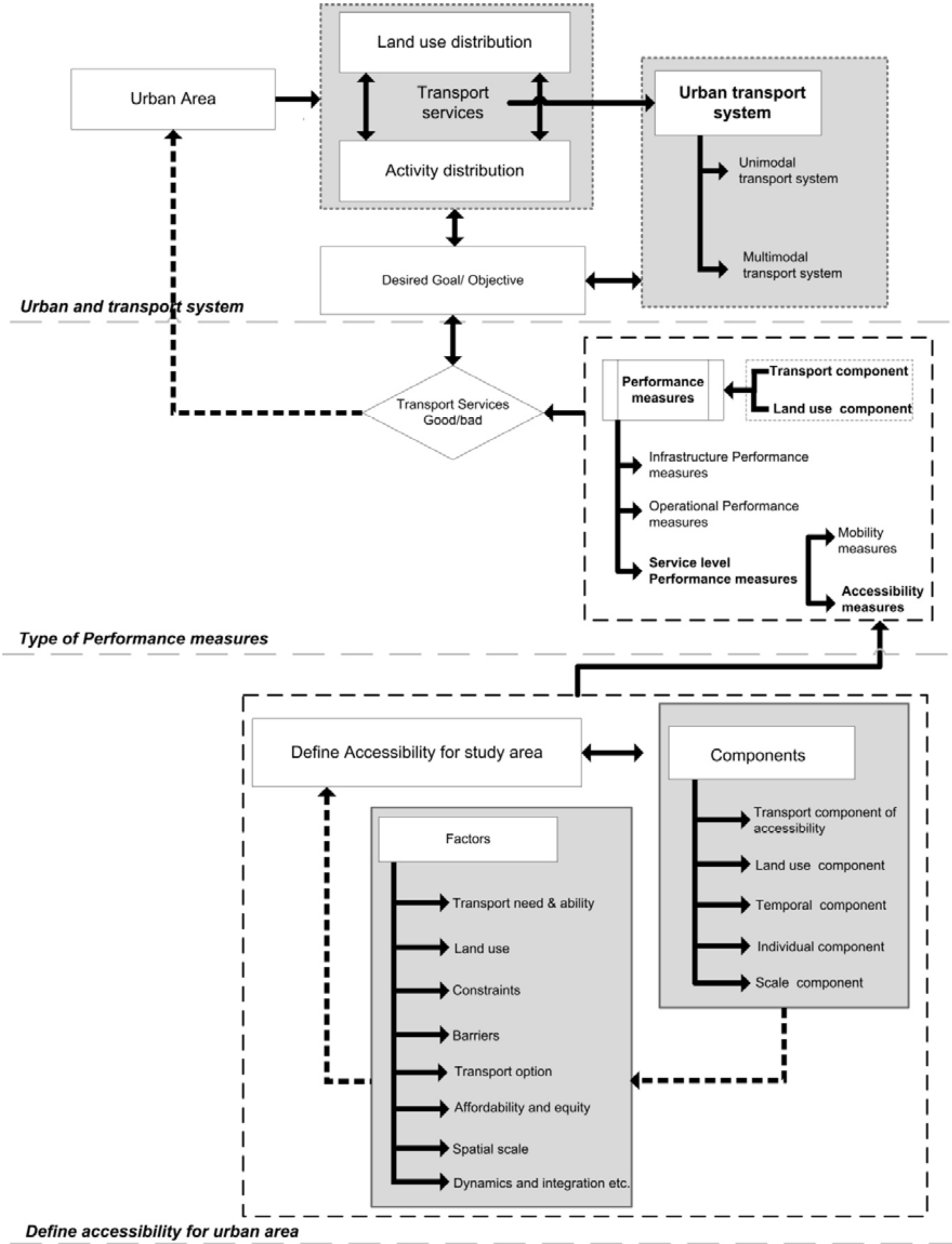


Figure 6: Reflection of various performance measure, factors and components which define accessibility

2.6.2. Review of accessibility measures

In order to compare the various accessibility measures, a comparison matrix has been developed. The accessibility measures are divided in to three main categories: infrastructure, activity and utility based accessibility measures based upon Geurs and Bhat work (C Bhat, et al., 2005; Karst T. Geurs & van Wee, 2004).

For each measure, four types of information were extracted from the various research papers. The first information is the general equation of the accessibility indictors, second is a description of the approach or measure, third is what are the advantages of the various measures and fourth is the disadvantage of various indicators. Review is summarized in appendix 2 and shown in figure 7.

From the review of various accessibility measures it was realized that accessibility measures have been developed on various factors and have been developed for different objectives. The infrastructure based accessibility measures are founded on the observed performance of transport system. Activities based measures are founded on the distribution of activities in space and time and the utilities based accessibility measures are founded on the benefit people derive from access to the spatially distributed activities.

2.6.3. Usability of various accessibility measure of multimodal transport system

This section reviews the usability of various accessibility measures for multimodal transport system. This accessibility review tries to identify which are the accessibility measures that can explain accessibility for multimodal system and it is discussed in appendix 3 and tries to reflect the usability of various accessibility measures for multimodal transport system in figure7. Figure 7 shows various factors which influence multimodal transport and accessibility measures. Based upon attributes of accessibility measure and selected criteria, usability of different accessibility was defined for multimodal transport system in this study.

From appendix 3, it was found that there is tradeoff between interpretation and methodological soundness of the measures. Infrastructures based accessibility measures and distance measure do not incorporate land use / spatial distribution of activities but are easy to implement and does not show true picture of multimodality because it can only deal with one mode at time. Contour measures can reveal multimodality in urban area. Potential measure and gravity measure is looking in to all aspects of multimodality, easy to interpret and useful to apply. Gravity measure also reveals the competition effects on destination and origin location. Utility based measures are the most appropriate for analysis for multimodal system because they compare the utility of multimodality over single mode and also look in to the spatial interpretation between various land use and activities but this cannot be easily interpreted and to apply it, one required a lot of data and support from various economic theories.

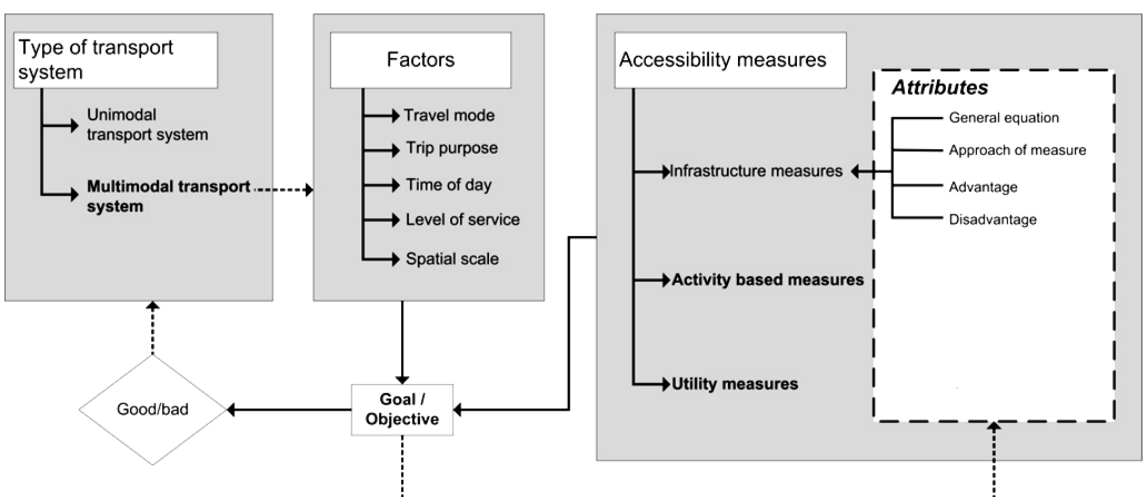


Figure 7: Reflection of appendix 3 through concept plan

2.7. Conclusion

Different Researchers apply accessibility measures and review them according various criteria like theoretical basis, ease of communication, interpretation, the data requirements and their usability in order to compare the result. From the literature review , it was found that accessibility measure applied in various case studies shows different measures and can lead to different conclusion (C Bhat, et al., 2005). This essentially highlights the statements that different situations and purposes demand different approaches. Guy (1983) did a comparative study of different accessibility measure to see the effectiveness of various measure and he found that gravity measures are far more nearer to reality than other measures. It considers various modes, competition among the opportunities and looks into the perceived cost experienced by the customers. Whereas Kwan (1998) compared gravity measure, cumulative measure and space time measure in one of his comparative studies. He mentions that, gravity and cumulative measures are good for measuring accessibility as they can take into account the various factors of accessibility. These measures have been used to characterize the potential impacts of transport project, change in accessibility over time, effects of land use and transport system and illustrate difference in various land use pattern and discrepancies between population groups. Wilson (1967) outlines various questions needed to answer before accessibility measure can be developed or selected , some of questions are :

- What is the degree and type of disaggregation desired?
- How are origin and destination defined?
- How is attraction measured?
- How is impedance measured?

Comparing the objectives of this study and research questions, it is realized that the above mentioned questions are critical for understanding the multimodality. As per the need of this study, accessibility measures for multimodal should able to tell the areas where, opportunities are not/ less accessible by multimodal transport system from various origin and destination points. Accessibility measures should be such that are easy to measure accessibility of various activities like jobs, market areas, school, college etc . Selected measures should also be able to reflect the impedance in term of cost and its affect on accessibility as costs increase or decrease.

Based on literature, it was found that infrastructure based measures could not address the above mentioned questions. In the case of activity based measures, there is a weight factor given explicitly in relation to travel time or impedance function; that gives less weight to more distant attraction. Activity based measure is typically applied at zonal level, an approach that assigns a uniform attractiveness to a zone and the same accessibility to all individuals within it. This measure easily incorporates socio-economic variables that reflect differences between individuals in the valuation of these factors. Utility measures might be good to measure the accessibility but they require more detailed data, are difficult to interpret and implement but are directly derived from travel behaviour theory.

3. OVERVIEW OF SELECTED ACCESSIBILITY MEASURES

This section gives an overview of selected accessibility measures. First section of this chapter describes various criteria through which accessibility measure selected for this study. Next section presents an overview of application of selected accessibility measures found in literature and the last section of this chapter giver the overview of various distance decay functions and cost calculation method adapted for this study

3.1. Selecting an Accessibility Measure

There are number of accessibility measures in literature each with their own pros and cons. This section describes the measures that are the most appropriate to use as accessibility measures to evaluate multimodal transport systems. Different measures are used to evaluate transportation plans and projects depending on the goals and concerns of those conducting the analysis (Levinson, 1998). Accessibility is one of the numerous methods to evaluate plans and systems. Other types of measures that are used include mobility, cost benefit analysis (CBA), productivity and social equity. For this study, some criteria have been found to be relevant in the choice of accessibility measures to evaluate accessibility. This study adapts some of the criteria from Geurs and van Wee's (2004) work for selecting accessibility measure and these are theoretical basis, ease of communication and interpretation, the data requirements and their usability as social, economic or sustainability indicators . These criteria are discussed below:

Theoretical Soundness

The theoretical basis of accessibility measures refers to how closely the measure fits existing theory and how closely the results represent reality. Ideally, an accessibility measure should incorporate all the elements that compose travel behavior, and it should be sensitive to changes in the transportation network and in the land-use system. Geurs and van Wee (2004) define five rules accessibility measures should obey to be considered theoretically sound:

1. Any changes in the service levels of a transport mode to an area should results in changes in accessibility levels in the area
2. Any changes in the number of opportunities should result in changes in accessibility levels in the area
3. Any changes in the demand for an opportunity with capacity limits should result in changes in accessibility levels
4. Any increase in opportunities for an activity in an area should not change accessibility levels of individuals not able to participate in the activity because of temporal constraints
5. Any transportation improvements or increase in opportunities for an activity in an area should not change accessibility levels for individuals not able to participate in the activity because of personal constraints

These five rules are a measure of how closely accessibility measure represents reality. However, respecting all these rules will require extensive data and complex calculations; whereby a tradeoff is required between theoretical soundness and simplicity.

Communication and Interpretability

The ease of communication and interpretation of an accessibility measure will be determinant in how often the measure is actually used in practice, and how useful it can be to urban and transport planners, policymakers or residents of a community. An easily understood measure that corresponds to the common-sense view of the transportation system may be more valuable than a theoretically sound one that requires lengthy explanations (Koenig, 1980). Another important consideration is the manner in which the accessibility level, or the result of the measure, is expressed. A ranking of local levels at the regional scale, a comparison of changes in accessibility, or a monetary value may be easier to communicate than potential values (S. L. Handy & Niemeier, 1997). However, there is no easy way to translate these measures from research to practice.

Data Requirements

The availability of the data required to calculate the accessibility measures will certainly play an important role to the selected accessibility measure. From the literature it was found that individual accessibility measures are very useful in terms of evaluating personal or temporal constraints faced by individuals. However, they are so data-intensive that most studies have only been conducted on a small number of individuals. The use of new activity-based models, access to large OD surveys may help overcome these barriers. The more popular location-based methods use data that is available or easy to acquire.

Economic Indicator

Transportation or land-use projects can have two types of economic impacts: direct user benefits such as reduced travel times and increased capacity and speeds; and indirect benefits such as improved productivity and the general economic impact on a specific sector. Measures currently used are reduced travel times and congestion, increased capacity, and cost-benefit analysis such as the consumer surplus and productivity measures. To be used as an economic indicator, an accessibility measure must be tied to economic theory, by measuring consumer surplus as the utility-based model does, or serve as input to calculate the benefits derived from a project (Karst T. Geurs & van Wee, 2004). The economic potential of a project can also be estimated using simple location-based measures if access to employment or an increase in the catchment area is defined as an economic objective.

3.2. Activity based accessibility measure

There are several types of accessibility measures used in urban and transport studies. On the basis of the above criteria, activities based measures are useful for this study. This study focuses on the following measures:

1. Contour measure
2. Potential measure
3. Gravity based accessibility measure

The detailed applications of each measure are described below.

3.2.1. Contour measure

The simplest accessibility measure that considers the distance and objective of trip is contour measure. This measure defines a travel time or distance threshold and uses the number of potential opportunities within the threshold as the accessibility for that spatial unit.

$$A_t = \sum_t O_t \qquad (2)$$

Here t is the threshold, and O_t is an opportunity that can be reached within that threshold. The contour does not consider opportunities over selected threshold. Breheny (1978) identifies three type of contour measure:

1. Fixed costs
2. Fixed opportunities
3. Fixed population

Applications of contour measure

Contour measure has often been used to measure accessibility to job, different sub-population, retail services, public services, health services and educational services (Levinson & Kumar, 1994; Mowforth, 1989). For instance, the number of job opportunities is used as the attraction to evaluate impacts on different subpopulations based upon income, employment type, gender and socio-economic parameters. This measure has been used to monitor changes in accessibility due to change in land use, the transport system or growth pattern in general. Allen and Perincherry (1996) used contour measure in their model to derive utility equation demonstrating the effect of accessibility on vehicle availability.

The main criticism of the contour measure is that there is no behavioural dimension and all opportunities are treated equally (Voges, Naudé, Transport, & Research, 1983). Weibull (1976) addresses the former issues by including a parameter related to car ownership, while Handy (S. Handy, 1993) addresses both issues with her distance-decay function calibrated from observed travel choices.

3.2.2. Potential accessibility measure

According to Carey citied by Geurs and van Wee (2004), the concept of potential was introduced in 19th century . It has been used and developed in the form of market potential in location analysis (Harris, 1954). Hansen (1959) was the pioneer who used this concept to describe accessibility to employment opportunities, defining accessibility as the potential of opportunities for interaction. The general description of potential accessibility is as follow:

$$A = \sum_{\boldsymbol{j}} D_j \ F(C_{ij}) \tag{3}$$

C_{ij} is generalised cost between *i* and *j* . The generalised cost can be in terms of time, monetary cost or travel distance. $F(C_{ij})$ is the impedance function, and in many studies impedance function has been modified into various alternative including negative exponential function, Gaussian function and logistic function.

Application of potential measure

Hansen's work has been widely used by others for accessibility analysis to different destinations like jobs (Linneker & Spence, 1992), population (Patton & Clark, 1970), retail services (Guy, 1983), health services, education etc. However, the work of Harris (1954) was also repeated in many accessibility measures as market potential, with income as the destination. There are many studies where potential accessibility measure have been applied, for example Patton and Clark (1970) analysed economic potential to measure a region's attractiveness for the manufacturing industry by taking regional income and cost of distance. (Keeble, Owens, & Thompson, 1982) analysed the centrality of economic centres in Europe using potential measure.

3.2.3. Gravity measure

The gravity model is the most popular method to calculate accessibility; it was first developed by Hansen (1959) and has been adapted in many ways since. The gravity measure includes an attraction as well as separation factors. Contrary to the cumulative opportunity method where all destinations are considered equivalent, the gravity measure proposes a balance between the utility of a destination and its required travel cost from a given origin (H. Miller, 2005). The general form of the model has an attraction factor weighted by the travel time or distance raised to some exponent: The measure can be expressed as:

$$A_i \ = \sum_j \frac{O_j}{t_{ij}^{\propto}} \tag{4}$$

Where *Ai* is the accessibility at point *i* to potential activity at point *j*, *Oj* is the opportunities at point *j*, tij is the travel time between zone *i* and *j* and *a* is an exponent used to describe the effect of travel time between zones. The data requirements for this measure are the size and location of the attraction from origin and the travel time or distance between zones in the study.

Contour measure is criticized for treating opportunities equally, whether they are right at the origin of study or just inside the contour threshold. Including the time or distance in the denominator of the equation, gravity measure provides a weight to various opportunities and that devalues attraction far from the origin. Many researchers have applied the impedance function of the gravity equitation. The cost of moving between an origin and a destination impacts the attractiveness of an opportunity. The further an opportunity is from the origin, in terms of time or distance or generalized cost, the lower is its accessibility. The choice of the impedance factor in the accessibility measure can play a decisive role; the impedance factor determines the relationship between accessibility and travel costs in time or distance. Much of the literature defines impedance using a negative exponential function. Estimating travel impedance is complex, especially for transit and multimodal trips (H. Miller, 2005). The form of the function should be selected with caution, using the most recent data available (Karst T. Geurs & van Wee, 2004). Replacing the impedance function by a generalized measure of travel costs including time, distance, fares and waiting times should improve the realism of the measures (Bruinsma & Rietveld, 1998). However, any impedance function will give more weight to the center than the periphery, which may underestimate accessibility levels in peripheral areas (J Gutiérrez, Monzon, & Pi ero, 1998), or place emphasis on closer destinations over more attractive further ones (J Gutiérrez & Urbano, 1996).

Application of gravity measure accessibility measure

Gravity measure have been used to measure accessibility to medical facilities, grocery stores, railway station, shopping and jobs (CR Bhat, Carini, & Misra, 1999; Guy, 1983; S. Handy, 1993; Hansen, 1959; Lee & Goulias, 1997; Niemeier, 1997) . In addition to using accessibility measure to evaluate access to particular type of activities, researchers have utilised gravity measure to compare different transportation configurations. Gravity based measures are also an effective way to track accessibility over a period of time.

Handy (1993) has applied accessibility indices to two pairs of communities and found important distinctions between the minimum distance to shopping and the variety of possible shopping destinations. Another study done by Cervero et al. (1999) investigated through gravity based measure the extent to which citizens have access to jobs in their income bracket. Their work also considered the local area jobs/ housing mix and accessibility change over time.

At the national level, Linneker and Spence (1992) used a gravity measure to assess the effect of construction of highways around London . But there are several researchers who criticize the ability of gravity based accessibility measure to actually reflect accessibility. One criticism pointed out is that most measures assign the same level of accessibility to all individual in a particular zone (Ben-Akiva & Lerman, 1979). Another criticism is that the general form of the gravity model implies a trade-off between attraction and distance (Morris, et al., 1979)

3.3. Cost

Individuals always want to have more accessibility to opportunities at less cost. People always keep in mind the cost factors while taking the decisions to choose a transport mode. Cost has significant impacts on the structure of land use. Cost is an important factor when conducting an accessibility analysis for any urban area. The two main components of the cost incurred by individual users during travel are: time and money (fare). The measurement of travel time is very difficult because it is difficult to quantify from user's perception as users are very sensitive to different components of the total travel time. On the individual level, the evaluation of perceived travel time is based on the definitions given in the beginning of this chapter 2 like access, waiting, transfer, and in-vehicle travelling. The measurement of fare is rather direct, and clearly additive. Complications involved in the issue mainly lies in how the user perceives to the cost. The monetary cost can be directly out of pocket or if paid by travel cards, it may be less perceivable.

During the literature review and study from various case studies it was realized that different modes are characterized by the different transport costs. For this study, calculation of travel time cost for car is easy to calculate with current GIS's with the ability to perform network analysis. But in the case of multimodal transport system it becomes more difficult.

For this study (multimodal transport system) the method for calculating cost has been adapted from the work of Liu and Zhu (Liu & Zhu, 2004). But during the process of calculation of cost it was realized that Liu and Zhu's adapted method did not take care of all the costs incurred in the multimodal transport network and it does not show true picture of total cost . After this, various cost methods like Average cost method, Harmonic mean method and Logsum cost method were identified and studied from literature for application in this study. It was find out that only Logsum cost method is able to reveal the true cost of multimodal transport network. Logsum cost method is explained in next section.

3.3.1.1. Logsum cost

Historically, the impedance measure has been defined to be the peak period network travel times for the Home-Based Work trip purpose, and base period (or off peak) travel times. In quite a few trip distribution models, generalized costs have been used as the impedance measure where the shared-ride and/or transit modes have the potential to affect trip distribution patterns. Williams stated in his work (Williams, 1977)that the composite measure of accessibility can be directly obtained from the denominator of the mode choice model, and composite cost calculation is very sensitive to some factors like :

- Sensitive to all modes of travel.
- Sensitive to both travel times and costs.
- Sensitive to the income or auto ownership of the traveller.

The composite impedance (or Logsum) measures the spatial separation between zones giving adequate consideration to travel time, travel cost, and other measures, such as the number of transit transfers (depending upon the variables contained in the mode choice model). At the same time, the impedances give weight to the socio-economic characteristics (i.e., income, auto ownership) of the traveller, through inclusion of the income. The (utility) values resulting from trip distribution model must be combined in such a way that:

- The combined values fall within a reasonable range
- The combined value decreases as any mode improves (i.e., as the time or cost decreases)
- The combined value increases if any mode is unavailable.

Based on upon the work of (B. Allen, 1984; Williams, 1977), two formulations meet each of the above criteria. One formulation is a variation of the Harmonic Mean formula which is equation (5):

$$I = \frac{K}{\sum(1.0/((A_i + C))} \tag{5}$$

Where:
I = is the composite impedance
Ai = is the mode choice utility function for mode i
C = is a constant chosen to make all Ai's a positive value
K = is a constant chosen to scale the results like all I should be in Range between 5-50

The second formulation uses the exponential function of the utility expressions, sums their values, and takes the natural logarithm of the result. This Logsum formulation is expressed in equation (6):

$$\tilde{c}_{ij}^{n} = -\frac{1}{\lambda^n} \ln \sum_{\bar{k} \in H(n)} \exp[-\lambda^n(\delta^{\bar{k}} + \tilde{c}_{ij}^{n\bar{k}})] \tag{6}$$

$$\tilde{c}_{ij}^{n\bar{k}} = -\frac{1}{\Delta^n} \ln \sum_{k \in Y(\bar{k})} \exp[-\Delta^n c_{ij}^{k(\bar{k})}] \tag{7}$$

$$c_{ij}^{k} = \sum_{\eta} \alpha_\eta Z_{ijk}^{\eta} , \tag{8}$$

Here Z_{ijk} denotes a set of variable, such as time, distance and cost which varies over modes and destination. δ^k is the source of correlation between the sub modes in the composite set *k* and $\sum_{k \in Y(k)}$ denotes summation over all modes in that composite set.

In addition to meeting the criteria defined earlier, the Harmonic Mean Formula is simplistic in form and computation. However, the manner in which this measure combines the impedances of each mode lacks a theoretical basis. The Logsum method takes advantage of the decision rule implied by the mode choice model. Therefore, all else being equal, the probability of selecting a particular destination should be proportional to the sum of these values for all available modes.

3.4. Conclusion

The appropriate accessibility measure for any study depends on the intended application (Morris, et al., 1979). In addition the parameters of the selected model influence the results. Therefore it is important to clearly set the goals and objectives of the study before selecting the most appropriate measure for the defined goal (Talen & Anselin, 1998). Each accessibility measure has its own strengths and weaknesses. For this reason, several studies have used a combination of measures, either to highlight different aspects of a location's accessibility (S. L. Handy & Niemeier, 1997) or to reduce the weaknesses of each method through the strengths of the others (Primerano, Taylor, Pitaksringkarn, & Tisato, 2008) . Analysis of accessibility levels can be useful for transportation planners to identify needs, rank different areas, and formulate goals.

The goal of this study is to see accessibility through multimodal transport system and compare with unimodal system and look in to the scenario of mode, trip length, trip purpose and spatial area. This study adapts some of the criteria from Geurs and van Wee's (2004) work for selecting accessibility measure and these are theoretical basis, ease of communication and interpretation, the data requirements and their usability as social, economic or sustainability indicators

On the basis of above selected criteria, activity based and utility based measures are useful for this study. There are several types of activity-based measures used in urban and transport planning studies but only contour measures, potential measures and gravity based measures which have foundation in theoretical soundness, interpretation and availability of minimum data are selected for conducting accessibility as discussed in the previous section. Activity-based measures are comparatively easy than utility measure, to model in GIS , require less data and easy to understand, which makes them fit for use in this study. On the other hand, utility based measures are better in defining accessibility from the perception of multimodal transport, but lack sound interpretation tools and data. Therefore, this study is not looking into utility based measures.

During the overview of accessibility measure it was realized special attention is required to cost estimation methods and the selection of distance decay function. From the application of various distance decay function it was realized that only loglogistic function describes the data better for this study and it was also realized that the choice of function can make an important difference for predication of job accessibility for various measure. For calculating the generalized cost for the accessibility analysis Logsum methods was selected for cost calculation.

4. STUDY AREA AND ACCESSIBILITY FRAMEWORK

This chapter include the brief discussion of different element of the study area. It gives the overview of demography, economic and overall transport system. Second section discussed about the selection of accessibility measure for this study. Third section talks about how distance decay function derived for this study. The fourth section gives the overview how accessibility measurement model.

4.1. Demarcation of research area

To show the land use component of accessibility, the demarcation of the total research area is required. The choice of the research area for accessibility analysis depends upon the aim of the study. Many studies chose case study based upon the administrative boundary or within the boundary like country, region or town boundary. For this study accessibility analysis will be done on two levels and the reason behind this is that the case study at city level is only 118.29 km² still and developing, this might not reveal the true picture of ground reality of multimodality and appropriate results. For this reason there was need to look at the region level and compare the results. For this study two levels are selected:

- City Level: Almere city
- Regional Level: Almere, Amsterdam and Utrecht region

4.2. Introduction to the case study

Chapter two explained the demarcation or selection of case study for this study, which is at two levels: City level (Almere city) and Regional level (Almere and its surrounding cities like Amsterdam, Utrecht, Amersfoort and Hilversum etc) and is shown in figure 8. Almere is the city and municipality in Flevoland, the Netherlands. Almere is the fastest growing town not in Netherlands but also in Europe. The municipality of Almere comprises the districts Almere Stad, Almere Haven, Almere Buiten, Almere Hout, Almere Poort (under construction) and Almere Pampus (design phase). The total area of Almere is 248.77 km², out of which 130.47 km² is land and the rest is water (118.29 km²). The density of Almere is 1,369/km².

4.2.1. Demography

Almere is new town designed thirty years ago on land reclaimed from the sea. Almere is the youngest city. It is the largest municipality in Flevoland with 184,405 citizens (7 July 2008), and the 8th largest in the Netherlands. In October 2007, the city council of Almere made agreements with the government to expand the population of the city to 350,000 inhabitants by 2030. Table no. 6 shows the population trend and figure 9 shows the population distribution in Almere city and figure 10 shows the population distribution at regional level.

Table 6: Population trends in Almere, 2007

Year	Total population of Almere	Population growth rate (%age)
1990	71087	-
1995	104496	46.9
2000	142797	36.6
2005	175008	22.5
2007	180998	3.4

Source: http://en.wikipedia.org/wiki/Almere ("Demography," 2010).

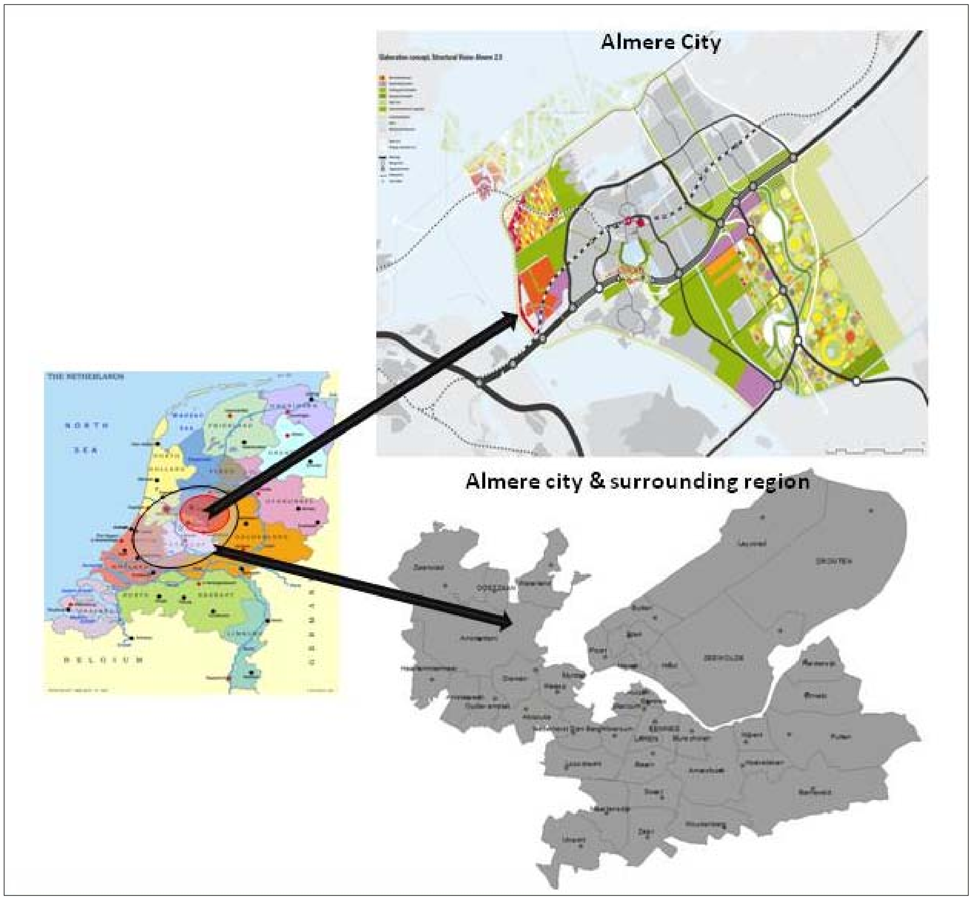


Figure 8: Study area: Almere city and its surrounding region

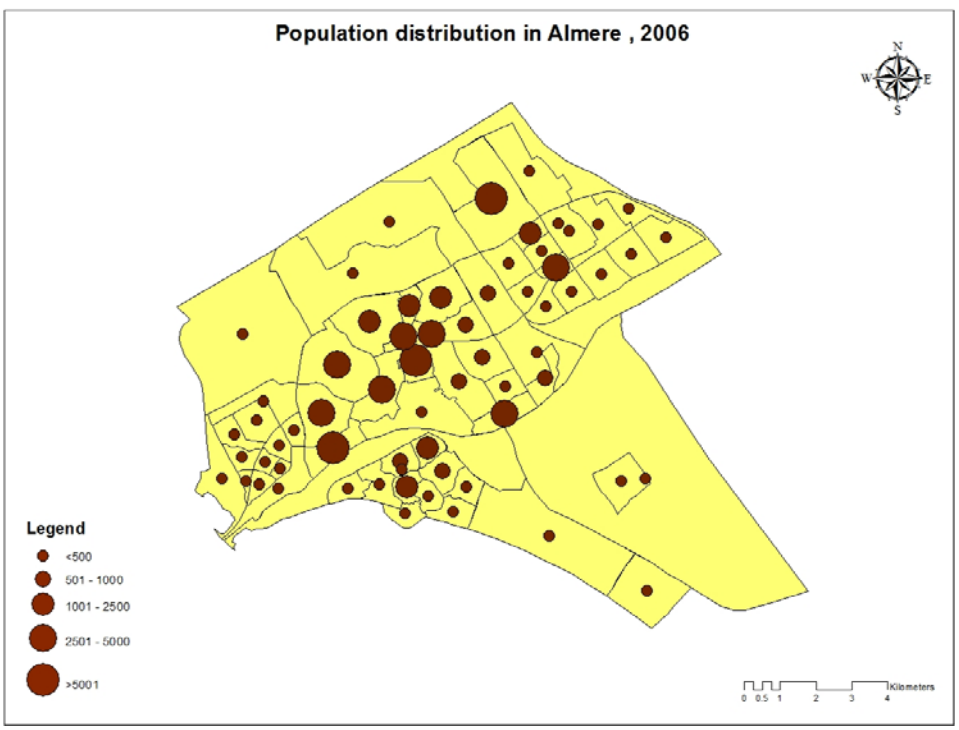


Figure 9: Population distribution in Almere, 2006

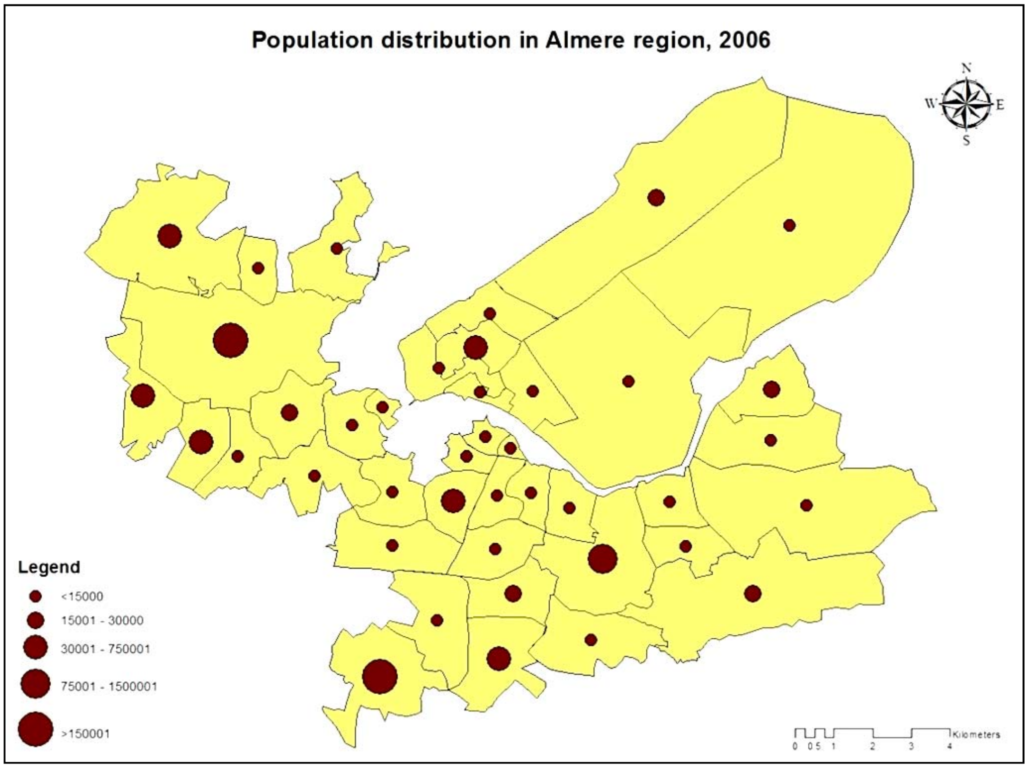


Figure 10: Population distribution in Almere region, 2006

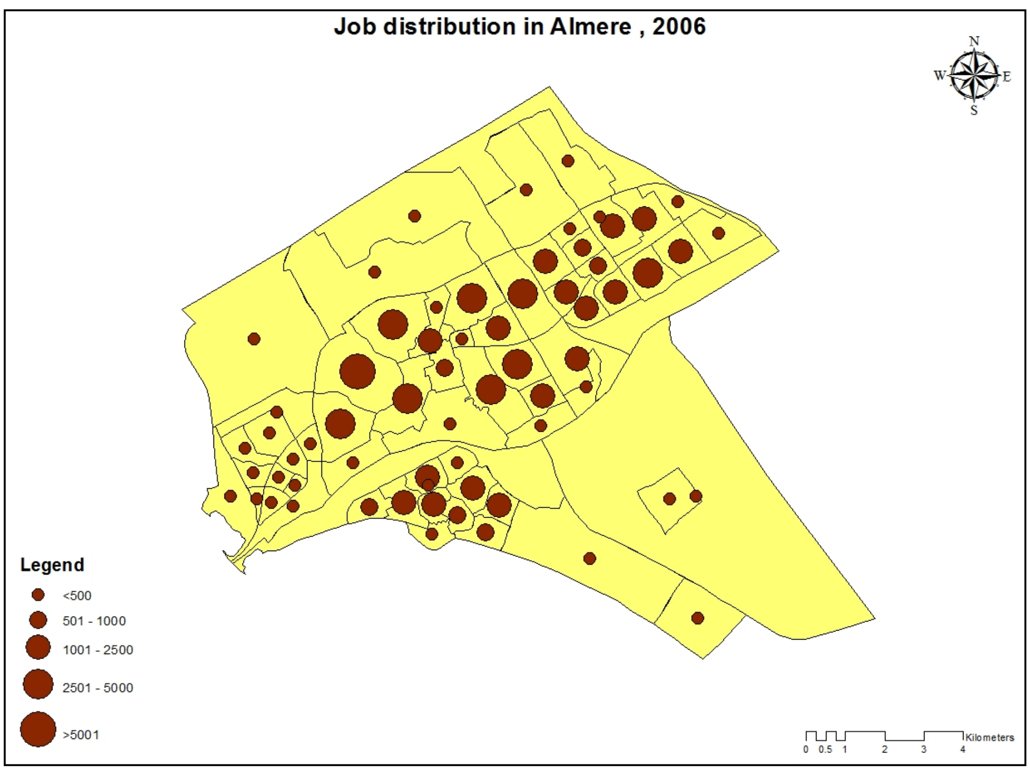


Figure 11: Job distribution in Almere, 2006

4.3. Transport

The traffic infrastructure in Almere is recognisable because of its separate infrastructure for cycles (which have separate cycle paths), cars and buses (In Almere the buses drive on a separate bus lane). Almere is connected to the motorways A6 and A27. The A6 motorway is just over 100 kilometres in length and it connects the A1 motorway at interchange Muiderberg, and with the A7 motorway at interchange Joure. The A27 motorway is approximately 109 kilometers towards Utrecht. The map of transport network is shown in appendix 6. Almere was connected to the national railway system in 1987 with the fully completed Flevolijn which connected Weesp to Lelystad Centrum. Almere currently has five railway stations. In Almere there are 10 bus lines which service the urban area. Most buses run about every 7 minutes. Besides the local bus lines there are regional bus lines to Hilversum, Zeewolde, Harderwijk, Schiphol, Amsterdam and Amstel etc.

4.3.1. Economic perspective of Almere city

Employment in Almere has developed actively in recent years. Its economy is driven by the powerful economies of Utrecht and Amsterdam. This can be seen from the huge daily commuter traffic from Almere, which consists of most of the working population travelling every morning from Almere to Amsterdam or Utrecht. A better relation between employment and the size of Almere's population would be indispensable for a mature, sustainable city. The creation of an additional 100,000 jobs requires government authorities at all levels to work together. Besides broad-based economic growth, Almere has qualitative growth potential of knowledge based jobs. This refers to providing incentives for cluster development, which is of national and international significance. The current job distribution in Almere can be seen in figure 11 and regional job distribution can been seen in figure 12.

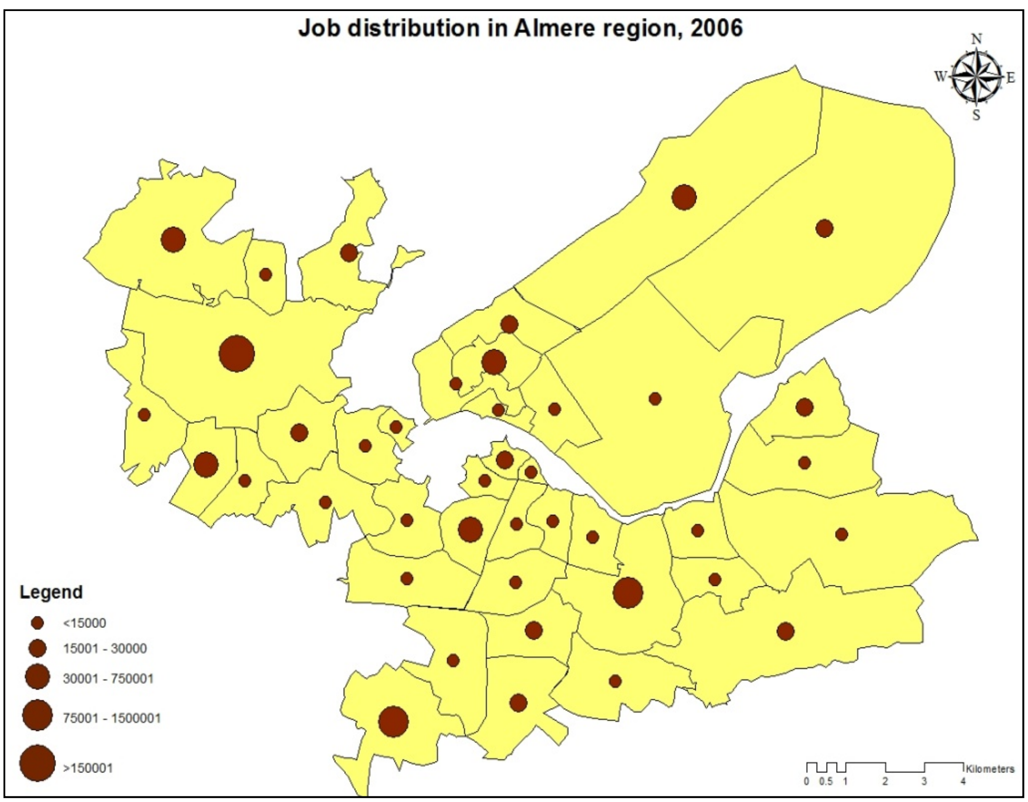


Figure 12: Job distribution in Almere region, 2006

4.4. Data used for study and data issues encountered

The following data were used in developing the accessibility indicators:

1. Social economic data: generated TAZ layer , including population and job numbers for year of 2006
2. Road network data: road network, including design speeds for the years 2010
3. Public transport data: bus network data, including bus route information and bus stops locations and rail network data with rail route and rail station
4. Other data: facility distribution in 2006 (schools, markets and medical facilities, etc.)
5. Primary Survey: In order to perform accessibility analysis, travel behaviour information was required, which was missing from collected source. To generate new TAZs, distance decay curve and to calculate cost, three day travel survey were conducted in Almere for various districts in Almere for different age group and different modes. 126 travel behaviour surveys were collected in Almere city on peak and off peak hour in 2011.

Socio-economic and transport data for Almere and surrounding region (2006) for this research were acquired from OmniTRANS International (company of Goudappel Coffeng BV) with the approval of the Municipality of Almere. The datasets were checked on anomalies and after discussion held with the officials of Municipality of Almere corrected. Spatial data was spatially referenced and connected to existing GIS data.

4.5. Conceptual framework : Accessibility measurement model

The purpose of the conceptual framework is to identify various components for conducting accessibility analysis for this study. The main focus of the study is to defines accessibility, perspective and identify different theory and performance measure to assess accessibility of a multimodal transport system. Identifying accessibility indicators for multimodal transport system needs a different conceptual approach because multimodal transport system has different characteristics and attributes than the uni-modal system .

The concept framework for this study look in to the various aspects of performance measure, there usability for multimodal transport system from different perspective and assumption. There are three components of the conceptual framework (figure 11)

1. Define perspective , dimension and performance measures
2. Development of transport network and costs
3. Evaluation of multimodal transport system

After looking in to the various factors and attributes of multimodal system, we develop car based and multimodal based transport networks and its costs

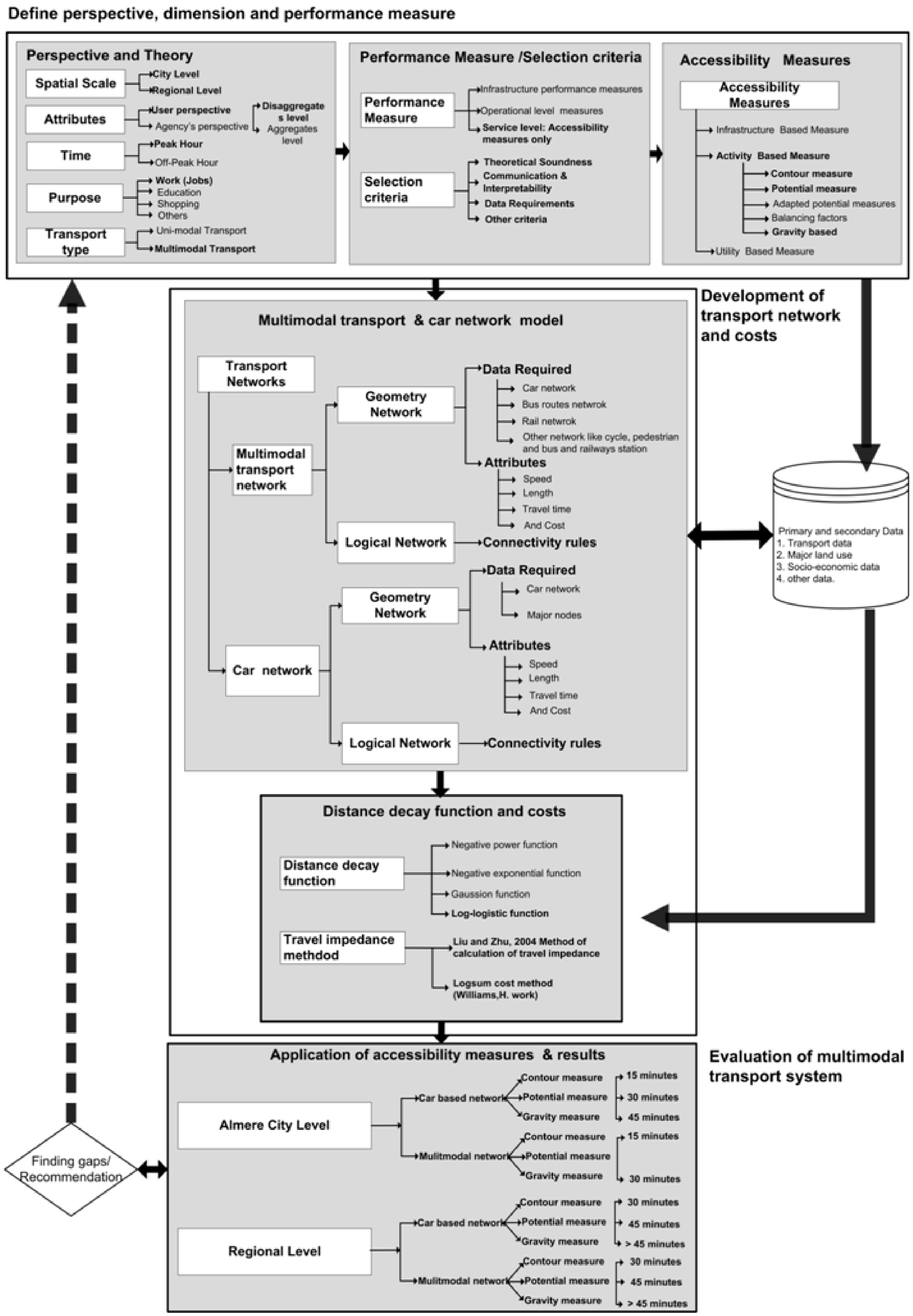


Figure 13: Conceptual framework: Accessibility measurement model

4.6. Development and application of Conceptual framework

4.6.1. Development of TAZ

TAZs serve as the primary unit of analysis in a travel demand forecasting model. They contain socio-economic data related to land use. TAZs are where trips begin and end. One should also consider the following additional factors when delineating TAZs:

- Highway network compatibility
- Boundary compatibility
- Socioeconomic data
- Access

The primary purpose of delineating TAZ boundaries in Almere and regional level was to keep the consistency with location geography and value addition to analysis of model outputs. Travel demand models often need to analyze/evaluate travel patterns relevant to certain predefined political geographies, such as cities or counties. TAZs in Almere were created on the bases of various districts in Almere. Every district has different land use property. 65 TAZs were created for Almere city, and at regional level it was 41 TAZs which include all the small and major cities near to Almere and this is shown in appendix 5 and 6.

4.6.2. Development of multimodal transport and Car network

Car and multimodal transport network was needed for calculating the cost to conduct accessibility measure. Based upon the objective of this research, a multimodal transport network and car network proposed to develop in GIS environment. The proposed model consists of two phases: the GIS phase and the routing choice for calculating cost between OD. The development of car and multimodal network is briefly discussed in next section:

4.6.2.1. Construction of the multimodal network

Geometric network

The Road Layer

Road network layer covers main road networks, cycle tracks, walking street etc. Other transport networks are usually built on the road network layer. The main attributes in the road network are: points, line strings and transportation features.

The Bus Routes layer

The bus layer in this study is separate layer. Almere city has a well developed BRTS network. The main components are bus stops, route segments and routes.

The Rail network Layer

The rail layer is a comparatively independent layer among all the transport modes. Although the rail layer passes through the city, the planning of the train route is independent of the existing road networks. Other than these considerations, the travel speed, schedule and distance make the train a very special transportation mode. The main components in the train layer are: train station, rail segment and rail.

The railway station and bus stops layer

This layer is an important layer in the multimodal transport system. This is the layer where switching between modes of transports. In this study, it is considered that this layer which records all the transfers between modes. Taking into account different people, transfer times and locations, the switching results can be very different. However, the main components in this layer can be confirmed as:

- Nodes location: the location of the switching. Generally these are bus stop, railway station, car park or other public facility.

- Nodes link: the route segment that connects two nodes locations.
- Switching mode: switching from car to bus, bus to train, and so on.

Logical network

Logical network shows the relationship between the various network layers mentioned above and logical network is one-to-one or one-to-other relation between various geometric networks. In the logical network, all the connectivity rules have been defined for the car and multimodal network. The logical network consists of rich network attribute model that helps model impedances, restrictions, and hierarchy for the network.

Network Object

A network object is the multimodal transport network. This is representation of the combination of various geometric networks like transport network, transit networks and various attributes them in GIS environment.

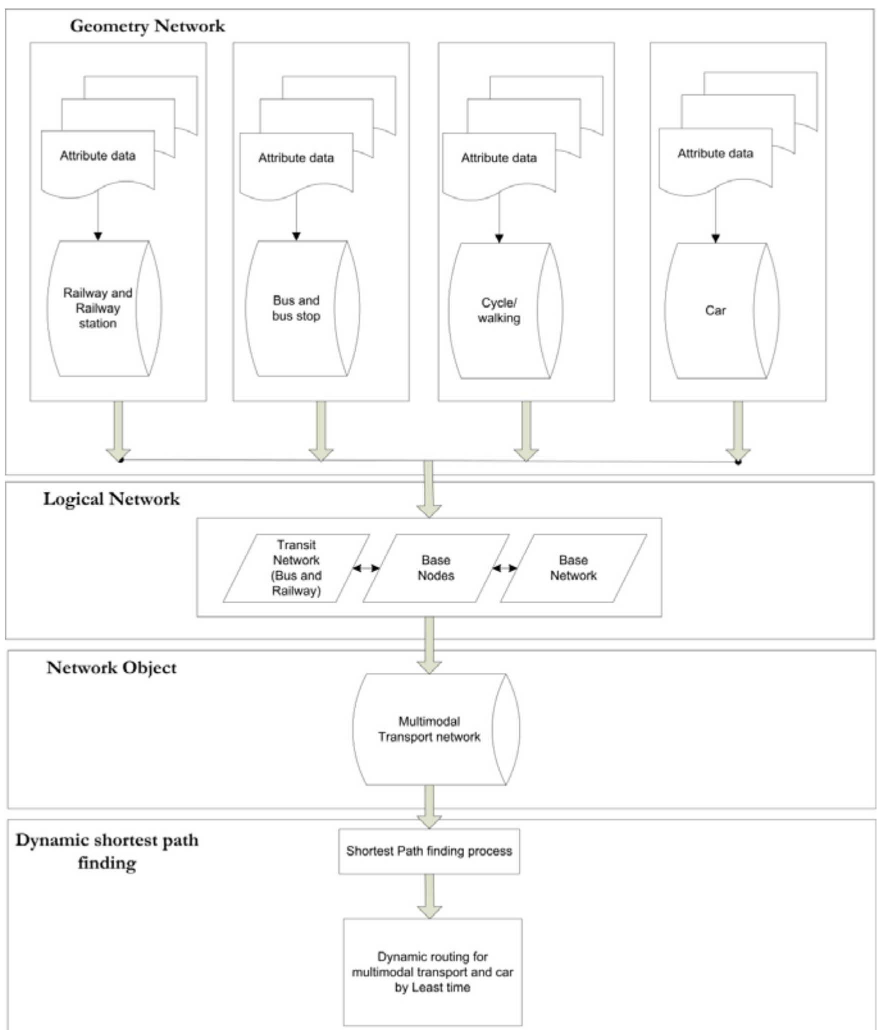


Figure 8: The proposed multimodal network building method

4.6.3. Measurement of travel impedance

The method applied here to measure the travel impedance was adapted from the work of Liu and Zhu (Liu & Zhu, 2004). He stated that the travel distance between an origin and a destination can be considered to consist of three parts for the base netwrok:

- Part 1: the distance (d1) from the origin to the nearest point on the road network for travel by car or walking or bicycling, or to the nearest transit stop on the transit network for travel by public transport. The nearest point or transit stop is called the boarding point (OB);
- Part 2: the network distance (d2) from OB to the point on the road network nearest to the destination for travel by car or walking or bicycling, or to the transit stop nearest to the destination for travel by public transport. The nearest point or transit stop is called the alighting point (DA); and
- Part 3: the distance (d3) from DA to the destination.

The procedure for measuring the travel impedance for car, train is shown in appendix 7 and 8. In the case of car, the cost factor is calculated from above method. But in the situation of multimodal transport system , it was difficult to calculate the overall cost because it also considered other factors which are explained in chapter 3 cost section. For this reason Logsum cost was calculated for multimodal transport system. The procedure for measuring the travel impedance for multimodal transport is explained in next section.

4.6.3.1. Logsum cost

The distribution model was run for this study which is a standard gravity model. It shows the number of trips for a given TAZs is directly proportional to the number of trips produced at origin and number of trips attracted to a destination TAZ and inversely proportional to the travel impedance. For this study, model was developed for job trips purposes and for same socio-economic level. Observed person trips come from the primary travel behaviour data collected for Almere city, 2011. Where *a* and *β* were calculated from the observed data from primary survey with the help of MS Excel/SPSS. The coefficient α and *β* were found adequate because of their relationship between opportunities and impedance adequately. The calibration of model consists of best fitting curve for observed data. This reports the estimated trips stratified by each unit of impedance. Regression analysis was used to obtain a least square fit for the coefficients *a*, *β*. and after calibrating the, *β* was used to calculate Logsum cost for multimodal network.

$$\tilde{c}_{ij}^{n} = -\frac{1}{\lambda^{n}} \ln \sum_{\bar{k} \in H(n)} \exp\left[-\lambda^{n}\left(\delta^{\bar{k}} + \tilde{c}_{ij}^{n\bar{k}}\right)\right] \tag{6}$$

$$\tilde{c}_{ij}^{n\bar{k}} = -\frac{1}{\Delta^{n}} \ln \sum_{k \in Y(\bar{k})} \exp\left[-\Delta^{n} c_{ij}^{k(\bar{k})}\right] \tag{7}$$

$$c_{ij}^{k} = \sum_{\eta} \alpha_{\eta} Z_{ijk}^{\eta} \; , \tag{8}$$

Here Z_{ijk} denotes a set of variable, such as time, distance and cost which varies over modes and destination. δ^{k} is the source of correlation between the sub modes in the composite set *k* and $\sum_{k \in Y(k)}$ denotes summation over all modes in that composite set. For this study logsum cost is calculated at two levels: city level and region level, from the application of above mentioned equation (6) Logsum cost for Almere is 7.27 and for Almere region it is 9.07. These Logsum cost applied for potential and gravity accessibility measure at city and regional level.

4.7. Estimation of distance decay function

Distance decay functions are central to determining accessibility measures, particularly those based on potential and gravity model formulations. Since these models specify access as a declining function of separation, the distance decay or impedance parameter will impact accessibility by either increasing or decreasing the degree of separation between two locations. As far as planning methods are concerned, a good place to start would be with a thorough understanding of individuals' current travel behaviour by all modes, drawn from observations of actual behaviour. This information can form the foundation of more elaborate accessibility measures. An impedance function can be derived on the base of the observations. The choice of the impedance function can strongly influence the result of an accessibility measure. For this purpose, there is a need to analyse the relationship between the various impedance functions and travel behaviour. For this study, primary travel survey was conducted in Almere city in 2011.The data collected through primary survey related to total trip distance covered by different user, trip purpose, travel modes used during trip, number of transfers etc. With the aid of primary data, maximum likelihood estimation technique was applied to different modes with job as trip purpose. In this study, the correlation between distance decay functions and actual travel behaviour was analysed with the primary travel survey data and it provides the estimation results for the set of decay function to each modes. From the result of decay function the best curve fit was identified from the preliminary analysis, , it was realized that log-logistic decay function was found to have the best fit with the observed travel data:

$$F(d_{ij}) = \left[1 + \exp\left(a + \beta \ln d_{ij}\right)\right]^{-1} \qquad (9)$$

Where d_{ij} is travel time between *i* and *j*, and α and β are parameters to be estimated. It is to be noted that the impedance function is developed from limited amount of travel data. It is expected to change if travel data is more and travel impedance is probably not constant. The derived impedance function would be used to generate the potential measure and gravity measures of accessibility.

Table 7: Parameters for log-logistic distance decay function

Mode	β	α
Bus	-0.090	0.67
Rail	-0.060	0.21
Car	-0.091	0.52

4.8. Conclusion

This chapter described the various components of accessibility measure model i.e. development of car and multimodal network, selection of impedance function and development of logsum cost for this study to measure accessibility through multimodal network and estimation and calibration of its parameters.One of concerns related to multimodal transport network is defining accurate methods to built multimodal transport network from bus routes, rails in combination with cycle and road networks. Developed multimodal transport network is not able to incorporate important information like detailed turn attributes, assumed average speed for various road network and services bus/train schedules and this might result in inaccurate aggregate trip time reports. During the application of accessibility measure it was realized special attention is required to cost estimation methods and the selection of distance decay function. From the application of various distances decay function it was realized that only loglogistic function describes the data better for this study and it was also realized that the choice of function can make an important difference for predication of job accessibility for various measure. For calculating the generalized cost for the accessibility analysis Logsum methods was selected for cost calculation. For this study the costs were calculated through logsum which is 9.07 for Almere region and 7.27 for Almere. The time interval selected from accessibility analysis was 15, 30 and 45 minutes for Almere and 30, 45 and 60 minutes for regional level which is analyzed in next chapter.

5. APPLICATION OF ACCESSIBILITY MEASURE

In this chapter various activity-based measures have been applied at two levels: city level and at regional level using car and multimodal transport network and enabling a comparison between their results. The first section of this chapter briefly describe the results at city level for contour, potential and gravity measure and second section gives the overview of above mentioned measure at regional level. Last section describe about the analysis on descriptive characteristics of multimodal trips on the basis of primary survey.

5.1. Result at City Level

Accessibility to jobs and other opportunities (Markets, school and hospital) was calculated for the selected case study area for 15, 30 and 45 minutes travel time by both car and multimodal transport network at city level. Emphasis during the analysis was given to job accessibility.

5.1.1. Job accessibility by car at city level

This section describes the city level job accessibility by car for selected accessibility measure.

Contour measure

Figure 15 shows the spatial distribution of job accessibility by car for 2006 in Almere city, using contour measure with 45 minutes as maximum travel time for car. The figure15 shows that the city is densely-populated in the centre where job accessibility is highest, where in the case of peripheral area in the city i.e. northwestern, southern part of the city, job accessibility is low accessibility by car in 15 and 30 minutes time interval. Within 45 minutes as maximum travel time all the jobs in city are accessible by car.

Potential accessibility measure

Figure 17 shows the spatial distribution of the potential accessibility measure and it has higher job accessibility in the central area and less in southern districts of the city and on periphery. Compared to the contour measure, job accessibility from the potential accessibility measure is less because of distance decay and it also reflect that the jobs that are accessible within smaller distance are relatively more important.

Gravity measure

Figure 19 shows the spatial distribution of the gravity measure and it also has higher accessibility level in the central area and lower in southern part of the city and on periphery. Compared to the contour measure and potential measures job accessibility from the gravity accessibility measure is less because of distance decay as well as competition factors in the job from various districts in the city and job available to them. In gravity measure, competition was an important factor where number of jobs available and those required by various districts were considered while performing the gravity measure.

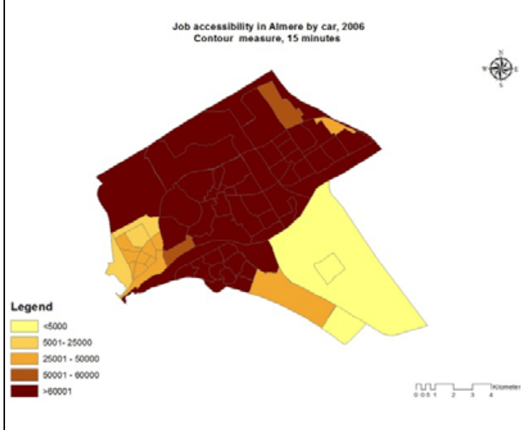
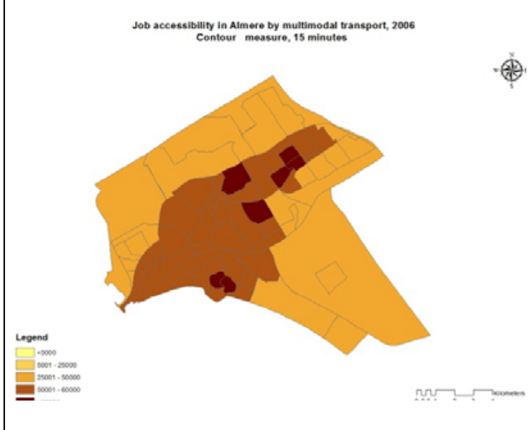
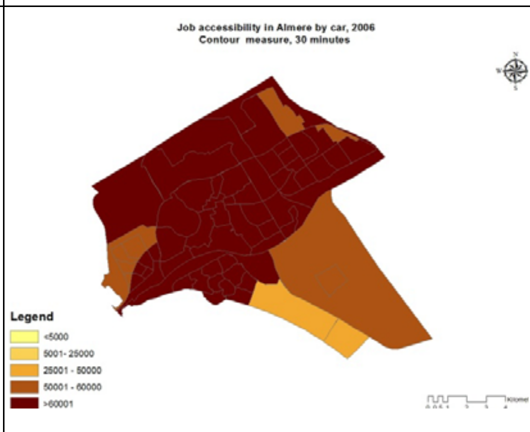
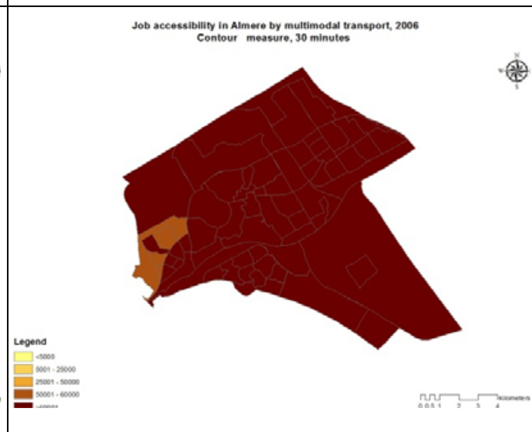
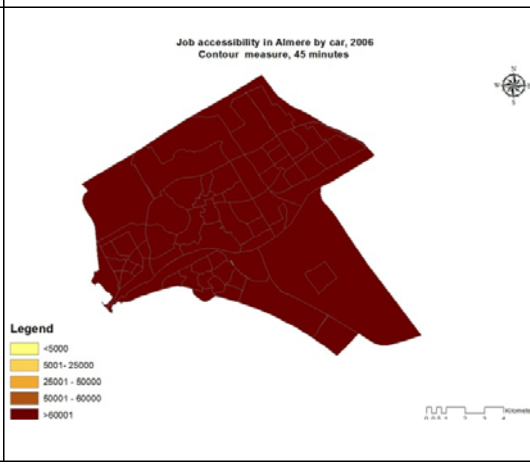
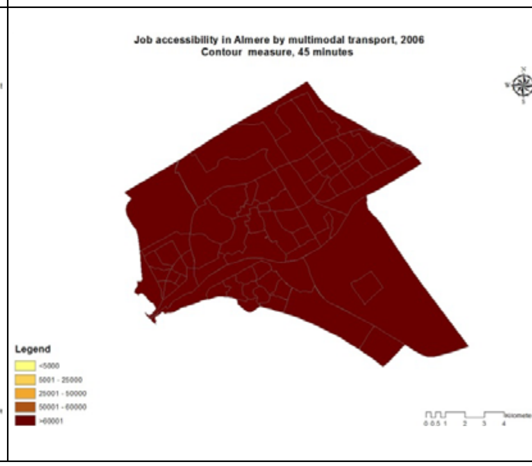
Travel time (min)	**Contour measure by Car** (no. of job)	**Contour measure by multimodal transport system** (no. of job)
15		
30		
45		

Figure 9: contour job accessibility by car and multimodal transport for travel time 15, 30 and 45 for Almere city

Figure 16 illustrates the relationship between job accessibility through car for various accessibility measures. It shows that the contour and potential measures have high job accessibility than gravity measure and also that the there are more jobs available when trip length increases more then10 kilometres.

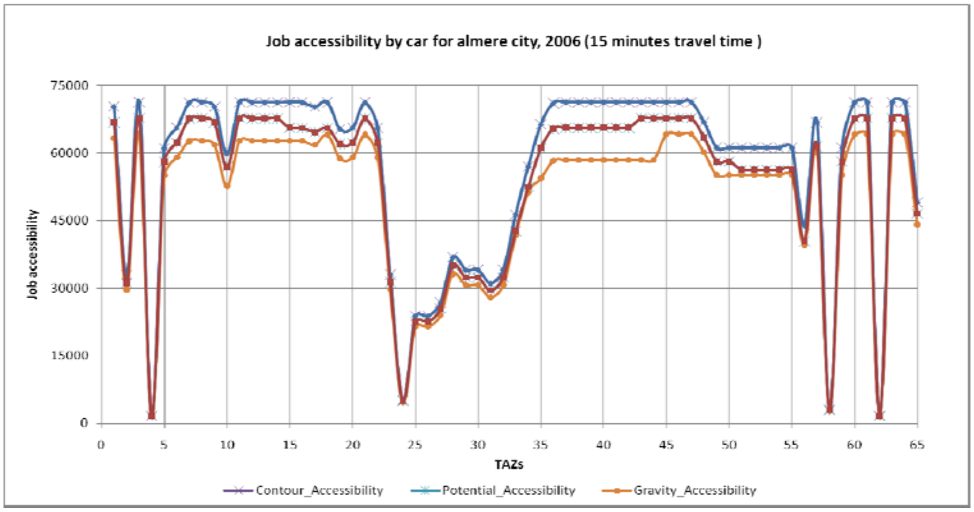


Figure 10: Job accessibility by car for Almere city for 2006, according to various measures for 15 minutes

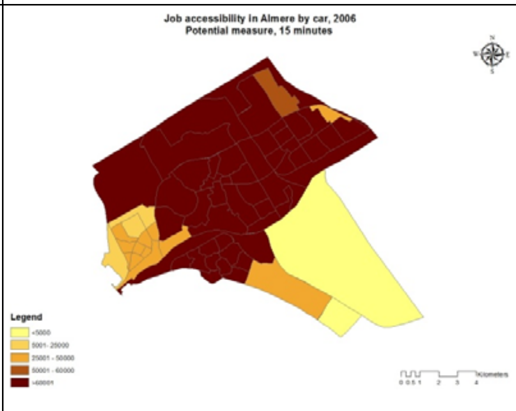
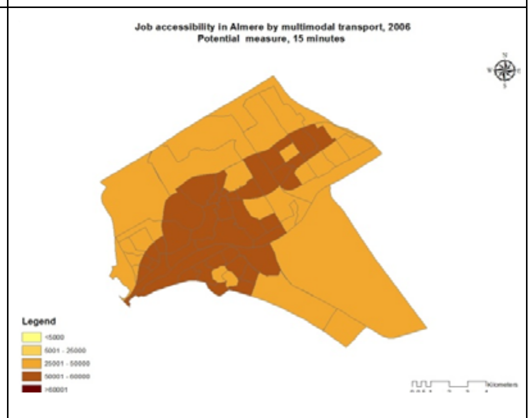
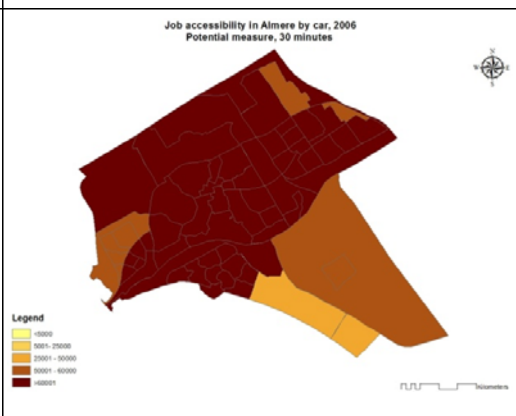
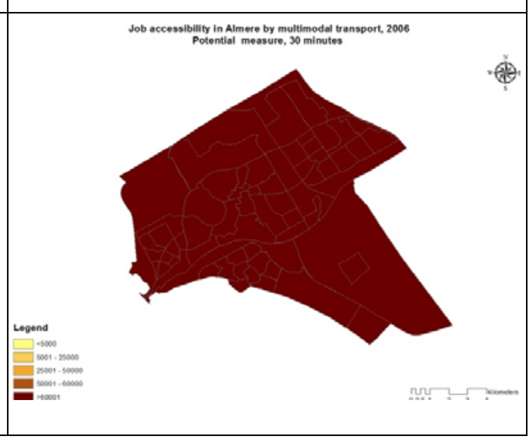
Travel time (min)	**Potential measure by Car** (no. of job)	**Potential measure by multimodal transport system** (no. of job)
15		
30		

Figure 11: Potential job accessibility by car and multimodal transport for travel time 15, 30 and 45 for Almere city

5.1.2. Job accessibility by multimodal transport at city level

Contour measure

Accessibility to jobs using the multimodal transport has a different spatial distribution than that using the car network. Figures 15 shows contour measure accessibility to jobs using transit in combination of other modes in Almere. Multimodal transport network has included the access times and waiting times in the transit travel times. Contour accessibility measure show better job accessibility multimodal transport netwrok in Almere city, reason behind this is Almere city has well designed multimodal transport system and because of this, car has disadvantages when compared to the public transport job accessibility. If compare the transport network map of Almere city car has to travel long distance to reach centre and has no direct access to the city center. Once the distance between the origin and destination increases accessibility level through multimodal transport system begin to increase and they are clearly linked to the different transport system like road network (cycle, car and BRTS) and commuter rail lines. Figure 15 shows that most of TAZs in Almere city are accessible to different jobs within the travel time of 15 minutes and within 30 minutes travel time, jobs are accessible through multimodal transport system.

Potential accessibility measure

Figures 17 shows the potential accessibility measure and it shows smoother distribution of job through multimodal transport system. If it is compare to potential measure by car, it shows relatively better job accessibility than car. One other reason for this was the cost factor developed for the multimodal transport system that was logsum cost or overall generalized cost of travel and impedance function chosen for the analysis which was log-logistic impedance function, which is discussed and calculated for this study in chapter 3and 4. In 30 minutes of maximum time interval, the entire jobs are available to all the TAZs from any location in the city.

Gravity measure

Figures 18 shows the spatial distribution of jobs through gravity measure and it also has higher accessibility level in the central area and lower in southern part of the city and on periphery. Compared to the contour measure and potential measure, job accessibility from the gravity accessibility measure is less because of competition factors in the job from various districts in the city and job available to them. The cost factors selected for carrying out the analysis was logsum cost and loglogistic impedance functions. Compared to potential measure job accessibility is relatively less for some of the districts than potential measure within 15 minutes time interval but most of the jobs are accessible within 30 minutes of maximum time interval.

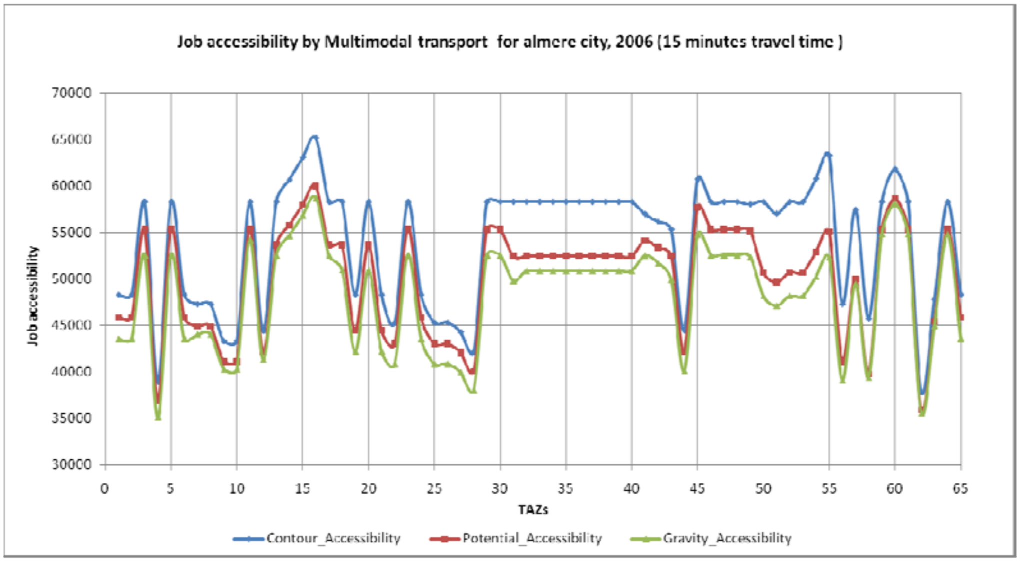


Figure 12: Job accessibility by multimodal for Almere city for 2006, according to various measures for 15 minutes

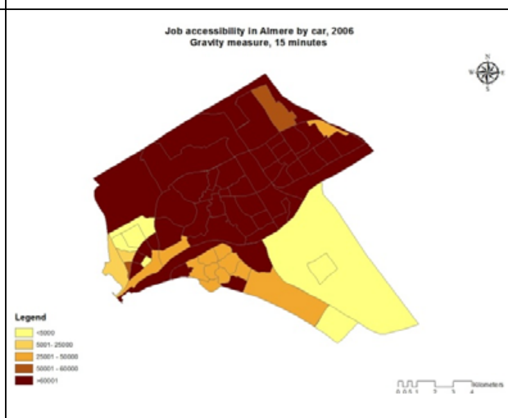
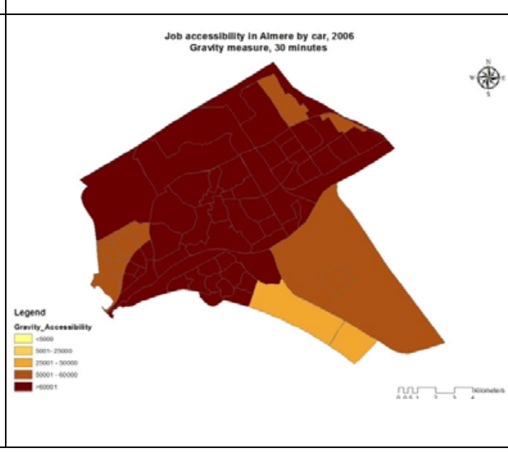
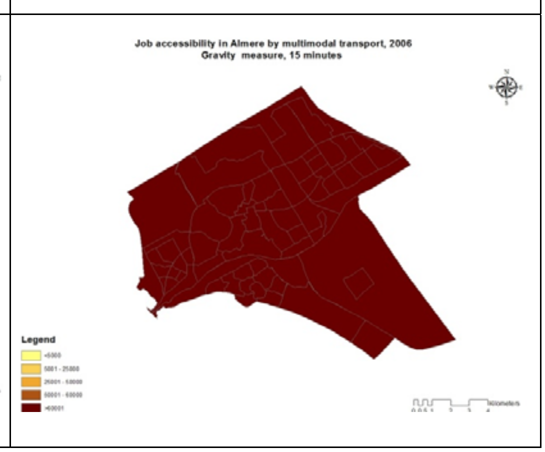
Travel time (min)	**Gravity measure by Car** (no. of job)	**Gravity measure by multimodal transport system** (no. of job)
15		
30		

Figure 13: Gravity job accessibility by car and multimodal transport for travel time 15, 30 and 45 for Almere city

Figure 18 shows some interesting facts related to job accessibility by car and multimodal transport network. It shows that here is not a sharp change in all the accessibility measure for multimodal transport system but one of the key facts was found that the numbers of jobs accessible through multimodal transport system within 15 minutes of travel time are less than car. One of the reason for this might be the influence of various components like travel time access to station, waiting time, egress time and also the frequency of various modes service etc. and it was also found that most of TAZs in Almere city show equal amount of job accessibility by multimodal transport system but in the case of car some TAZs have high job accessibility while some have very less job accessibility within15 minutes of travel time.

5.2. Result at Regional Level

This section describes the regional distribution of job accessibility by car and multimodal transport system. In multimodal transport system, BRTS and rail lines played important role because of high speed and less waiting time at railway station for long distance jobs. In the case of car however, there are limitations of speed in city area, waiting time at intersection, parking space in the city area and congestion on roads and junctions.

5.2.1. Job accessibility by car at regional level

This section describes the regional level job accessibility by car for selected accessibility measure.

Contour measure

Figure 20 shows the spatial distribution of job accessibility by car for 2006 in regional level, using contour measure with 60 minutes as maximum travel time. Figure 18 shows regional distribution of jobs like 1) there is densely populated region in and around Amsterdam and its surrounding region where job accessibility by car is the highest 2) the other region is city of Utrecht and Amersfoort and its nearby cities, where jobs accessibility is relatively less than Amsterdam 3) and the last region is Almere and its surrounding town like Laystand etc. Compared to other region this regions is has lowest accessibility. The contour measure with 60 minutes travel time shows smoother picture. Job differences between all the regions largely disappear at 60 minutes of travel time as all the jobs are accessible by car through the entire region.

Potential accessibility measure

Figure 24 shows the spatial distribution of the potential accessibility measure. It shows higher accessibility level in the Amsterdam and its surrounding region and less in other regions. Compared to the contour measure, job accessibility through potential accessibility measure is less because of distance decay function and it also reflect that the job accessible at less distance have relatively more utility than longer distance. The results of potential measure have been shown at 30, 45 and 60 minutes of travel time , in 30 minutes of travel time job accessibility in Amsterdam region is high , but once travel time interval shift from 30 to 45 minutes job accessibility to other regions also increase like areas along A1,A2,A4,A6,A7,A9,A10,A12 and A28 Highway and in 60 minutes, comparatively all the jobs are accessible in entire region.

Gravity measure

Figure 25 shows spatial distribution of jobs through gravity accessibility measure and it also shows the same results i.e. higher accessibility level in the Amsterdam and its surrounding region and lowers in other region. Compared to the contour measure and potential accessibility measures job accessibility is relatively less because of distance decay and the competition for jobs among various region. The results of gravity measure have been shown at 30, 45 and 60 minutes of travel time. In 30 minutes of travel time most of job accessibility in Amsterdam region is high, but once travel time shifts from 30 to 45 minutes job accessibility to other regions also increases and in 60 minutes approx. all the jobs are accessible in entire region.

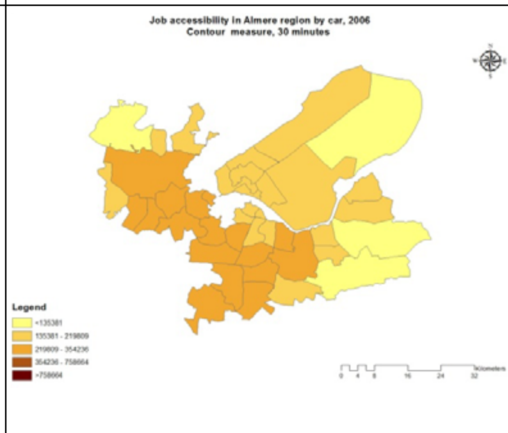
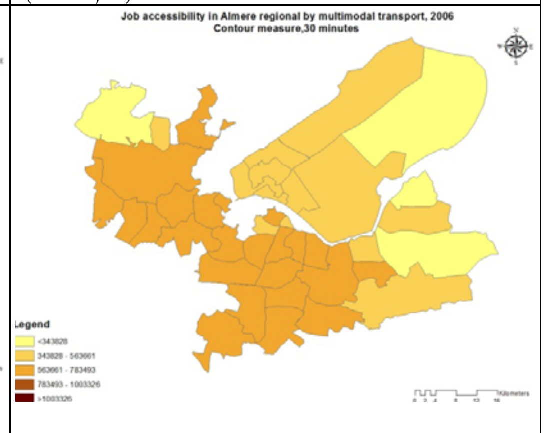
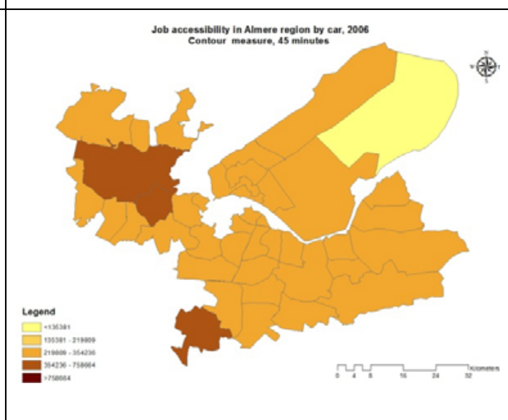
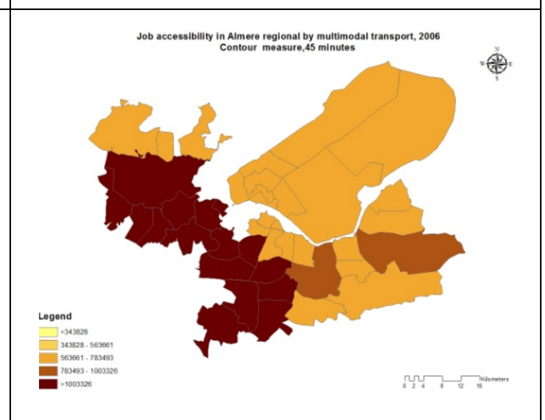
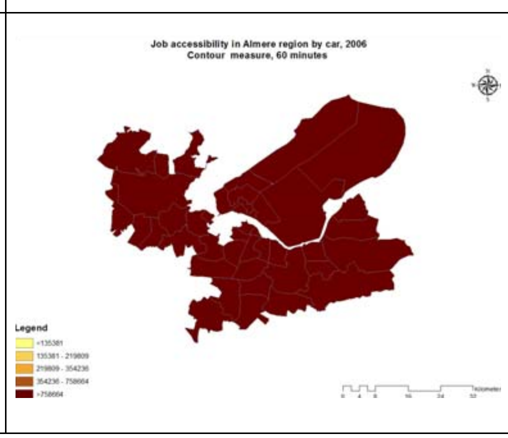
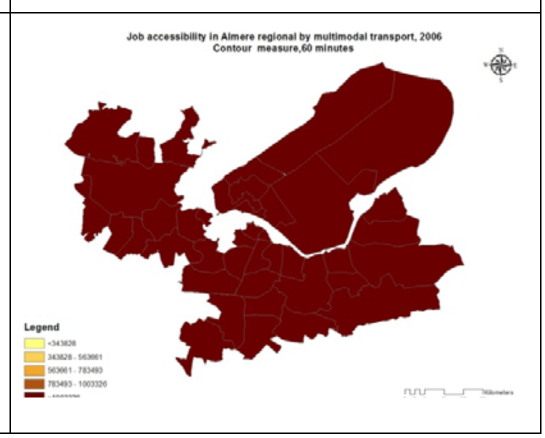
Travel time (min)	**Contour measure by Car** (no. of job)	**Contour measure by multimodal transport system** (no. of job)
30		
45		
60		

Figure 20: Contour job accessibility by car and multimodal transport for travel time 15, 30 and 45 for Almere region

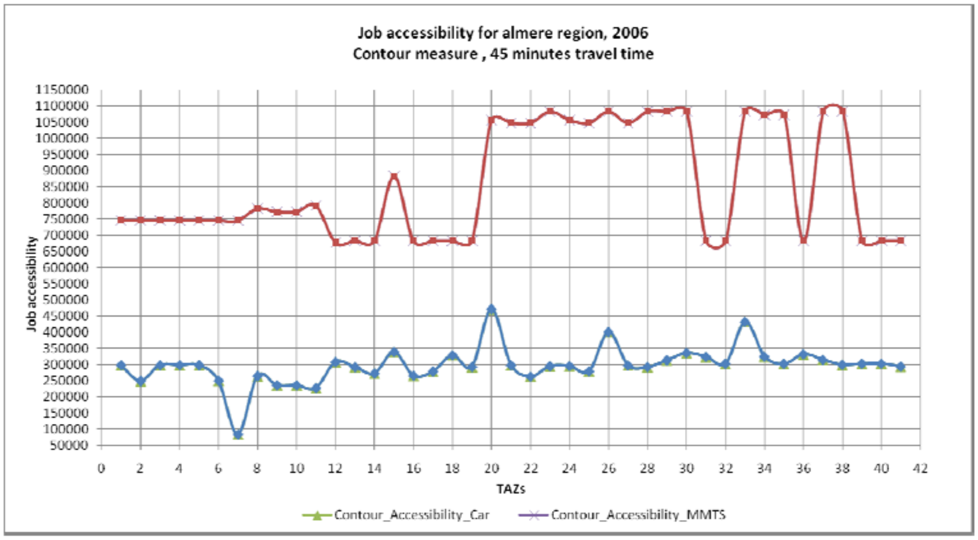


Figure 21: Job accessibility for Almere region for 2006, Contour measure for 45 minutes

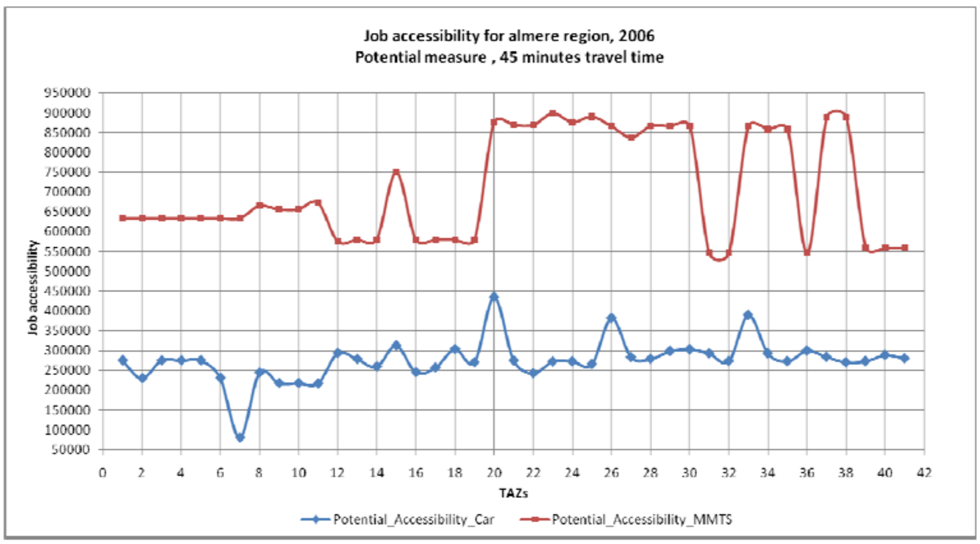


Figure 22: Job accessibility for Almere region for 2006, Potential measure for 45 minutes

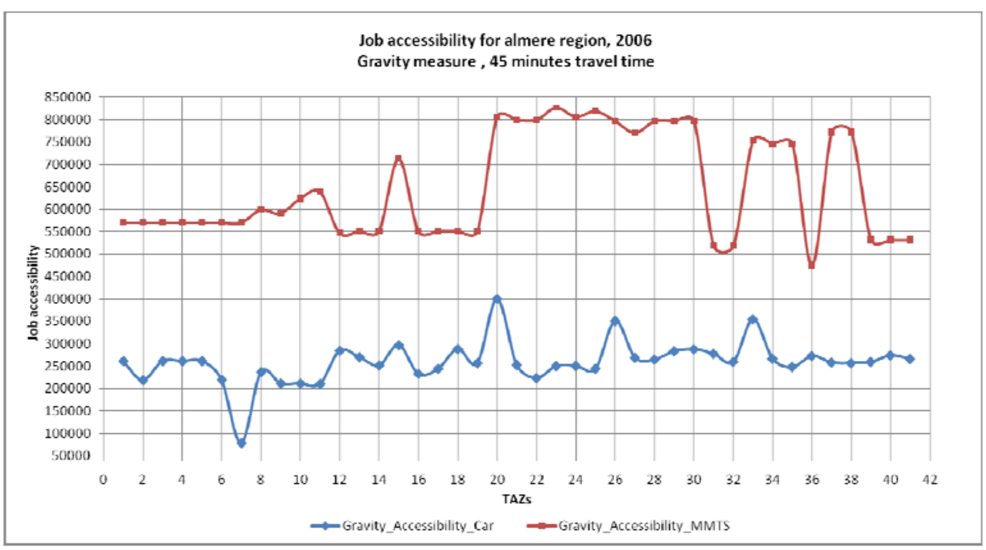


Figure 23: Job accessibility by car for Almere region for 2006, Gravity measures for 45 minutes

From figure 21, 22 and 23, it can be seen that the contour, potential and gravity job accessibility through multimodal transport system at regional level is very high at 45 minutes of travel time compare to car. Some of the reasons are that most of the jobs are in big cities and developed along the railway station or transit stations, and have a trip length more than 15 kilometers. In peak hour, multimodal transport shows very high time accessibility than car. The utility attached to multimodal transport system is very high for longer distance and in peak hour having trip purposes like work, education and shopping etc. over car. These figure also shows the job accessibility through various accessibility measures being same but in some of the regions it is high for potential and gravity measure and less for some of the regions one of the reason is high jobs in some region and less competition as well as utility of car to those area are high.

5.2.2. Job accessibility by Multimodal Transport at regional level

Contour measure

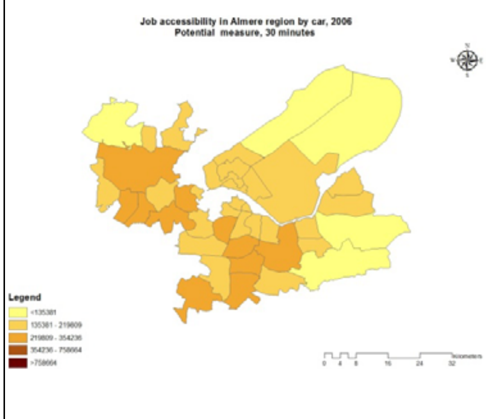
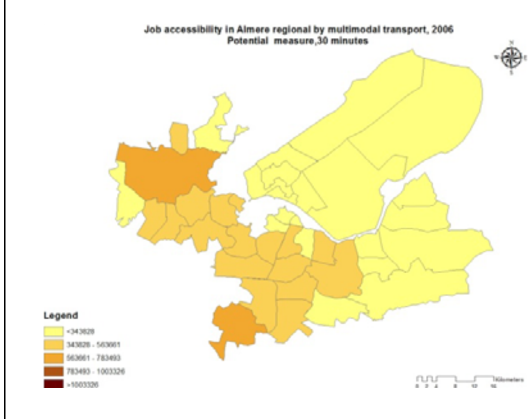
Figure 20 shows contour measure with 30, 45 and 60 minutes as maximum travel time. The spatial distribution of job accessibility through multimodal transport network is relatively high in time interval of 30-45 travel time compared to job accessibility by car. Jobs in Amsterdam, Utrecht, Amersfoort and Almere can be reached within 45 or 60 minutes travel time. One of the important fact found was that most of the big cities, in term of population and jobs, are well connected with public transport system and have very high job accessibility since most of job centres are around the transport hubs like railway station, tram station or metro stations etc. However it is not possible to easily access these jobs by car because of long distance driving, traffic jams, high parking price or lack of parking space and other disutility attached to a car. In the case of small cities job accessibility is high by car because of smaller public transport network and good road network.

Potential accessibility measure

Figure 24 shows the potential accessibility measure. It shows smoother distribution of jobs through multimodal transport system especially in the region of Amsterdam and its surrounding area. This was the result of the large number of jobs in this region. Other factors which influence the potential job accessibility are the cost factor and distance decay function selected for the accessibility. It shows that the accessibility is higher in Amsterdam region and lower in surrounding area. Utrecht region also has relatively high job accessibility through multimodal transport system after Amsterdam.

Gravity measure

Figure 25 describes the gravity measure. It shows spatial distribution of job by multimodal transport system. If compare the results of gravity measure with other measures , Amsterdam region show relatively lower job accessibility compared to potential measure because the gravity measure deals with distance decay, cost factor and high job competition.

<table>
<tr><th>Travel time (min)</th><th>Potential measure by Car
(no. of job)</th><th>Potential measure by multimodal transport system
(no. of job)</th></tr>
<tr><td>30</td><td>
</td><td>
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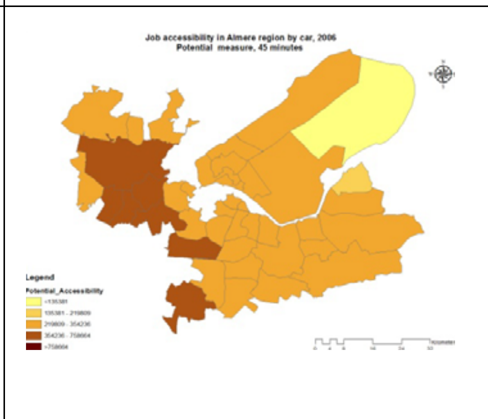
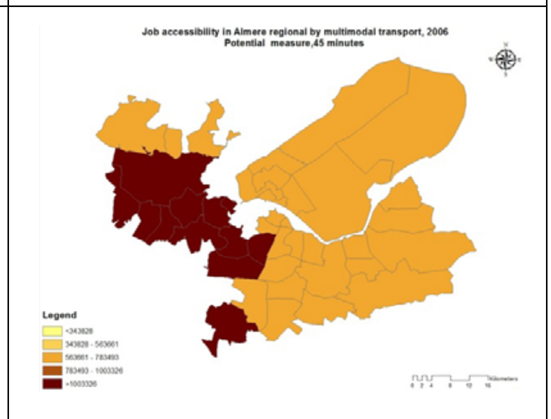
<tr><td>45</td><td>
</td><td>
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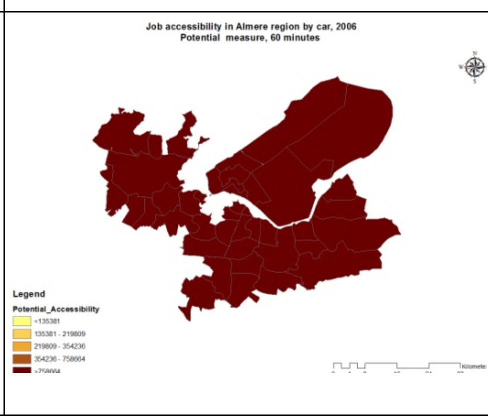
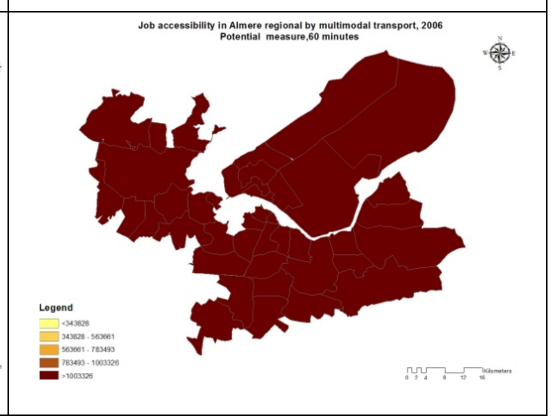
<tr><td>60</td><td>
</td><td>
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Figure 14: Potential job accessibility by car and multimodal transport for travel time 15, 30 and 45 minutes for Almere region

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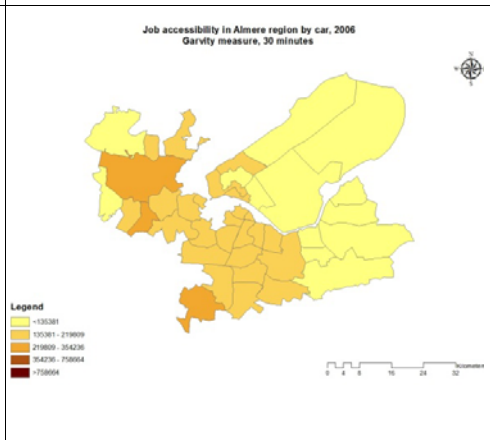
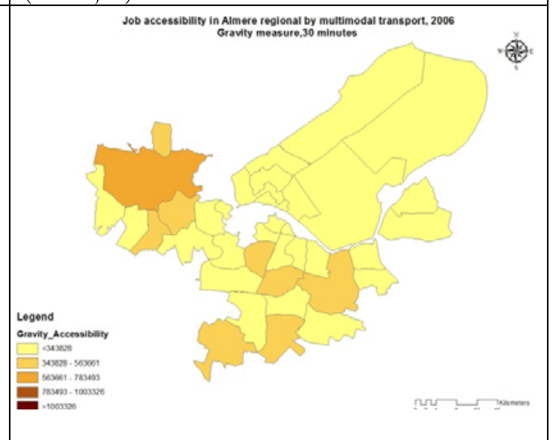
(no. of job)</th><th>Gravity measure by multimodal transport system
(no. of job)</th></tr>
<tr><td>30</td><td>
</td><td>
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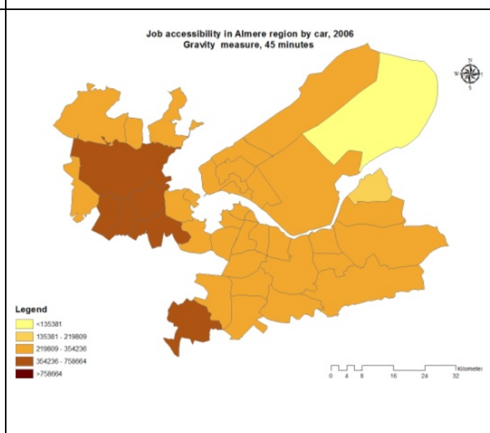
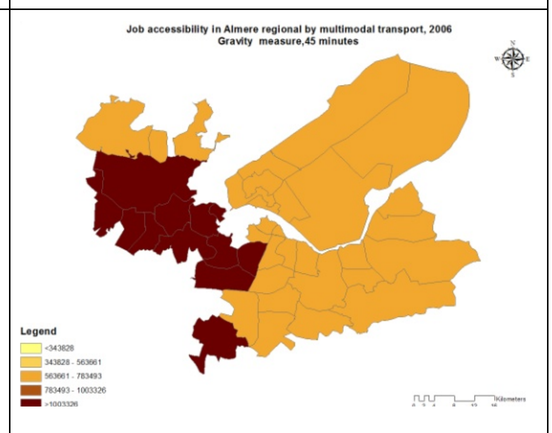
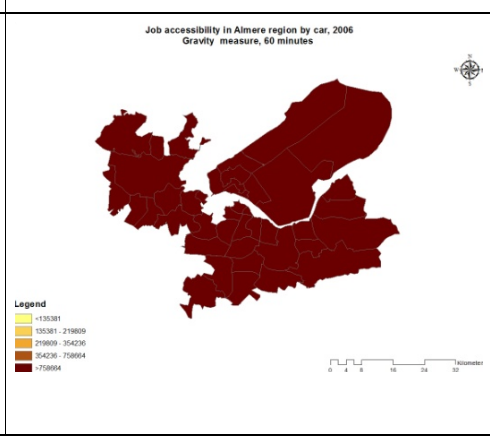
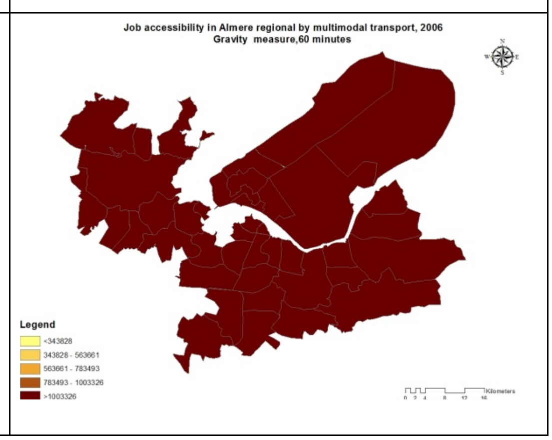
<tr><td>45</td><td>
</td><td>
</td></tr>
<tr><td>60</td><td>
</td><td>
</td></tr>
</table>

Figure 15: Gravity job accessibility by car and multimodal transport for travel time 15, 30 and 45 for Almere region

5.3. Other anlysis on descriptive characteristics of multimodal trips

Figure 26 shows the main mode used for all trips made under multimodal trips from the primary survey conducted in Almere city for this study in 2011. The first observation that can be made is that the share of multimodal trips is much higher in Almere city when compared with the descriptive characteristics described by (Nes, 2002) for multimodal trips : which is 40% for Almere city against 2.9-10 % to other cities in The Netherlands. Introduction of Students Public Transport Card and other travel pass has also led to a substantial increase in public transport usage for the students/ young part of the population.

From the analysis it was found that walking and cycling is main made for trip made under 3-5 km trip length and for longer trip lengths, bus and rail is main mode. Walking and cycling is plays an important role for accessing the main mode in Almere city. However, bus and rail is main mode of travel which accounts for 21.6% and 52.8 % for longer distance trips. This description of multimodal trips gives some insight into the main characteristics, but does not provide an explanation. As discussed in chapter 2 Nes talked three factors, these factors are proved to be dominant in discriminating between unimodal and multimodal: trips trip distance, trip purpose and type of destination area.
In this study an analysis was done for above mentioned first two factors from the primary survey done for Almere city, 2011. These three main factors have been discussed below in more detail.

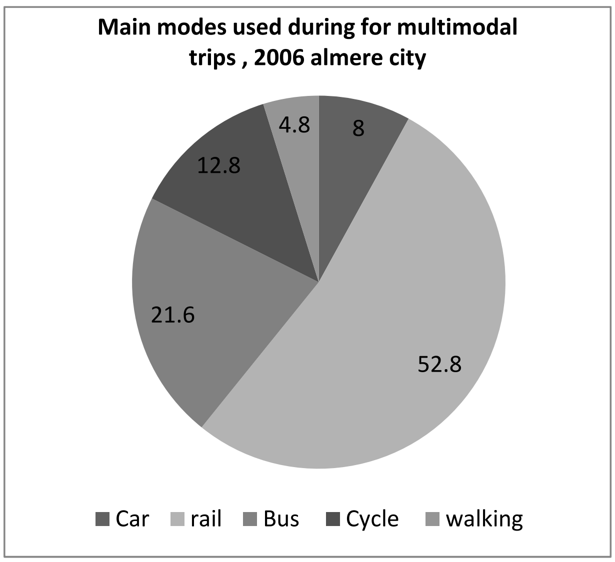


Figure 16: Main modes used during for multimodal trips , 2006 Almere city

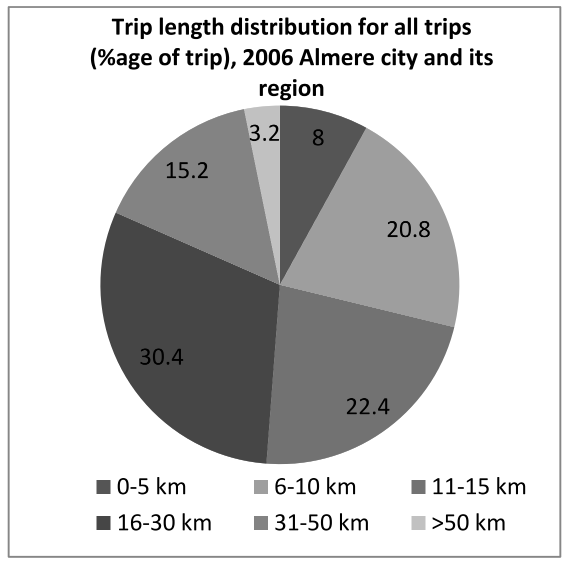


Figure 17: Trip length distribution for all trips (%age of trip), 2006 Almere city and its region

5.3.1. Trip length

The importance of trip length can clearly be seen from figure 27 which shows the trip length distribution. The average trip length of multimodal trips is 40 kilometers, which is 4.5 times more than average unimodal trip length in the case of Netherlands which is 10 kilometers (Nes, 2002). In the case of Almere, multimodal transport trips account for more than 40% and have trip length of more than 30 kilometers. Multimodal transport appears to be viable for trips longer than 10 kilometers and becomes an interesting alternative for trips longer than 30 kilometers. There is, however, a large difference in the distances with respect to the main modes used in the multimodal trip. For Short trip lengths, walking and cycling were the main mode (5 kilometers) and bus above5 -15 kilometers.

5.3.2. Trip purpose

The second discriminating factor for multimodal travelling is trip purpose. As we can see from figure 28, multimodal transport plays an important role for work, shopping, recreation and especially for education trips. Multimodal transport appears less interesting for trip purposes such as personal care, social and other trips. This trip purpose has a strong orientation to the centers of the main cities. Similarly, the longer distances related to shopping explain the high share of multimodal transport for this trip purpose. One of the interesting facts found from the primary survey was that 95% of trips have at least two transfers, since because of good frequency of bus and train; penalty of a transfer seems to be acceptable. At least the overall benefits prevail over the discomfort of the transfer. Second, these trips are usually made in peak periods, when the quality of public transport in terms of time-accessibility is usually the best. Third, the trip-frequency related to these trip purposes indicates that sufficient knowledge of the transport system may be expected to be available. Finally, it should also be noted that during the periods that most of these trips are made, the quality of the car system is worst due to congestion and that parking is often difficult to find and expensive.

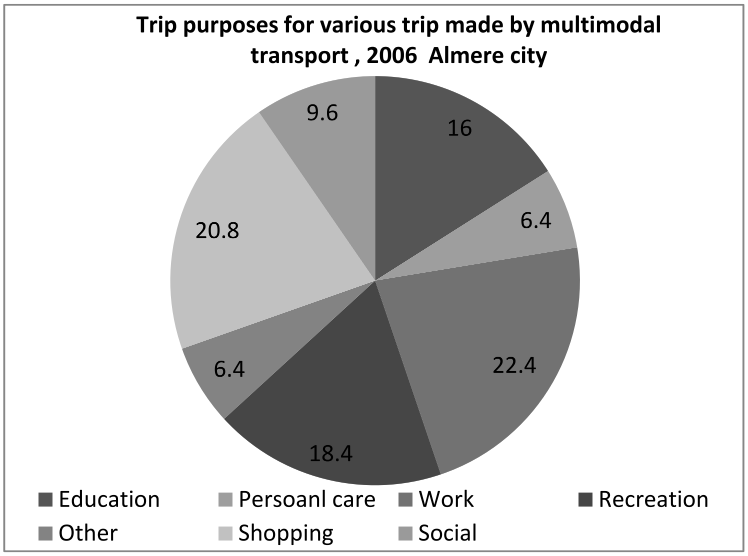


Figure 18: Trip purposes for various trips made by multimodal transport, 2006 Almere city

5.4. Conclusion

From the above analysis, it can be seen that there are certain limitation in terms of lack of knowledge about what we want to define or say defining accessibility and description of the different factor that constitute accessibility. This study was only limited to application of various accessibility indicator which can be applied for multimodal transport system. Through this study we are aiming to evaluate the multimodal transport system and improve travel time and travel time reliability on multimodal transport system and or able to improve the transport infrastructure. But this study only dealt with conventional transport system not the land use perspective. One of the most important assumptions behind accessibility study from literature is the combined impact of land use and transport system. However, this study limited to broad land use impact of transport strategies. The analysis done in this chapter was not able to deal with the level of services provided by the multimodal transport system which is the degree to which this multimodal transport system enables various people from different socio-economic background to make use of the necessary facilities to carry out the desired activities. To deal with this, there is need to incorporate all factors which influence accessibility as discussed in chapter 2. In conclusion, I would say that the accessibility analysis, choosing appropriate accessibility measure for conducting accessibility measure depend upon the assumption chosen for the accessibility analysis and results will differentiation with the socio-economic and modes used analysis. And for the case of multimodal transport system in above applied accessibility measure gravity measure is more accurate to explain the accessibility through multimodal transport system. From the above study it was found that the main factors associated with multimodal transport are trip length, destination area type and trip purpose. Multimodal transport is interesting for longer and preferably more than 30 kilometers, is focused on larger cities and especially city centers, and is mostly used for work, education and shopping trips. Furthermore, it is found that multimodal transport has been stimulated by the introduction of the transport card.

6. DISCUSSIONS

6.1. Introduction

The concept of accessibility is important in the field of land use and transport policy. The different perceptions and definitions make accessibility operational in a wide range of forums. This research uses the transport perspective integrating it with social – economic and land use perspectives. The objective of this study is to identify or develop accessibility measure for multimodal transport system which can provide significant contribution to evaluation of multimodal transport system in urbanised areas. Second was to model identified measures in the GIS environment. The research work is conducted on two levels; city level and regional level with a focus on car based versus multimodal transport network.

This chapter discusses critically the outcomes and limitations of implementing the accessibility measures.

1. Application of accessibility measures

The identification of various accessibility measures and examine their usability for evaluating multimodal transport system. From the literature and application of accessibility measures, it is found that there isn't a best approach for accessibility (Karst T. Geurs & van Wee, 2004) because different assumptions, situations, purposes and audience demand different approaches. The study showed that the best accessibility measures to evaluate multimodal transport system were activity based and utility based. In this study only activity based measures were successfully applied, due to lack of desired data utility based measure was not applied. From the study it is found that gravity based indicator is best to describe the accessibility through multimodal transport system. Gravity measure is able to show the distance decay affects on job opportunities from different TAZs and also able to show the competition between the jobs from various regions for this study. Accessibility measures' results vary for different area/case study as per objective or aim of the study.

2. Accessibility evaluation

Three activity based measures have been applied to the study area: contour measure, potential measure and gravity measure. The contour measure shows the broad picture of job accessibility by car and multimodal transport. Without considering any impedance or distance decay, it showed the total number of jobs that can be reached within a maximum travel time. From this measure, policy maker can easily identify where most jobs are distributed and which mode is better to reach the maximum number of jobs. It thus helps to do direct comparison of job accessibility between car and multimodal transport system.

In the case of potential accessibility measure, however, results differ from contour because of the absence of impedance function in contour measure. Potential measure just based upon impedance function shows that the job accessibility decreases with the increase of impedance. On a regional level, job accessibility by car drops down to app.10-20% according to the contour measure. The multimodal transport system however shows better job accessibility than by car. The potential measure shows higher level of job accessibility in Amsterdam region at regional level and central area in Almere city. But one of the important points which potential measure is not able to deal with is competition factor towards the job.

Gravity measure is able to overcome the disadvantages of potential measure. Gravity measure can deal with both the factors of accessibility to potential jobs in the region and interdependence between jobs and competition among the jobs. But one of the constraints that limited the use of gravity measure in this study is that it can only consider the broad competition among the jobs and only the same socio-economic level for the entire region; which is not true in reality. A region is divers in terms of socio-economic background of the people, education levels and their needs. Lack of socio-economic data limited the use of gravity measure in this study and only same socio-economic level, education level and income level for the entire region was considered, which is not ideally true.

3. Influence of distance decay function and cost

The choice of impedance function strongly influenced the results of this study. During the application of accessibility analysis, various impedance functions were tried for analysis and all of them showed different relationship between impedance function and actual traffic behaviour. For this study several form of impedance function were estimated using a travel surveys that were done for Almere city. Travel surveys were conducted with information on trip length, trip time, trip purpose, modes used and likelihood of travel by various modes. During the estimation of impedance function, the loglogistic function show good correlation with the observed travel behaviour than other impedance functions. Geurs and van Eck (2003) also drew similar conclusion based upon their study. Log logistic distance function was also used for the application of potential and gravity based accessibility measure. Compared to negative exponential function, this is known to be more accurate for the kind of modes selected in this study.

4. Estimated impedance function for car and multimodal transport system

The calculation of the travel cost in terms of money and time between an origin and destination influences the results or attractiveness of jobs for various locations. The travel cost to various regions has an affect on the job accessibility and job accessibility with high travel cost have very high disutility. In this study only travel time was considered for the job accessibility analysis by car. In the case of multimodal transport system however, two methods were applied to calculate the travel cost: the first method was adopted from Liu and Zhu's study (Liu & Zhu, 2004), where travel time for different regions were calculated with the combination of various modes. However during the analysis it was found that it was not able to show the true picture of cost factor for multimodal transport network like the combination of various travel cost : access time, egress time , waiting time, travel time and utility with the travel time with fare cost and utility of various modes. To eradicates this problem the second method was adopted from work of (B. Allen, 1984; De Jong, Daly, Pieters, & Van der Hoorn, 2007; Williams, 1977), where logsum cost was estimated and used as cost for accessibility analysis for multimodal transport system .

5. Dealing with the transport components of accessibility and uncertainties

Generally speaking the transport components of accessibility describe the disutility for an individual in covering the distance between origin and destination using specific modes. In this study it is related to the individual's (travellers) valuation of cost to access the opportunity at the proposed destination and uncertainties in the transport system. In conventional transport planning, cost function describes the disutility of travel. It includes the travel time between origin and destination. But in the case of multimodal transport system it is difficult to calculate overall cost because it includes other costs like access time , egress time , waiting time , travel time , fare cost, reliability of various modes, safety and comfort. In addition travellers' valuations of these factors are very sensitive. The traveller's decision to make a trip is depended upon these factors. This study was only able to analyze various time cost and fare cost and could not deal with other factors like safety and comfort.

The uncertainties in the transport system depend upon the traveller's choice to the available transport option and the costs and benefits associated with these. Due to lack of disaggregated data only some part of uncertainties can be accounted for. In this study, it was assumed that in any trip between the origin and destination only those modes will be considered which have high utility in terms of less travel cost and less travel fare for maximum benefit from the opportunities.

6. Job accessibility through car based and multimodal based network

In this study, comparison of job accessibility by car and multimodal transport based approaches were done, based on work trip purposes through activity based measure. It was found that multimodal trips showed good accessibility with trip lengths between 10 kilometer and above. Also for destinations outside the original city it follows the recommendation of Nes's work on multimodal transport system (Nes, 2002). It was found that multimodal transport will play an important role in work, education and shopping trips today, and other trips such as visiting and recreation will make up for the largest part of this increase. Given the trip length of 10 kilometers or less, the main competing mode is private cars. An increase of multimodal transport will thus lead to a reduction of trips by private car. It should be noted that peak hours have a big impact on above mentioned trip purposes and utility attached to multimodal transport is very high in the peak hours.

7. CONCLUSION AND RECOMMENDATION

7.1. Relevance of study

This study demonstrates the importance of accessibility as a measure of the quality of the multimodal transportation systems. The literature on accessibility measures is synthesized which included the most recent research in the field. Accessibility measures were shown to be useful to transportation planners, urban planner and policy makers in urban development in particular. They help in ranking different areas according to an urban or regional scale and evaluating the impacts of land use plans, policies and strategies that can influence the performance of land-use and transportation systems.

The goal of this research was to identify a variety of accessibility measures, as well as to apply them for multimodal transport system in order to understand the distribution of job accessibility. This would help policymaker to understand which measure would be useful to understand accessibility through the multimodal transport perspective and extract trends for future development.

Through the application of various accessibility measures it was found that potential and gravity measures were highly correlated for both by car and multimodal transport system. Gravity measure on the other hand was found to be very precise in understanding the accessibility as it included distance decay factors as well as job competition. The contour and potential measure were simpler to calculate and interpret than gravity measure.

7.2. Specific conclusion

1. There are number of accessibility measures in literature each with their own pro and cons. Different measures are used to evaluate transportation plans and projects depending on the goals and concerns of those conducting the analysis (Levinson, 1998). Accessibility is only one of the methods to evaluate plans and systems. Other types of measures that are used include mobility, cost benefit analysis (CBA), productivity and social equity. For this study criteria have been found to be relevant in the choice of accessibility measures to evaluate accessibility. This study adapts some of the criteria identified by Geurs and van Wee (2004) and other for selecting accessibility measure. These are:
   - Theoretical basis behind the desired system
   - Ease of communication and interpretation
   - The data requirements
   - Their usability as social, economic or sustainability indicators.
   - And others like mode availability, trip length, trip purpose and spatial area. ,

   From above identified criteria it was realized that the infrastructure measure approach of measuring accessibility was inadequate for the purpose of this study. The other form of accessibility measure like activity based and utility measure met the criteria of this study.
2. The appropriate accessibility measure for any study depends on the intended application, and the parameters of the selected model influences the results. Therefore it is important to clearly set the goals and objectives of the study before selecting accessibility measure to use . Each accessibility measure has its own points of strengths and weaknesses. For this reason several studies have used a combination of measures, either to highlight different aspects of a location's accessibility (S. L. Handy & Niemeier, 1997) or to reduce the weaknesses of each method through the strengths of the others (Primerano, et al., 2008) . For this study activity-based measures are selected for accessibility measure .They are comparatively easy than utility measure, easy to model, require less data and easy to understand; all of which makes them fit for use in the current study. Whereas utility based measures are better to define accessibility from the perception of multimodal transport but lack sound interpretation tools and sufficient data

3. One of the challenges of the research was defining the accurate method to build a multimodal transport network using bus routes, rails, and cycle and road networks in the GIS environment. Developed multimodal transport network lack some important information like detailed turn attributes, bus/train schedules and this might result in reporting inaccurate aggregate trip times as a result. When applying accessibility measures it was realized special attention is required to cost estimation method and the selection of distance decay function. From the application of various distance decay function it was realized that only loglogistic function describe the data better for this study and that the choice of function can make an important difference in the predication of job accessibility for various measure. For calculating the generalized cost for the accessibility analysis Logsum methods was selected for cost calculation.
4. It was found from the accessibility analysis that choosing the appropriate accessibility measure for conducting accessibility measure depend upon the assumptions chosen for the accessibility analysis. In this study accessibility measured applied to multimodal transport system for Job as trip purpose and the entire case study treated at same socio-economic structure, which is not true. Accessibility results also differ with different socio-economic structures and modes(of what) used. In the case of multimodal transport system gravity based measure is more accurate to explain the accessibility through multimodal transport system. From the analysis it was found that the main factors associated with multimodal transport are trip length, destination area type and trip purpose. The Multimodal transport would be preferred for trip length of 30 kilometres and more. It was found that the multimodal transport was more efficient in larger cities, especially city centers and is mostly used for work, education and shopping trips. Furthermore, it is found that multimodal transport has been stimulated by the introduction of the transport card

7.3. Further research

This thesis has reflected an initial step to develop multimodal transport system and how to evaluate accessibility with various accessibility measures for land use and transport development. However further research in this field is required.

Firstly there is an emerging need to develop a multimodal transport network which is able to integrate other factors within its framework. The multimodal transport network used for this study had a lot of limitation in term of data on cost (travel cost, fare cost, reliability of mode, safety and travel information).

Secondly further work is required in defining impedance factors and cost factors. In this study impedance factors was derived by two method: first from the OD matrix using ArcMap and other method adopted from (Liu & Zhu, 2004) to find out the impedance factors for multimodal transport system. But these methods were only able to calculate the impedance factor in term of travel cost but were not able to calculate the other costs. To eradicate this problem (Williams, 1977) logsum cost or composite cost method was applied for multimodal transport system. But one of the important factor which influence the cost factors is that it required lot of disaggregate travel data , which was limited in this study. In future there will be a need to collect desired travel data at disaggregate level which also includes the parameters of safety, reliability and utility of various modes.

Thirdly accessibility needs to be evaluated from the perspective of various socio-economic groups. In this study the entire population was treated as equal, no competition was considered in term of education and income level. Evaluating accessibility by taking into account the diversity in the socio-economic structure of the society would result in more accurate results.

Lastly there is a need for the development and application of utility based accessibility. Utility based measure can incorporate factors such as traveller's attitude towards different source of uncertainties in the transport system and value of time. According to (Karst T. Geurs & van Wee, 2004) utility based approach assumes that the travellers respond to probabilities in a strictly rational manner. Till date limited research has been done on these issues from the perspective of multimodal transport system. Application of utility based method will help in developing more realistic models of travel behaviour within the paradigm of random –utility maximization.

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APPENDIX

Appendix 1: Accessibility definition available in literature

Author	Definition	Key factors in accessibility
Handy, 2004	The ability to get what you need, ideally with a choice of destinations and using a choice of modes	• Need • Choice of destination • Choice of modes
Litman, 2003a	Accessibility refers to the ability to reach desired goods, services, activities and destinations (together called opportunities). Accessibility depends on mobility, mobility substitutes and opportunities as follows: Mobility - provided by walking, cycling, public transport, car sharing, taxi, cars, and other modes. All else being equal, an increase in the speed, service quality or affordability of a mode will improve access by that mode. Mobility substitutes - telecommunications and delivery services. These can provide access to some types of goods and activities, particularly those involving information. Land uses - the geographic distribution of activities and destinations. Generally equal dispersion of common destinations increases the amount of mobility needed to access goods, services and activities, reducing accessibility. When real estate experts say "location, location, location" they mean "accessibility, accessibility, accessibility". Other factors - information availability, affordability, convenience and comfort, security and prestige.	• Mobility • Mobility substitutes • Land use
Geurs et al, 2001	The extent to which the land-use transports system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s).	• Land use • Transport system • Destination • Transport modes

Ross, 2000	The ease of reaching some destination, and may include real or perceived costs in terms of time or money, distance travelled, level of comfort, availability and reliability of public transport, or any combination of these.	• Destination • Costs • Reliability • Modes
David Simmonds Consultancy et al (1998)	A way of measuring the ease with which a particular category of persons can reach a defined set of destinations, from a given origin (origin accessibility), or the ease with which a given destination (destination accessibility) can be reached by a particular set of potential individuals	• Destination • Ease • Potential individuals
Gray, 1989	A measure of the relative access of an area or zone to population, employment, opportunities, and community services	• Relative access • Area • Opportunities

Source:(Jones, Lucas, Wixey, & Aldridge, 2005)

Appendix 2: accessibility measure review

Accessibility Measure	**Methodological measure**	**General equation**	**Approach/ Measure**	**Advantages.**	**Disadvantages**
Infrastructure measure	Spatial Separation Model (C Bhat, et al., 2005) Infrastructure Measures (Karst T. Geurs & van Wee, 2004) Travel Cost Approach (BARADARAN & RAMJERDI, 2001)	$Ai = \frac{\sum_j dij}{B}$ dij is the distance between zones i and j and b is a general parameter	Resistance between origin and destination, or between nodes. Travel impediment measures can include: • Physical (Euclidean) distance • Network distance (by mode) • Travel time (by mode) • Travel time (by network status—congestion, free-flow, etc.) • Travel cost (variable user cost or total social cost) • Service quality (e.g. public transport frequency)	• Data is generally easily available from digital mapping material and other public sources. • Easy to understand because of the simplicity of model construction. • Quite easy to calculate.	• Neglect variations in the quality of locations • Neglect variations in the value of time among travelers, • Highly sensitive to the choice of demarcation area • Do not consider the behavioral aspects of travelers • No consideration of land use patterns and spatial distribution of opportunities.
Activity Measure	Contour measure, Potential accessibility measure , Competition measure, Person-based measure and Time-space measure (Karst T. Geurs & van Wee, 2004)	$At = \sum_t Ot$ t is the threshold cost and Ot is an opportunity that can be reached within the threshold cost and	• Defines catchment areas by drawing one or more travel time contours around a node, and measures the number of opportunities within each contour (jobs, employees, customers, etc). • Defines catchment areas by measuring travel impediment on	• Incorporates land use and attends to infrastructure constraints by using travel time as indicator for impediment. • Provides a regional perspective on accessibility.	• Methodology cannot capture variation in accessibility between activities within the same contour. • Does not differentiate between travel purposes and individual drivers for travel. • Sensitivity to the choice of demarcation area,

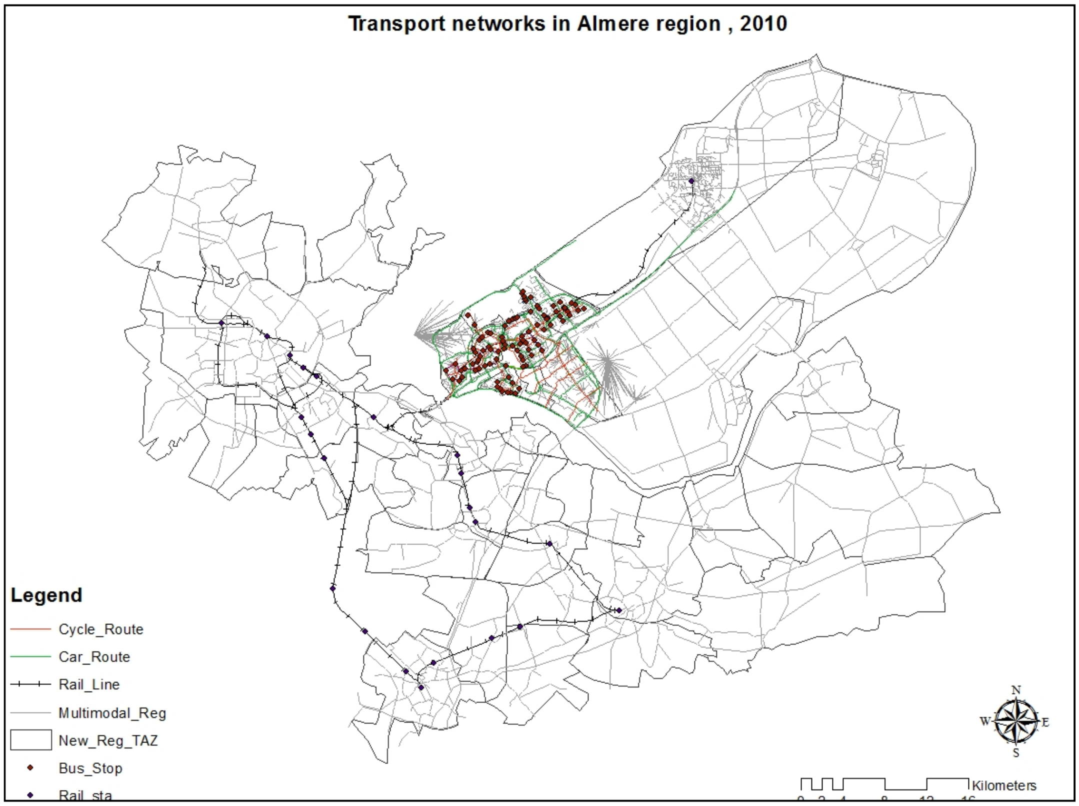
	Cumulative opportunity and Gravity model (C Bhat, et al., 2005)	$At = \sum_{t} \frac{Oj}{t_{ij}^{\propto}}$ Oj opportunity in zone j , tij travel time between zone I and j and α is parameter of calibration	a continuous scale. • Incorporates capacity constraints of activities and users into accessibility measure.	• Well-suited to examine trip-chaining and spatial clustering of activities. • Usually requires project-specific user surveys, limiting the geographical range and compatibility of data.	• Deficiency in treatment of travelers with dispersed preferences, and Ambiguity in what the magnitude of indicators express (dimension problem).
Utility Measure	Utility measure (C Bhat, et al., 2005; Karst T. Geurs & van Wee, 2004) Utility surplus approach (BARADARAN & RAMJERDI, 2001)	$An = E[Max\ Uin_{i \in C}\ ] = \log \sum_{i \in C} \exp(Vin)$ n is individual, i is spatial destination and C is set of choice	Measures individual or societal benefits of accessibility. Indicators can include: • Economic utility (to the individual, or to the community) • Social or environmental benefits (e.g. social inclusion, greenhouse effects) • Individual motivations of travel (by activity or travel purpose) • Option and non-user benefits of transport infrastructure	The empirical link between infrastructure provision and economic performance. This indicator can analyze existing motivations of travel and they are supported by relevant travel behavior theories.	• Cannot anticipate feedback effects between land use and travel patterns, or future behavior patterns of users. • Modeling demands extensive data on locations and individuals' travel behavior and their choice sets, • The assumption of non presence of an income effect is restrictive.

Appendix 3: Review of accessibility measure for multimodal transport system

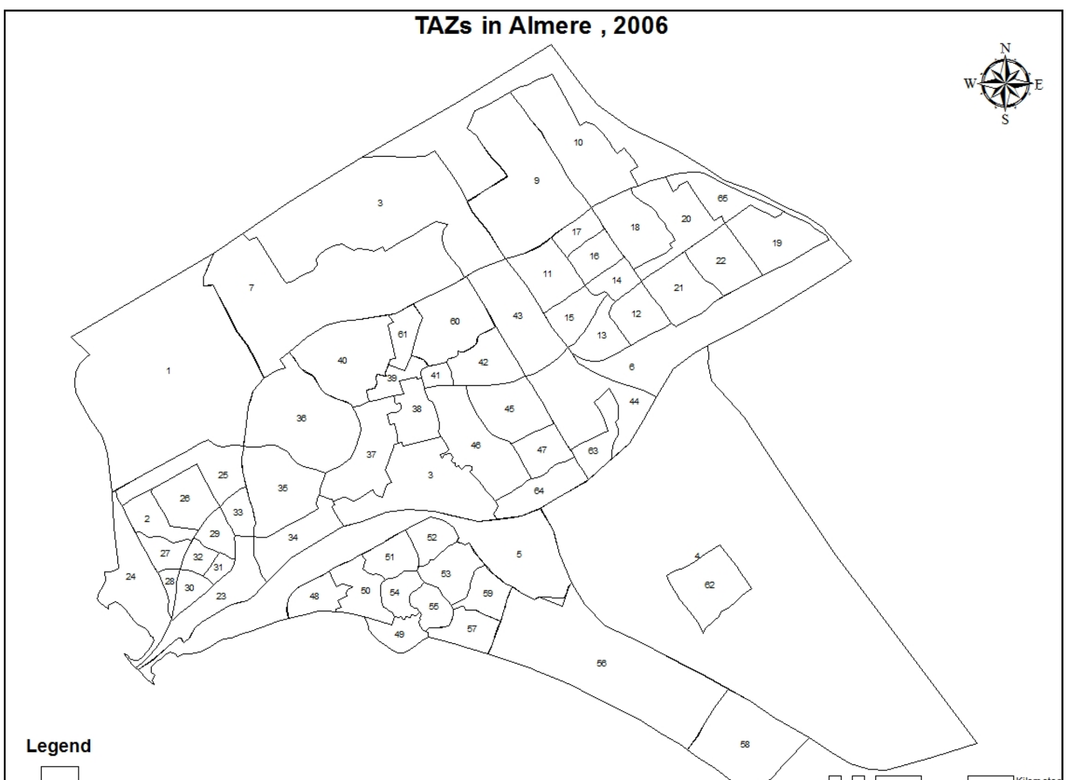
Accessibility Measure	**Method and approach**	**Multimodal transport factors**				**Land use/ spatial scale**	**Remarks**	**Usability for evaluation of multimodal transport system**
		Travel mode	**Trip purpose**	**Time of day**	**Level of service**			
Infrastructure Based Measure	Measures travel impediment or resistance between origin and destination, or between nodes	Automobile based or single mode	Home-based work, home based other and non-home-based	Average weekday	Distance or Speed	Zone level or Districts	Data easily available ,easy to calculate but no consideration of land use patterns and spatial distribution of opportunity	4
Location Based Measures								
Distance Measure	Measures travel impediment	Auto	Employment and health facilities	_	Distance	Zone	Methodology cannot capture variation in accessibility between activities within the threshold time	4
Contour measure	Defines catchment areas by drawing one or more travel time contours around a node, and measures the number of opportunities within each contour (jobs, employees, customers, etc).	Walk, Auto, and transit	Employment and public and private facilities	Peak period	Travel time	Zone	Definition of travel time contours may be arbitrary and does not differentiate between activities and travel purposes.	1
Potential measure	Incorporates capacity	Auto and	Non-worker	_	Distance	Individual	More accurate representation	2

	constraints of activities and users into Accessibility measure.	non-motorized			, Travel time		of travel resistance than in contour measure,	
Gravity measure	Defines catchment areas by measuring travel impediment on a continuous scale and Incorporates capacity constraints of activities	Walk, auto and transit	Shopping, employment Health services and work	Peek/off-peak Weekday	Distance , perceived cost , impedance function	Household, zone, weighted by number of household	Tends to be less legible. Does not differentiate between travel purposes and individual drivers for travel. Provides a regional perspective on accessibility.	2
Space–time measure	Measures travel opportunities within pre-defined time constraints.	Auto and transit	Activity	All day	Travel time	Individual level	Well-suited to examine trip-chaining and spatial clustering of activities.	3
Utility Based Measures								
Logsum benefit measure	Measures individual or societal benefits of accessibility. Indicators can include: Economic utility Social or environmental benefits Individual motivations of travel Option and non-user benefits of transport infrastructure	Walk, auto and transit	Employment School and shopping	All day	Travel time , travel cost	Zone	The empirical link between Infrastructure provision and economic performance is tenuous and contested. This indicator can analyze existing motivations of travel, but cannot anticipate feedback effects between land use and travel patterns, or future behavior patterns of users.	3

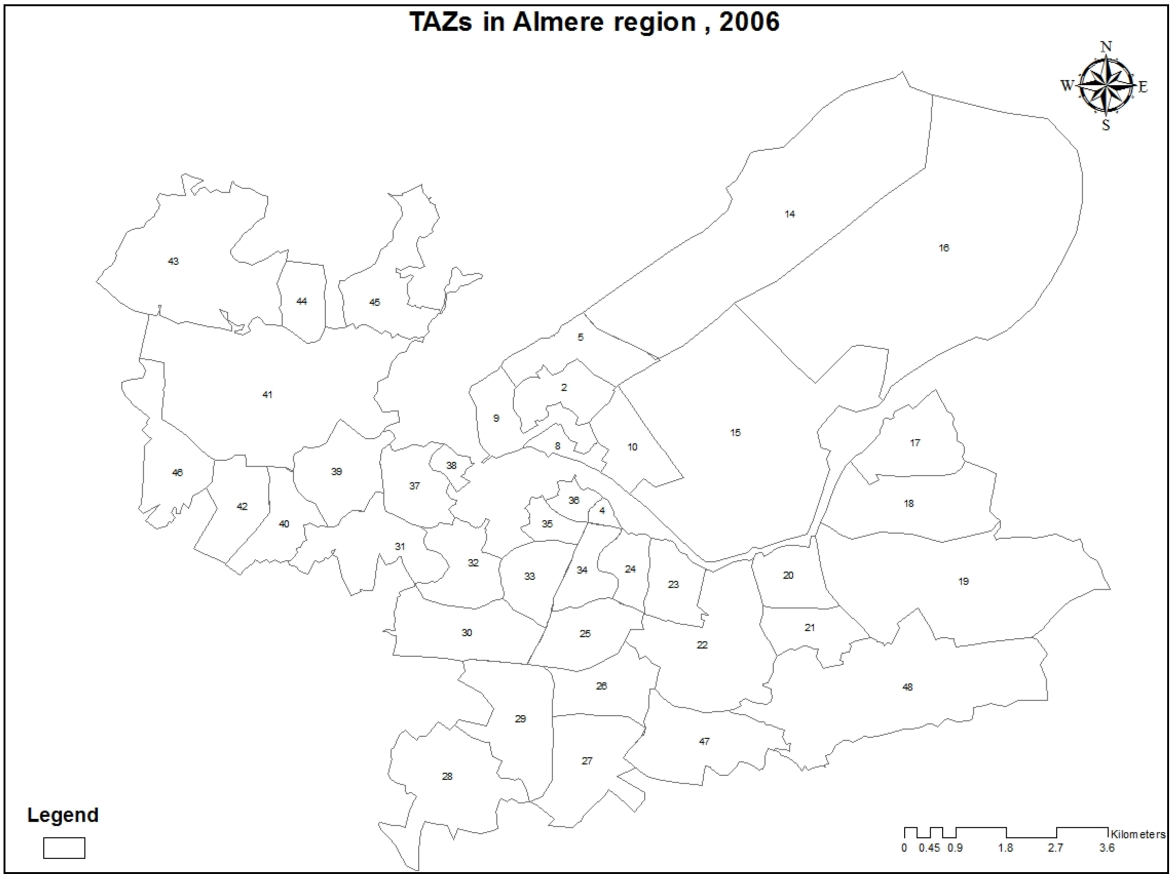
Appendix 4: Transport network in Almere region, 2006



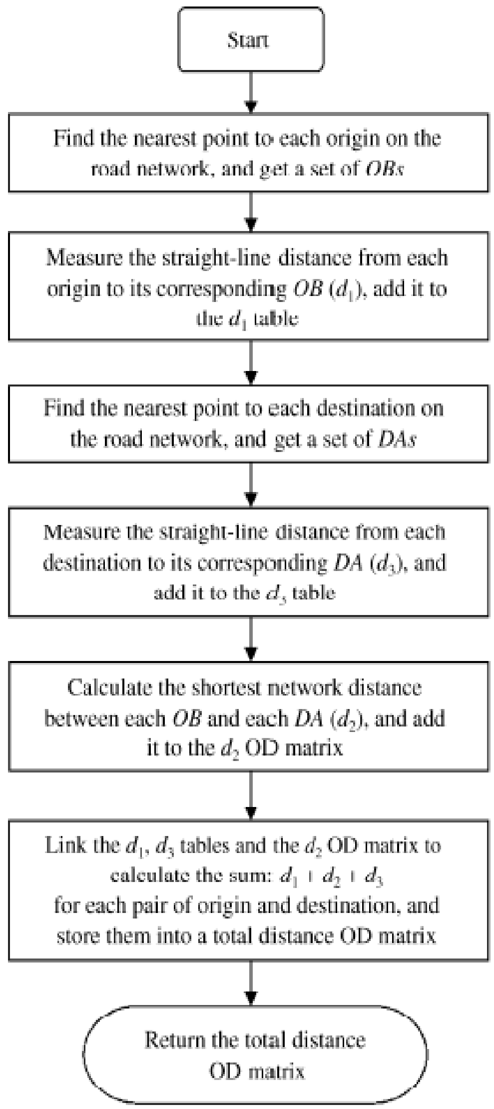
Appendix 5: TAZs in Almere, 2006



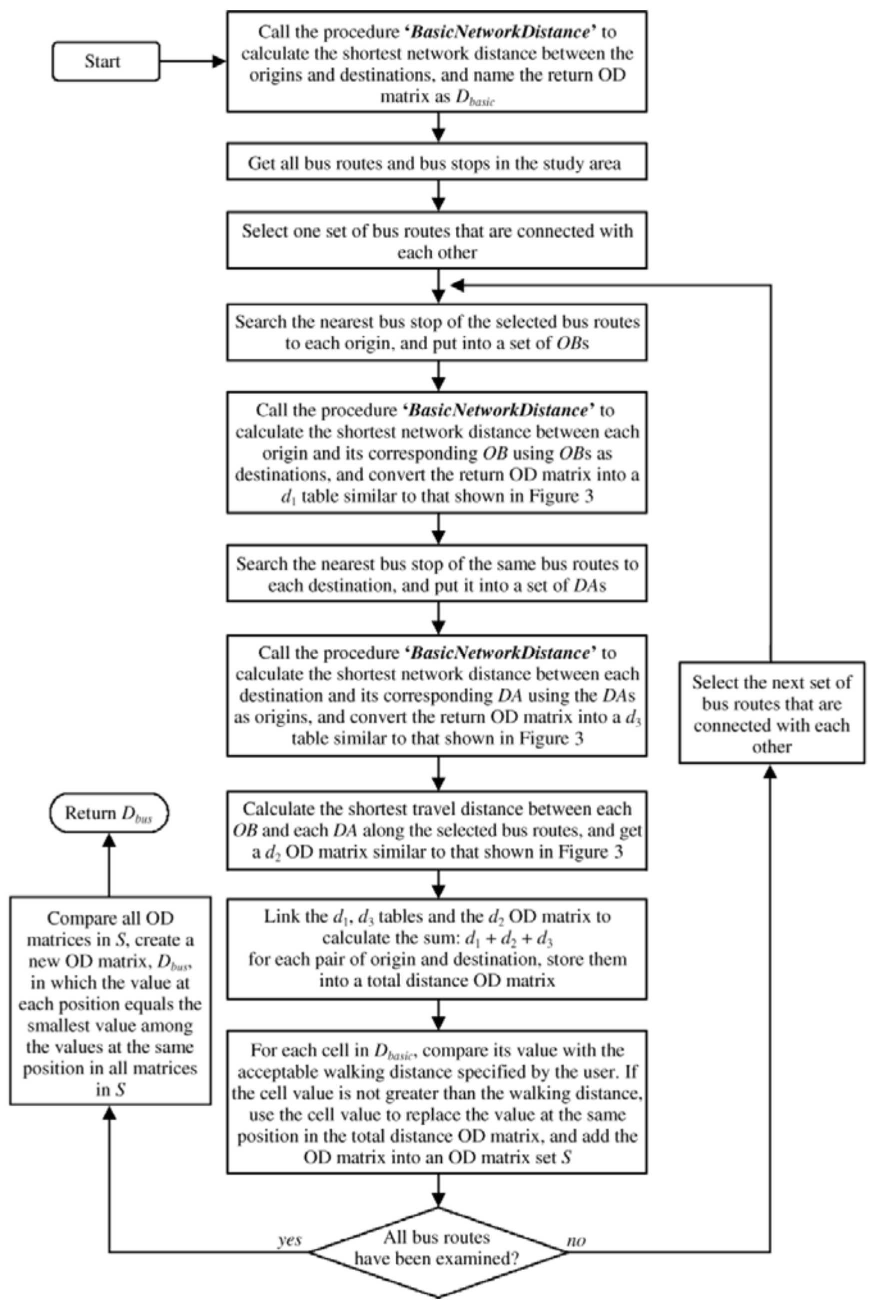
Appendix 6: TAZs in Almere region, 2006



Appendix 7: The procedure basic network distance for measuring the network distance for travel along the shortest road network path



Appendix 8: The procedure train network distance for measuring the network distance for travel by train



Appendix 9: Travel time matrix Almere region, 2010 (Seconds)

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	396	299	545	345	319	551	993	1158	1169	1454	1819	920	1125	1163	1109	976	962	1312	1465
2	396	0	419	576	462	268	570	1012	1177	1188	1457	1782	883	1088	832	778	645	631	981	1134
3	299	419	0	584	401	342	512	954	1119	1130	1415	1842	943	1148	1186	1132	999	985	1335	1488
4	545	576	584	0	411	499	729	1171	1336	1347	1632	1985	1086	1291	1343	1289	1156	1142	1492	1645
5	346	463	402	412	0	386	616	1058	1223	1234	1519	1886	987	1192	1202	1148	978	1001	1351	1504
6	319	268	342	499	385	0	493	935	1100	1111	1384	1709	810	1015	1035	981	848	834	1184	1337
7	552	571	513	730	616	494	0	746	911	922	1207	1876	1095	1300	1338	1284	1151	1137	1487	1640
8	994	1013	955	1172	1058	936	746	0	1147	400	685	1354	995	1200	1390	1599	1593	1579	1929	1788
9	1158	1177	1119	1336	1222	1100	910	1146	0	1322	1607	2276	1701	1906	1944	1890	1757	1743	2093	2246
10	1169	1188	1130	1347	1233	1111	921	399	1322	0	347	1016	657	862	1052	1261	1627	1561	1675	1450
11	1454	1457	1415	1632	1518	1384	1206	684	1607	347	0	669	763	968	1158	1367	1733	1667	1781	1556
12	1820	1783	1843	1986	1886	1710	1876	1354	2277	1017	670	0	900	1139	1420	1579	2059	1993	2107	1882
13	920	883	943	1086	986	810	1094	994	1701	657	763	899	0	252	533	679	1159	1093	1207	982
14	1125	1088	1148	1291	1191	1015	1299	1199	1906	862	968	1138	252	0	480	682	1285	1219	1333	1108
15	1164	833	1187	1344	1202	1036	1338	1390	1945	1053	1159	1420	534	481	0	654	981	915	1077	852
16	1110	779	1133	1290	1148	982	1284	1599	1891	1262	1368	1579	680	683	654	0	927	861	1161	1100
17	976	645	999	1156	977	848	1150	1592	1757	1627	1733	2058	1159	1285	980	926	0	779	1129	1370
18	963	632	986	1143	1001	835	1137	1579	1744	1562	1668	1993	1094	1220	915	861	780	0	770	1043
19	1313	982	1336	1493	1351	1185	1487	1929	2094	1676	1782	2107	1208	1334	1077	1161	1130	770	0	973
20	1466	1135	1489	1646	1504	1338	1640	1788	2247	1451	1557	1882	983	1109	852	1100	1371	1043	973	0
21	1242	911	1265	1422	1280	1114	1416	1858	2023	1691	1797	2122	1223	1349	1092	1280	1147	1133	1213	600
22	1450	1119	1473	1630	1488	1322	1624	2066	2231	1951	2057	2382	1483	1609	1352	1488	1355	1250	1302	860
23	1395	1064	1418	1551	1365	1267	1569	2011	2176	2134	2240	2565	1666	1792	1487	1433	1300	1224	1574	1503
24	1235	1312	1291	1261	1075	1235	1465	1907	2072	2083	2368	2735	1836	2041	1889	1835	1665	1688	2038	2191
25	1224	1099	1280	1250	1064	1224	1454	1896	2061	2072	2275	2600	1701	1827	1522	1468	1298	1321	1671	1649

26	848	517	871	908	722	720	1022	1464	1629	1587	1693	2018	1119	1245	940	886	716	739	1089	1144
27	668	337	691	848	706	540	842	1284	1449	1319	1425	1750	851	977	672	618	308	471	821	1062
28	594	198	617	774	660	466	768	1210	1375	1386	1655	1980	1081	1286	1030	976	843	829	1179	1332
29	787	391	810	967	853	659	961	1403	1568	1579	1848	2173	1274	1479	1223	1169	1036	1022	1372	1525
30	960	1037	1016	986	800	960	1190	1632	1797	1808	2093	2460	1561	1766	1614	1560	1390	1413	1763	1916
31	450	527	506	476	290	450	680	1122	1287	1298	1583	1950	1051	1256	1136	1082	912	935	1285	1438
32	615	692	671	641	455	615	845	1287	1452	1463	1748	2115	1216	1421	1269	1215	1045	1068	1418	1571
33	1235	1312	1291	1261	1075	1235	1465	1907	2072	2083	2368	2735	1836	2041	1889	1835	1665	1688	2038	2191
34	1294	1371	1350	1320	1134	1294	1524	1966	2131	2142	2427	2794	1895	2100	1948	1894	1724	1747	2097	2250
35	1168	1245	1224	1194	1008	1168	1398	1840	2005	2016	2301	2668	1769	1974	1822	1768	1598	1621	1971	2124
36	1882	1959	1938	1908	1722	1882	2112	2554	2719	2730	3015	3382	2483	2688	2536	2482	2312	2335	2685	2838
37	1509	1586	1565	1535	1349	1509	1739	2181	2346	2357	2642	3009	2110	2315	2163	2109	1939	1962	2312	2465
38	1507	1584	1563	1533	1347	1507	1737	2179	2344	2355	2640	3007	2108	2313	2161	2107	1937	1960	2310	2463
39	1592	1261	1615	1772	1630	1464	1766	1770	2373	1433	1539	1864	965	1091	834	1082	1409	1343	1258	1002
40	2316	1985	2339	2496	2354	2188	2490	2494	3097	2157	1846	1958	1667	1509	1518	1806	2133	2067	2181	1956
41	2432	2084	2456	2621	2472	2297	2615	2619	3252	2265	1938	2056	1750	1584	1594	1896	2240	2170	2290	2054

O/ D	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**
1	1242	1449	1394	1234	1223	847	668	593	786	959	449	615	1234	1293	1168	1882	1509	1506	1591	2315	2431
2	911	1118	1063	1311	1098	516	337	197	390	1036	526	692	1311	1370	1245	1959	1586	1583	1260	1984	2083
3	1265	1472	1417	1290	1279	870	691	616	809	1015	505	671	1290	1349	1224	1938	1565	1562	1614	2338	2455
4	1422	1629	1550	1260	1249	907	848	773	966	985	475	641	1260	1319	1194	1908	1535	1532	1771	2495	2620
5	1281	1488	1365	1075	1064	722	707	660	853	800	290	456	1075	1134	1009	1723	1350	1347	1630	2354	2472
6	1114	1321	1266	1234	1223	719	540	465	658	959	449	615	1234	1293	1168	1882	1509	1506	1463	2187	2296
7	1417	1624	1569	1465	1454	1022	843	768	961	1190	680	846	1465	1524	1399	2113	1740	1737	1766	2490	2615
8	1859	2066	2011	1907	1896	1464	1285	1210	1403	1632	1122	1288	1907	1966	1841	2555	2182	2179	1770	2494	2619

9	2023	2230	2175	2071	2060	1628	1449	1374	1567	1796	1286	1452	2071	2130	2005	2719	2346	2343	2372	3096	3251
10	1691	1950	2133	2082	2071	1586	1319	1385	1578	1807	1297	1463	2082	2141	2016	2730	2357	2354	1432	2156	2264
11	1797	2056	2239	2367	2274	1692	1425	1654	1847	2092	1582	1748	2367	2426	2301	3015	2642	2639	1538	1845	1937
12	2123	2382	2565	2735	2600	2018	1751	1980	2173	2460	1950	2116	2735	2794	2669	3383	3010	3007	1864	1958	2056
13	1223	1482	1665	1835	1700	1118	851	1080	1273	1560	1050	1216	1835	1894	1769	2483	2110	2107	964	1666	1749
14	1349	1608	1791	2040	1826	1244	977	1285	1478	1765	1255	1421	2040	2099	1974	2688	2315	2312	1090	1508	1583
15	1093	1352	1487	1889	1522	940	673	1030	1223	1614	1136	1270	1889	1948	1823	2537	2164	2161	834	1518	1594
16	1281	1488	1433	1835	1468	886	619	976	1169	1560	1082	1216	1835	1894	1769	2483	2110	2107	1082	1806	1896
17	1147	1354	1299	1664	1297	715	308	842	1035	1389	911	1045	1664	1723	1598	2312	1939	1936	1408	2132	2239
18	1134	1250	1224	1688	1321	739	472	829	1022	1413	935	1069	1688	1747	1622	2336	1963	1960	1343	2067	2170
19	1214	1302	1574	2038	1671	1089	822	1179	1372	1763	1285	1419	2038	2097	1972	2686	2313	2310	1258	2181	2290
20	601	860	1503	2191	1649	1144	1063	1332	1525	1916	1438	1572	2191	2250	2125	2839	2466	2463	1002	1956	2054
21	0	663	1279	1967	1425	920	839	1108	1301	1692	1214	1348	1967	2026	1901	2615	2242	2239	1242	2196	2306
22	664	0	1487	2175	1633	1128	1047	1316	1509	1900	1422	1556	2175	2234	2109	2823	2450	2447	1502	2456	2579
23	1280	1487	0	2052	1160	843	992	1261	1454	1477	1299	1433	2052	2111	1986	2700	2327	2324	1915	2639	2771
24	1968	2175	2052	0	1751	1409	1394	1509	1661	1131	1009	620	820	791	883	1760	1424	1004	2317	3041	3193
25	1426	1633	1160	1751	0	845	1027	1292	1294	975	998	1132	1751	1810	1685	2399	2026	2023	1950	2674	2808
26	921	1128	843	1409	845	0	445	714	838	1000	656	790	1409	1468	1343	2057	1684	1681	1368	2092	2197
27	839	1046	991	1393	1026	444	0	534	727	1118	640	774	1393	1452	1327	2041	1668	1665	1100	1824	1915
28	1109	1316	1261	1509	1292	714	535	0	503	1234	724	890	1509	1568	1443	2157	1784	1781	1458	2182	2291
29	1302	1509	1454	1661	1294	838	728	503	0	1386	908	1042	1661	1720	1595	2309	1936	1933	1651	2375	2494
30	1693	1900	1477	1131	975	1000	1119	1234	1386	0	734	600	1131	1190	1050	1834	1461	1403	2042	2766	2904
31	1215	1422	1299	1009	998	656	641	724	908	734	0	390	1009	1068	943	1657	1284	1281	1564	2288	2402
32	1348	1555	1432	619	1131	789	774	889	1041	599	389	0	619	678	553	1267	894	891	1697	2421	2542
33	1968	2175	2052	820	1751	1409	1394	1509	1661	1131	1009	620	0	854	797	1674	1338	1067	2317	3041	3193
34	2027	2234	2111	791	1810	1468	1453	1568	1720	1190	1068	679	854	0	730	1544	1458	667	2376	3100	3255
35	1901	2108	1985	882	1684	1342	1327	1442	1594	1049	942	553	796	729	0	1133	915	803	2250	2974	3123

36	2615	2822	2699	1759	2398	2056	2041	2156	2308	1833	1656	1267	1673	1543	1133	0	1470	1593	2964	3688	3872
37	2242	2449	2326	1423	2025	1683	1668	1783	1935	1460	1283	894	1337	1457	915	1470	0	1518	2591	3315	3481
38	2240	2447	2324	1004	2023	1681	1666	1781	1933	1403	1281	892	1067	667	804	1594	1519	0	2589	3313	3479
39	1243	1502	1915	2317	1950	1368	1101	1458	1651	2042	1564	1698	2317	2376	2251	2965	2592	2589	0	1938	2035
40	2197	2456	2639	3041	2674	2092	1825	2182	2375	2766	2288	2422	3041	3100	2975	3689	3316	3313	1938	0	2103
41	2307	2579	2771	3193	2808	2197	1916	2291	2494	2904	2402	2543	3193	3255	3124	3873	3482	3479	2035	2556	2208

Appendix 10: Cost matrix Almere region, 2010 in Euro (2nd class, discounted fare)

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	2.4	2.4	2.4	2.4	5.2	5.2	5.2	13.4	13.4	12.6	11.2	9.4	9.4	9.4	9.4	6.6	6.6	6.6	6.6
2	2.4	0	2.4	2.4	2.4	5.2	5.2	5.2	13.4	13.4	12.6	11.2	9.4	9.4	9.4	9.4	6.6	6.6	6.6	6.6
3	2.4	2.4	0	2.4	2.4	5.2	5.2	5.2	13.4	13.4	12.6	11.2	9.4	9.4	9.4	9.4	6.6	6.6	6.6	6.6
4	2.4	2.4	2.4	0	2.4	5.2	5.2	5.2	13.4	13.4	12.6	11.2	9.4	9.4	9.4	9.4	6.6	6.6	6.6	6.6
5	2.4	2.4	2.4	2.4	0	5.2	5.2	5.2	13.4	13.4	12.6	11.2	9.4	9.4	9.4	9.4	6.6	6.6	6.6	6.6
6	5.2	5.2	5.2	5.2	5.2	0	5.2	6.2	17.2	17.2	16.6	15.4	13.6	13.6	13.6	13.6	10.8	10.8	10.8	10.8
7	5.2	5.2	5.2	5.2	5.2	5.2	0	6.2	17.2	17.2	16.6	15.4	13.6	13.6	13.6	13.6	10.8	10.8	10.8	10.8
8	6.2	6.2	6.2	6.2	6.2	6.2	17.8	0	17.2	17.2	16.6	15.4	13.6	13.6	13.6	13.6	10.8	10.8	10.8	10.8
9	14.2	14.2	14.2	14.2	14.2	17.8	17.8	17.8	0	2.4	2.6	3.8	5.8	5.8	5.8	5.8	8.8	8.8	8.8	8.8
10	13.4	13.4	13.4	13.4	13.4	17.2	17.2	17.2	2.4	0	2.4	3.2	5.2	5.2	5.2	5.2	8	8	8	8
11	12.6	12.6	12.6	12.6	12.6	12.6	16.6	12.6	2.4	2.4	0	2.4	4.2	4.2	4.2	4.2	7	7	7	7
12	11.2	11.2	11.2	11.2	11.2	11.2	15.4	11.2	3.8	3.2	2.4	0	3	3	3	3	5.8	5.8	5.8	5.8
13	7.6	7.6	7.6	7.6	7.6	7.6	13.6	13.6	5.8	5.2	4.2	3	0	4.5	4.5	4.5	3.8	3.8	3.8	3.8
14	9.4	9.4	9.4	9.4	9.4	9.4	13.6	13.6	5.8	5.2	4.2	3	4.5	0	4.5	4.5	3.8	3.8	3.8	3.8
15	7.4	7.4	7.4	7.4	7.4	7.4	13.6	13.6	5.8	5.2	4.2	3	4.5	4.5	0	4.5	3.8	3.8	3.8	3.8
16	10.4	10.4	10.4	10.4	10.4	10.4	13.6	13.6	5.8	5.2	4.2	3	4.5	4.5	4.5	0	3.8	3.8	3.8	3.8
17	7.6	7.6	7.6	7.6	7.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	0	3.8	3.8	3.8
18	7.6	7.6	7.6	7.6	7.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	0	3.8	3.8
19	8.4	8.4	8.4	8.4	8.4	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	3.8	0	3.8
20	6.6	6.6	6.6	6.6	6.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	0
21	7.6	7.6	7.6	7.6	7.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
22	6.6	6.6	6.6	6.6	6.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
23	6.6	6.6	6.6	6.6	6.6	10.8	10.8	10.8	8.8	8	7	5.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
24	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.4	6.8	5.8	4.6	2.6	2.6	2.6	2.6	2.4	2.4	2.4	2.4
25	8.8	8.8	8.8	8.8	8.8	12.8	12.8	12.8	8.4	7.6	6.8	5.6	2.6	2.6	2.6	2.6	2.4	2.4	2.4	2.4
26	11.8	11.8	11.8	11.8	11.8	12.8	12.8	12.8	8.4	7.6	6.8	5.6	2.6	2.6	2.6	2.6	2.4	2.4	2.4	2.4

27	9.8	9.8	9.8	9.8	9.8	14	14	14	9.6	8.8	8	6.8	4.8	4.8	4.8	4.8	4.2	4.2	4.2	4.2
28	8.4	8.4	8.4	8.4	8.4	11	11	11	13.8	13	12.2	11	9.2	9.2	9.2	9.2	6.6	6.6	6.6	6.6
29	6.8	6.8	6.8	6.8	6.8	11	11	11	13.8	13	12.2	11	9.2	9.2	9.2	9.2	6.6	6.6	6.6	6.6
30	6.8	6.8	6.8	6.8	6.8	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
31	5.8	5.8	5.8	5.8	5.8	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
32	5.8	5.8	5.8	5.8	5.8	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
33	7.4	7.4	7.4	7.4	7.4	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
34	7.4	7.4	7.4	7.4	7.4	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
35	7.4	7.4	7.4	7.4	7.4	10	10	10	13.2	12.6	11.6	10.4	8.6	8.6	8.6	8.6	5.6	5.6	5.6	5.6
36	3.8	3.8	3.8	3.8	3.8	8.2	8.2	8.2	11.2	10.6	9.8	8.6	6.6	6.6	6.6	6.6	3.8	3.8	3.8	3.8
37	3.8	3.8	3.8	3.8	3.8	8.2	8.2	8.2	11.2	10.6	9.8	8.6	6.6	6.6	6.6	6.6	3.8	3.8	3.8	3.8
38	5.2	5.2	5.2	5.2	5.2	8.2	8.2	8.2	11.2	10.6	9.8	8.6	6.6	6.6	6.6	6.6	3.8	3.8	3.8	3.8
39	6.4	6.4	6.4	6.4	6.4	10.6	10.6	10.6	13.8	13	12.2	11	9.2	9.2	9.2	9.2	6.2	6.2	6.2	6.2
40	7.4	7.4	7.4	7.4	7.4	10.6	10.6	10.6	13.8	13	12.2	11	9.2	9.2	9.2	9.2	6.2	6.2	6.2	6.2
41	7.4	7.4	7.4	7.4	7.4	10.6	10.6	10.6	13.8	13	12.2	11	9.2	9.2	9.2	9.2	6.2	6.2	6.2	6.2

O/D	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**
1	6.6	6.6	6.6	7.8	8.8	8.8	9.8	6.8	6.8	5.8	5.8	5.8	5.8	5.8	5.8	3.8	3.8	3.8	6.4	6.4	6.4
2	6.6	6.6	6.6	7.8	8.8	8.8	9.8	6.8	6.8	5.8	5.8	5.8	5.8	5.8	5.8	3.8	3.8	3.8	6.4	6.4	6.4
3	6.6	6.6	6.6	7.8	8.8	8.8	9.8	6.8	6.8	5.8	5.8	5.8	5.8	5.8	5.8	3.8	3.8	3.8	6.4	6.4	6.4
4	6.6	6.6	6.6	7.8	8.8	8.8	9.8	6.8	6.8	5.8	5.8	5.8	5.8	5.8	5.8	3.8	3.8	3.8	6.4	6.4	6.4
5	6.6	6.6	6.6	7.8	8.8	8.8	9.8	6.8	6.8	5.8	5.8	5.8	5.8	5.8	5.8	3.8	3.8	3.8	6.4	6.4	6.4
6	10.8	10.8	10.8	12	12.8	12.8	14	11	11	10	10	10	10	10	10	8.2	8.2	8.2	10.6	10.6	10.6
7	10.8	10.8	10.8	12	12.8	12.8	14	11	11	10	10	10	10	10	10	8.2	8.2	8.2	10.6	10.6	10.6
8	10.8	10.8	10.8	12	12.8	12.8	14	11	11	10	10	10	10	10	10	8.2	8.2	8.2	10.6	10.6	10.6
9	8.8	8.8	8.8	7.4	8.4	8.4	9.6	13.8	13.8	13.2	13.2	13.2	13.2	13.2	13.2	11.2	11.2	11.2	13.8	13.8	13.8
10	8	8	8	6.8	7.6	7.6	8.8	13	13	12.6	12.6	12.6	12.6	12.6	12.6	10.6	10.6	10.6	13	13	13
11	7	7	7	5.8	6.8	6.8	8	12.2	12.2	11.6	11.6	11.6	11.6	11.6	11.6	9.8	9.8	9.8	12.2	12.2	12.2
12	5.8	5.8	5.8	4.6	5.6	5.6	6.8	11	11	10.4	10.4	10.4	10.4	10.4	10.4	8.6	8.6	8.6	11	11	11

13	3.8	3.8	3.8	2.6	3.4	3.4	4.8	9.2	9.2	8.6	8.6	8.6	8.6	8.6	8.6	6.6	6.6	6.6	9.2	9.2	9.2
14	3.8	3.8	3.8	2.6	3.4	3.4	4.8	9.2	9.2	8.6	8.6	8.6	8.6	8.6	8.6	6.6	6.6	6.6	9.2	9.2	9.2
15	3.8	3.8	3.8	2.6	3.4	3.4	4.8	9.2	9.2	8.6	8.6	8.6	8.6	8.6	8.6	6.6	6.6	6.6	9.2	9.2	9.2
16	3.8	3.8	3.8	2.6	3.4	3.4	4.8	9.2	9.2	8.6	8.6	8.6	8.6	8.6	8.6	6.6	6.6	6.6	9.2	9.2	9.2
17	3.8	3.8	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
18	3.8	3.8	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
19	3.8	3.8	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
20	3.8	3.8	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
21	0	3.8	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
22	3.8	0	3.8	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
23	3.8	3.8	0	2.4	3.2	3.2	4.2	6.6	6.6	5.6	5.6	5.6	5.6	5.6	5.6	3.8	3.8	3.8	6.2	6.2	6.2
24	2.4	2.4	2.4	0	2.4	2.4	5.2	7.8	7.8	7	7	7	7	7	7	5	5	5	7.4	7.4	7.4
25	2.4	2.4	2.4	2.4	0	5.8	4.4	8.8	8.8	7.8	7.8	7.8	7.8	7.8	7.8	5.8	5.8	5.8	8.4	8.4	8.4
26	2.4	2.4	2.4	2.4	5.8	0	4.4	8.8	8.8	7.8	7.8	7.8	7.8	7.8	7.8	5.8	5.8	5.8	8.4	8.4	8.4
27	4.2	4.2	4.2	5.2	4.4	4.4	0	5.2	5.2	7	7	7	7	7	7	7	7	7	8	8	8
28	6.6	6.6	6.6	7.8	8.8	8.8	5.2	0	5.8	2.6	2.6	2.6	2.6	2.6	2.6	3.8	3.8	3.8	3.8	3.8	3.8
29	6.6	6.6	6.6	7.8	8.8	8.8	5.2	5.8	0	2.6	2.6	2.6	2.6	2.6	2.6	3.8	3.8	3.8	3.8	3.8	3.8
30	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	0	3.8	3.8	2.6	3.8	3.8	3	3	3	2.4	2.4	2.4
31	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	3.8	0	3.8	2.6	3.8	3.8	3	3	3	2.4	2.4	2.4
32	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	3.8	3.8	0	2.6	3.8	3.8	3	3	3	2.4	2.4	2.4
33	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	3.8	3.8	3.8	0	3.8	3.8	3	3	3	2.4	2.4	2.4
34	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	3.8	3.8	3.8	2.6	0	3.8	3	3	3	2.4	2.4	2.4
35	5.6	5.6	5.6	7	7.8	7.8	7	2.6	2.6	3.8	3.8	3.8	2.6	3.8	0	3	3	3	2.4	2.4	2.4
36	3.8	3.8	3.8	5	5.8	5.8	7	3.8	3.8	3	3	3	3	3	3	0	3.8	3.8	3.4	3.4	3.4
37	3.8	3.8	3.8	5	5.8	5.8	7	3.8	3.8	3	3	3	3	3	3	3.8	0	3.8	3.4	3.4	3.4
38	3.8	3.8	3.8	5	5.8	5.8	7	3.8	3.8	3	3	3	3	3	3	3.8	3.8	0	3.4	3.4	3.4
39	6.2	6.2	6.2	7.4	8.4	8.4	8	3.8	3.8	2.4	2.4	2.4	2.4	2.4	2.4	3.4	3.4	3.4	0	3.8	3.8
40	6.2	6.2	6.2	7.4	8.4	8.4	8	3.8	3.8	2.4	2.4	2.4	2.4	2.4	2.4	3.4	3.4	3.4	3.8	0	3.8
41	6.2	6.2	6.2	7.4	8.4	8.4	8	3.8	3.8	2.4	2.4	2.4	2.4	2.4	2.4	3.4	3.4	3.4	3.8	3.8	0