

MASTER

Amsterdam, infrastructure and transit oriented development

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Amsterdam, Infrastructure and Transit Oriented Development



Amsterdam,

Infrastructure and Transit Oriented Development

Eindhoven University of Technology

Department of the Built Environment
Master Architecture, Building and Planning
Specialization Urban Design & Planning
Master Thesis



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Preface

In this report I present my graduation project Amsterdam Infrastructure and transport oriented development which is the final part of the Masters Architecture, Building and Planning with the specialization in Urban Design and Planning at the Eindhoven University of Technology

This project has been carried out under supervision ir. A.W.J. (Aloys) Borgers, Prof. dr. T.A. (Theo) Arentze and dr. F. (Feixiong) Liao. I would like to express my gratitude to the members of my graduation committee, for their support and feedback throughout the project. Additionally, I would like to express my gratitude to Tony Maas for his help and explanations of the multi-state supernetwork model. Also I would like to thank all the members of the Graduation studio Amsterdam for their feedback and support during the project. Finally, I would like to thank my friends and family who have supported me over the course of my study and this graduation project.

Thomas Galetzka,
Eindhoven, August 2015

Abstract

The infrastructure of the Amsterdam metropolitan area is constant changing due to new developments and trends. One of these new developments and trends is Transit Oriented Development (TOD). TOD is a relative new phenomenon in the Netherlands, but since 2012 there is a movement to introduce a Dutch approach of TOD. The province of Noord-Holland has launched a program investigating the potential of TOD in the province.

This study investigates the effects of a Transit Oriented Development at a node in the Amsterdam transportation network. This to support policy makers in their decisions regarding future developments and to test likely effects of these new policy measures and developments.

Transit Oriented Development is a planning concept that encourage the development around a transit station. These developments which are concentrated within eight-hundred meters around a transit station and consist out of land use developments and focus mainly on densification and mixed use functions for more efficient use of the land capacity around the transit station. Next to that there are interventions that influence the travel behavior and accessibility by public transport, this to help reduce the car usage and to stimulate the bike use and ridership.

In order to assess the likely effects of TOD an activity based transportation demand model has been used. The recently developed multi-state supernetwork model by the Eindhoven University of Technology has been used to simulate likely effects on the transportation network of the Amsterdam area. In this model for each individual an activity diary is used, which will be projected on a network of roads and land use locations in the model. With this projected network the model can calculate the optimal activity-travel patterns for a specific scenario. The effects of different policy measures regarding land use and transportation then can be analyzed. Different scenarios can be generated in order to compare the results of these scenarios.

For the Amsterdam region databases had to be created to use the multi-state supernetwork model for this region. These databases concern the road network and the Public Transport network in terms of timetable, stops and connections. In addition, a land use dataset with information regarding land use, available floor space and parking prices had to be prepared. Furthermore a database of the individual activity programs and individuals profiles was created. To assess the effects of policy measures, these databases had to be adapted accordingly.

To investigate the effect of TOD on a node in the Amsterdam transportation network, a focus area around the Buikslotermeerplein in the district Amsterdam north was selected. This area lacks good infrastructure and is only connected with a few bus lines and roads to the rest of the metropolitan area. Options for redevelopment of the area including constructing a new light rail metro line and into the area as proposed by the local public transport company and the municipality offers this area great opportunities for new transit oriented developments.

According to the TOD principles different policy measures have been considered for the focus area. These policy measures include medium and high density mix-used land use developments, new public transport infrastructure such as the new North-South metro line and improvement of the current High Quality Public Transport (HOV) system and changes in the parking prices policies. These policy measures have been combined into seven combinations which are used as scenarios for the focus area. The likely effects of these scenarios have been assessed by simulation with the multi-state supernetwork model.

The results of the simulations show that the individual public transport and land use policy measures at one node in the network have relatively small effects on the indicators considered for the entire Amsterdam Metropolitan Area. These indicators concern the modal split, total distance travelled, average distance of all transport modes, travel time and public transport travel time. However, there are changes noticeable in these indicators for the focus area in the Amsterdam North area.

In the Amsterdam North area, the new North-South metro line and improved HOV-bus lines generate more movement in and usage of the area. Next the use of the areas around the stops along the new metro line increases which is a result of the new metro line providing better connections with the inner-city and northern district of Amsterdam. Also the results show that to influence an individual's travel behavior, parking prices seem to be the most effective way to affect car usage in an area. Furthermore, the results show that separate measures like increasing land use or improving public transport infrastructure have their individual effects. However, combining these policy measures according to the principles of TOD generates a stronger effect.

Therefore, when the municipality of Amsterdam wants to plan to develop Amsterdam North into a new transit hub according to the principles of TOD around the Buikslotermeerplein and Station Noord there is need to develop a plan that consist of a combination of infrastructure, housing, and other developments. These developments need to be of a sufficient but realistic size in order to attract people, businesses and enterprises to this part of the city. Of course, the decision to implement Transport Oriented Development not only depends on land use and transport policies. Many other effects have to be investigated and policy makers and stakeholders have to agree on implementing such developments.

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Chapter 1

Introduction

The infrastructure of the Amsterdam metropolitan area is constant changing due to new developments and trends. But the infrastructure is also changing because of the urban developments in the city and demographic, societal, climatic and technological changes in general. One of these new developments and trends is Transit Oriented Development (TOD).

Transit Orientated Development is a relative new phenomenon in the Netherlands. Calthorpe(1993), an American architect, first mentioned TOD in one of his papers and described it as the development around train station with a mixed use and focus on improvement of accessibility and transit, to reduce car use and focus on the use of bike, train, light rail, and feet. Since 2012 there is a movement in the Netherlands of focusing on a Dutch approach of TOD. The province of Noord-Holland (Provincie Noord-Holland, 2010) has launched a program investigating the potential of TOD. The province has asked the Deltrametropool organization (Deltametropool, 2013) to help with the initial analysis.

So what if these trends set out by the province continue and the Amsterdam Metropolitan Area is going to implement the concept of TOD, how can policymakers know what to do? And what will be the consequences of their decisions? To help policy makers with these problems the following research question is formulated.

For urban planners it is important to support policy makers in their decisions regarding future development of the city. To help urban planners assessing the likely effects of transport related policy measures, transportation models can be used. With these models future policies can be analyzed and tested on the effects they will have on the future transport and land-use system.

1. 1. Research question

This research will focus on the effects on the transportation network of the Amsterdam Metropolitan area in the case of transport oriented urban development around a node in the current network. First, it will be decided whether a new node will be added to the network or an existing one will be redeveloped. Subsequently the data and scenarios for the new development will be created and analyzed. The result of the research is an advice for the municipality if they want to implement the concepts of TOD at the selected node. The results will show the consequences regarding the Amsterdam transport network.

Research question:

“What will be the effects of TOD development at a node in the Amsterdam transportation network?”

This research will be done with the help of the multi-state supernetwork model, recently developed by Arentze and Timmermans (2004) and extended by Liao (2013). This model analyses the movements on the transport network based on the travel activities of the population and every possible decision they make regarding their travel activities such as choice of locations, route choice, and choice of transport mode.

1.2. Outline

The thesis is subdivided into seven chapters. After this introduction, a brief overview of Transit Oriented Development (TOD) will be given in chapter 2. Both realized developments abroad and current and future projects in the Netherlands will be discussed. Next, chapter 3 presents a general overview of some of the most important transport models that have been developed by several researchers in the past. Chapter 4 presents the study area and the location selected for future transport oriented urban development. In chapter 5, the model used in this research and the data required to run the model will be explained in more detail. Chapter 6 the model estimation and the different scenarios that may be developed will be discussed in this chapter. The thesis ends with conclusions about the implementation of transport oriented development in the Amsterdam Metropolitan Area, a discussion of the research findings and suggestions for further research.

Chapter 2

Transit Orientated Development

The concept of TOD was first mentioned by a American architect Calthorpe(1993). Transit oriented development (TOD) is defined (De Vos et al, 2014) as: “where compact, mixed-use neighborhoods are being realized around existing or new public transit stops.” Although there is no single definition that can fully capture the TOD concepts in their many forms, most of them share common characteristics. The main characteristics of TOD are proximity to a transit station or a node in a transport network and a mix of land uses. A node is defined by Deltametropool(2013) as: “*a place where different modes of transportation meet and a variety of urban activities take place*”. It is expected that transit oriented developments stimulate and increase ridership. To get a better understanding of TOD this chapter is organized as follows. First, a historical context of TOD is presented. Next, TOD in the Netherlands will be discussed. Finally, a summary of transit oriented development concludes this chapter.

2.1. Historical Context of TOD

In the early twentieth century the first commuter or transit lines were built. These lines were the tram lines and they were typically built by a single owner or company to add value to a residential development by providing a link between the city centre and the suburb (Tan, et al, 2013). The tram lines had many stops and a small service area to support the local residents and the commuters. This can be seen as an early representation of the modern TOD. These early days of the development of transit use, were also named “development-orientated transit” (Belzer, Aulter, 2002).

In the post-World War Two period transit use decreased and many rail systems were abandoned and dismantled. The remaining transit was still in operation but was heavily focused on buses as the primary travel mode (Curtis, 2008). As car congestion worsened a new generation of transit systems was planned and built in the early 1970s. These new systems were built to relieve congestion and designed to work with the automobile, with the assumption that most people would drive a car rather than walk, bike or use the bus (Tan, et al, 2013). These years can also be described as the “auto oriented transit” period (Belzer, Aulter, 2002).

Recently, the interest in TOD increased because policy makers realized that TOD brings more than just land added value. The last few decades saw a subtle shift in the transit and development landscape, with trends as: growing transit ridership, increased investments in transit, smart city growth and reducing car use (Curtis, 2008; Belzer, Aulter, 2002). But also people recognize the advantages of linking developments and transit.

In the 21st century Transit-oriented development can be a central part of the solution to a range of social and environmental problems such as car congestion, pollution and neighborhood revitalization. When implementing TOD, different aspects should be considered: location efficiency where the neighborhoods provides good transit connections, reduce car use and ownership and the ability to live, work and shop within the same

neighborhood. Next value recapture, where the effects of the location efficiency results in reduction of individual and community spending on transportation and therefore changes for additional spendings in the community and public space.

Also TOD can help with the liveability of a neighborhood with direct and indirect relations as air quality, increased mobility choices and better health and public safety. Another aspect is the financial return where TOD projects can give a positive financial outcome for the different actors and investors. Next, different options for the inhabitants can have in a TOD neighborhood. The last aspect concerns the regional land-use patterns where these patterns need to be more efficient to support the concepts of TOD. (Belzer, Aulter, 2002).

Next to that the policy maker can use planning concepts as proximity to the transit station (e.g. within 800 meters or a ten minutes walk), a mixture of residential, retail, commercial and community use in the area, with the offices and retail close to the transport hub and residential and community functions further away. In addition, pedestrian orientated developments may stimulate people using more alternatives to the car and reducing parking space near the town centre or station. High accessibility to the transit station and a frequent and rapid transit service may stimulate the use of alternative transportation modes (Tan, et al., 2013). These performance concepts can help creating viable plans.

2.2. Developments in the Netherlands.

In the Netherlands TODs have recently started. Several different organizations and governments are working on implementing the concepts of TOD. These developments range from an analysis of the potential developments to the development of a corridor.

The first TOD in the Netherlands was in the early 1970s when Zoetermeer with a local light rail line was connected to The Hague. After that other major cities in the Netherlands and their surrounded villages were connected with a regional or local (light)rail line (Tan, et al, 2013). Since these first developments the public transport system expanded and new opportunities for TOD came into existence. In the late 1990s the government highlighted six rail projects in de regions of Achterhoek, Zuid-Limburg, Arnhem/Nijmegen, Utrecht, Leiden and Den Haag/Rotterdam (van der Bijl, 2010; Van der Krabben, et al, 2013). These projects were developed by the government. Although the term TOD was not explicitly mentioned, these projects can be considered as major TOD projects. From the 2000s the concept of TOD became more important for policy makers.

So TOD in the Netherlands according to the strict American definition barely came into existence (Tan, et al, 2013), but in the last thirty years a good base was constructed and with the existing rail infrastructure and the regional infrastructural developments there are a number of opportunities for spatial development around transit stations.

But why is there no real Dutch TOD? This is because there are several barriers that prevent these kind of developments. These barriers are formal and informal (Tan, et al, 2013a). Formal barriers are related to the question "Who is in control?". Since the institutional sectors are really fragmented it is not clear who is responsible and which role each participant has. On top of that there is the financial barrier.

The informal Barriers consist of low support of public transport, this is because social and political communities mainly focus on short term effects and PT is subjected to the long term with a minimum of 15 to 25 years until effects are noticeable. Next to the lack of support there is a lack of communication between the involved parties which act as another barrier between the parties involved.

These barriers lead to the fact that working together and synergy is almost impossible. To counteract these barriers Van der Krabben, et al., (2013) gives several ways to stimulate the use of TOD in future developments. These stimuli entails combinations of judicial, financial and socio-cultural factors as lowering taxes, to force the incorporation of TOD into new legislation and visions, and financial benefits for TOD-programs. But after all these stimuli it is all about changing the mentality of the socio and political environment to transform the current situation into a more sustainable, livable and better future.

As one of the recent developments of TOD in the Netherlands, the Deltametropool organization was commissioned by the province of Noord-Holland(2010) to make a preliminary study of transit orientated development in the province of Noord-Holland. This province recognized that it has an extensive network of public transport lines and highways which can be utilized more effectively. So the Deltametropool organization made a strategic plan (Deltametropool, 2013) for the most important nodes in the province. This strategic plan is based on ten principles:

- 1) Increasing frequency of public transport services and spatial development mutually reinforce each other.
- 2) Realize at least 50% of the newly-built homes within the catchment areas of stations.
- 3) Prioritise existing land use plans within the urban growth boundary around stations.
- 4) Align the urban growth boundary with the transit orientated development strategy.
- 5) Reduce the number of vacant offices in areas that are not multimodal accessible.
- 6) Focus on the quality of working environments in the most accessible locations.
- 7) Locate regional facilities preferably at multimodal, accessible locations.
- 8) A smoother transfer between modes of transport.
- 9) Develop nodes as Gateways to the countryside.
- 10) Make space.

These principles express the opportunities for new policy for housing, working and other functions in combination with good accessibility.

Next to these principles the organization has used the “butterfly” model, see Figure 1. This model is based on the node-place model of Bertolini (1999). The butterfly model has six features to analyze the transportations nodes in the network. These six features consist of three node features on the right side of the model: position of the node in the transportation network, the road network and the slow traffic network. The three features on the left side are related to the place: density of inhabitants, employees and visitors, the proximity to the station itself and degree of functional diversity.

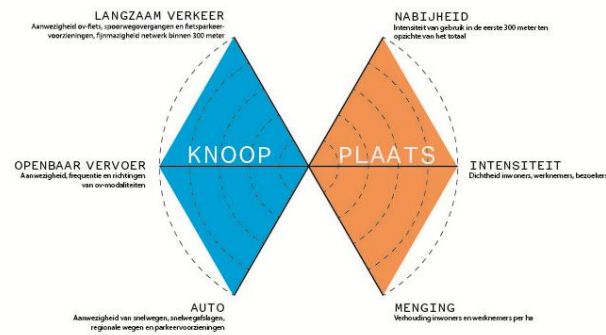


Figure 1. Butterfly Model, Deltametropool(2013)

Depending on the outcome of each of the six features, twelve ideal situations have been developed. These situation are used to discover what each node requires for future development. In reality many nodes do not even approach the most promising ideal situation. The butterfly model can only function properly when both wings are well balanced. The position of the poublic transport network and the intensity of inhabitants, employees and visitors, both in the middle of a wing, should be in equilibrium with each other. The better the position of the public transport network, the greater the intensity around the node, and vice versa.

Another factor within the Noord-Holland transportation network is that TOD can be realized at a corridor level, for example a railway line that services a region. For the Amsterdam region the Deltametropool distinguishes several corridors. Ring Amsterdam A10, the Zaancorridor, Schiphol-airport Corridor, Amsterdam-Almere-Lelystad and Amsterdam-Utrecht corridor.

Also the Dutch government decided recently to stimulate developing transport hubs. As part of the Ministry of Infrastructure and Environment, KiM, the Netherlands Institute for Transport Policy Analysis was asked to provide an overview of the possibilities for the national government providing directions to the development of hubs (Kennisinstituut voor Mobiliteitsbeleid, 2012). The KiM made an analysis of the transportation network of the whole Netherlands to see what are the most important hubs, which are Mainports Port Rotterdam and Schiphol. To analyze the network the KiM used the node-place model of Bertolini (1999). Next to that the KiM distinguished between passenger traffic and freight traffic but also between air, water and land transportation to analyze the current cases of TOD. To analyze the land nodes, KiM used six different types of nodes (Peek, 2006) focussing on the size of the node and the place in the city.

The national government is not able to control every aspect since there are several stakeholders involved such as provinces, municipalities and the private sector. So, the role of the national government regarding particular hubs is limited, However, the national government may affect policy regarding hubs in a network. This means that the government has a more coordinating role in which the government can give directions if it appears that provinces or municipalities are too unfocused in their stimulation of transport hubs. This role can also influence real estate development if there is a conflict with the transportation hub functions.

2.3. Studies

Beside the analysis of the current state and possible TODs in the Netherlands there are several studies done on the subject of TOD. These studies are done by researchers around the world. In this section a short overview will be given of these studies starting with typologies of TOD. Following the typologies other studies regarding TOD will be summarized.

2.3.1. TOD Typologies

Most research into TOD starts with categorizing the different nodes within a transportation network. Categorization of nodes into typologies helps with the planning, design, and policy making. It helps underpinning policies for different types of TOD and to create a common set of strategies or plans for transforming the nodes into a TOD location. The classifications also helps to identify potential developments and opportunities and necessary future adaptations within a metropolitan area. Classifying nodes into a typology is a way to group together areas that have common characteristics.

Over time there have been several different typologies developed. Most of these typologies have been developed according to their own context and their specific development area but these typologies can also be transformed for general use although can may lose their relevance. The early typologies of TOD were based on the attributes walkability, vehicle miles travelled or connectivity of the node. As one of first models of TOD Bertolini(1999) developed a conceptual framework of a Node-place typology of TOD (Figure 2). This model is based on train stations in Amsterdam and Utrecht, the Netherlands. In this model a node-index is made for each station based on connectivity, frequency and diversity of the transport services.

Bertolini indentified five types of the nodes within the node-place model. With these types the relation between the transport system and the spatial use of the nodes are the important factors. These types are represented in Figure 2. The first type is Accessibility, in which an area is both an accessible node and place. Here is the accessibility of a place take in account the number of connections to the node and how diverse the activities are at a place. An accessible area can be seen as an area when many different people can come to the area but also an area where people can do many different things.

Next is Stress, an area is under stress where the intensity and diversity of infrastructure and activities come close to their maximum potential. This means that this area is a strong location where there is a high demand for human interaction. But this also means that there is high chance of conflicts since there is limited space. Followed by Dependency, where there is no competition for free space. There is enough free space to develop due to the low demand for transport services and activities from the area inhabitants and companies. As a forth characteristic, the Unsustained places where in the area there is a relatively high demand and development of the urban activities of a place but the infrastructure demand is relatively low. Finally, the Unsustained nodes where the opposite of the unsustained places is true with an area where there is a relatively strong infrastructure demand and more developed infrastructure than the urban activities.

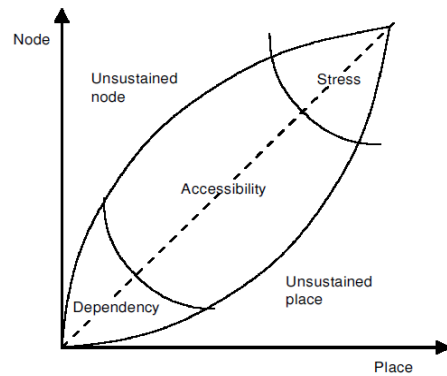


Figure 2. Place-Node model (Bertolini,1999)

Belzer and Aulter(2002) created a framework for typology of TOD for different types of stations in their respective contexts. The main criteria are scale (large city, small city and town), locations within the metropolitan area (central city, peripheral city and commuter town), transit type (commuter rail and frequent light rail), and other key attributes.

Peek (2006) made an classification of the railway stations (Figure 3). Since the nodes that will be chosen for TOD are often a railway station. There for this classification can be used to categorize nodes for a TOD location. Although, in this study there are more other locations in the study area thus making this a less relevant classification. Peek has classified the stations on two variables: the position in the city and the type of train. This results in six types of stations in the Netherlands.

Status	Place		
	Centre	City edge	Rural
Mst/IC	Type 1		
Intercity, sprinter	Very large station in center of a major city		
Intercity, sprinter	Type 2. Large station in center of a medium-sized city	Type 3. Suburban station with hub function	
Sprinter	Type 4. Station at a center of a small town or village	Type 5. Suburban station without hub function	Type 6. Station in a rural area close to a small town or village

Figure 3. Classification Typologies (Peek, 2006)

De Vos et al. (2014) made a general typology of TODs based on the initial stage of developments. This classification has been made in order to determine the dissonance between actual preferred development. This dissonance, in different levels according to the typology, will make it clear how residents adapt their attitudes to the new situation with respect to transport mode or the mix use developments. These types can also be used to restrict further urban sprawl or determine the potential of future public transportation developments. The classification consist of 1) new TODs with a development of a new neighbourhood around a new public transport service; 2) high-density TODs with a new public transport service in a compact, mix-use area; and 3) low-density TODs where there is a increased density and diversity around a new public transport service (Figure 4).

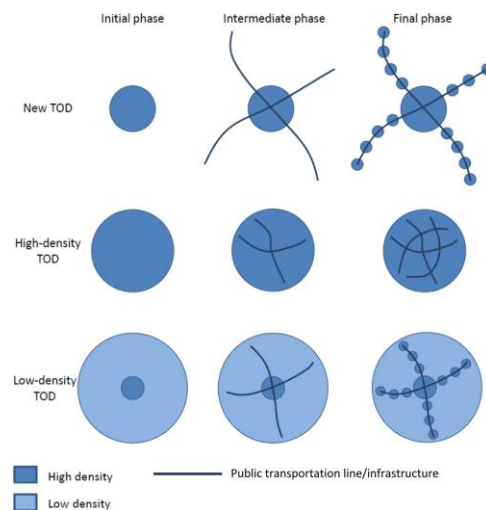


Figure 4. Classification Typologies (Vos et al, 2014)

Kamruzzaman et al. (2014) created TOD typologies based on a local case study in Brisbane, Australia. Kamruzzaman developed these TOD typologies because the existing TOD typologies are based on different contexts and a subjective evaluation of the context, Therefore, they are not useful for general use. Based on the local census and a ML regression model and analysis of the region four unique TOD clusters were recognized: residential TODs, activity centre TODs, potential TODs, and non-suitable TODs.

The residential TODs are neighbourhood areas in which the residential neighbourhood meet having the quality of a residential TOD, with good quality public transport and road connection, but also the housing density criteria specific to the area. Also in these area there are more than two type of land uses present which results in a relatively low employment opportunities in these area.

The potential TODs are areas within a city or region where there is a node that has the potential to develop into a new TOD. These area are within proximity of a transit service but there is still need to increase facilities also there can be a need for more dwellings. Activity centre TODs are areas where there is a high average net employment density. The density is required to successful operate an activity centre, although the study does not specify the total number of jobs. In addition to the employment density these neighborhoods also possess good quality public transport services and well-connected road networks.

Non-suitable TODs are area where they do not qualify for a TOD development. This is because the area do not have a sufficient road network, public transport connectivity levels or other place-related qualities as the sufficient density.

2.3.2. Other studies

Besides the typologies of TODs there are several other studies with a broad range of subjects. These subjects range from travel behaviour and transport mode use to the impact on property value.

The research into travel characteristics of TOD by Lund, Cervero and Wilson (2004) describes the characteristics in the case of the US state California. The rapid growth of in the urbanized areas of California creates many challenges in the transportation and land-use areas for policy makers. Lund, Cervero and Wilson examined current TODs and assessed their success of enhancing ridership and to understand the changes in accessibility of transit hubs and roadway congestion. The study supports the recent efforts to improve the effectiveness of TOD developments in California. Also the study assesses the likelihood of using transit in relation to travel behavior. This is done to give a more comprehensive understanding of travel decisions within TODs where the research findings concludes that TODs have a higher rate of transit use. With this transit use, TOD residents commute more trips work related than non-work travel. Next the research provide some recommendation to stimulate further developments of TOD by the regional planning entities. The research state that increasing ridership an important objective of TOD but not the only one. The policymakers should focus on other developments such as widening housing choices and providing affordable housing. Also improving the streetscape and design around the transit stations may influence the residents and ridership. Also the policymakers should emphasise on the role of parking supply, pricing policy, and employer worksite policies since they are the key influences on commuter mode choice in TODs.

Another study of travel behavior by Boschmann and Brady (2013) describes the Denver metropolitan area, Colorado, USA facing an aging population. This means the cities have to change in order to provide this increasing population of older adults with sufficient transportation infrastructure to facilitate and sustain their quality of life. This means that the travel patterns and travel characteristics will change. Boschmann and Brady used a regression model to analyze the trips, distances, mode choices, trip purposes, and time of day travel characteristics for older adults. Also in this study the relevance of residential proximity to a TOD is considered and the impact TODs have on the individual travel behaviour of older adults. Conclusion of this study are that TOD does have a significant influence on older adult residents and their travel behavior. The older adults makes more trips on average but their trips are shorter and more likely to be by modes other than automobile. The preferred non-car transport alternative is walking that is preferred above the transit use.

In his study, Dill (2007) reports what travel mode residents of transit-oriented developments choose along the MAX blue line in the cities Portland and Gresham, Oregon, USA. The travel mode was analyzed based on a survey in the area. It appeared that in TOD areas residents in households with less than one vehicle per driver were far more likely to use transit. Workers at the TODs are commuting more regularly than workers in other areas of the city. Parking pricing influences commute mode split, but if people move into a TOD area there was almost no change in mode. Although this research was done in a specific area with its own characteristics, this study can be helpful to understand how people choose their travel mode and to change in the urban environment or regional policies, such as improvement of transit accessibility and changes in the parking policy addressing the pricing and availability. These measures can provide an increase in the use of public transport and ridership.

Another study was about the impact of new stations on residential and commercial property value (Debrezion, Pels, Rietveld, 2007). In this study the influence of several attributes of new railway stations on property value is analysed. The location of a station is a major factor influencing the value of property. Location selection is a frequently discussed topic. Another important factor is the accessibility. This is provided by different modes of transportation and railways in particular, which affect the property value. These factors along with other minor effects are used in a meta-analysis whether a new location has a positive or negative effect on property value in the area.

2.3.3. Type of Interventions

Next to the typologies of TOD, history and current state of TOD, there are several possible interventions that can be implemented into an existing network to improve the development around a node. Many cities around the world have adopted guidelines for TOD development and design. In these guidelines there are many different types of interventions but these are all based on similar core principles.

As one of the principles is land use development. These developments are located around a node or corridor with focus on the area within a five to ten minutes walk or around 800 meters from the transit node. These land use developments focus mainly on densification and mixed use functions (ITDP, 2014).

Interventions that facilitate transit use consist of medium- to high-density development that support the communities' daily needs including a mix of residential, commercial and retail services, jobs, community infrastructure and open space relevant to the context of the surrounding area. This densification allows for more efficient use of the land capacity around the transit station and also to make transit a more attractive travel option. (Cervero, 2002)

Another principle is to focus on travel behaviour and travel mode choice. In a TOD area this means that there are interventions to create a shift from using the car to an area where walking, cycling and using public transport are promoted and supported. But also the accessibility of the transit station with good connections is needed (ITDP, 2014).

Interventions that facilitate and influence travel behavior and accessibility of the transit node consist of creating direct pedestrian and bicycle infrastructure to and from transit facilities, or creating new public transport lines connecting the transit nodes. Other interventions are to increase the parking cost directly around the node or decrease the available parking spots (Translink, 2012). A study in California found that inhabitants of a TOD location were up to five times more likely to take public transport as their travel mode than people outside a TOD area (Lund, Cervero, & Wilson, 2004).

2.4. Summary

This chapter analyzed the development of transit oriented development. In the Netherlands the developments of TOD are in an early stage since the program was initiated in the last decade by the government, provinces and municipalities. A few projects have been finished but most of them are still in the process of policy making and realisation. Typologies of TOD nodes seem to be popular. These categorizations consider the location, type of developments and functions. In addition, travel mode and travel behaviour are major elements in TOD studies.

With TOD there are a broad range of interventions that can be realized. These interventions which are concentrated within eight-hundred meters around a transit station consist out of land use developments focus mainly on densification and mixed use functions for more efficient use of the land capacity around the transit station. Next to that there are interventions that influence the travel behavior and accessibility with incentives as parking cost or creating new public transport lines.

Chapter 3

Transport models

Since transit oriented Developments concern both land-use and travel, travel demand models can be useful. These models are used to make forecasts of the changes in travel behaviour because of changes in the transport network and land use according to proposed policies and plans. To be able to use such a model it is important to know the background of these models. So this chapter consist of as short overview of the major developments in transportation models. One of these models, the multi-state supernetwork model will be used in the remainder of this project. Therefore, this model and the data required by this model will be discussed in more detail.

3.1. Trip-Based approach

The trip-based approach is most conventional tool of travel demand analysis. The trip-based approach typically starts with to determine the number trips. This is followed by determining the attributes of the trips and then produce the demand forecasts. The trip-based approach has been embodied with the four-step model (FSM), This model has dominated in the manner personal travel has been modeled (McNally, 2007).

Four step model (FSM)

During the mid-twentieth century the need for transportation and land use models was recognized by transport and urban planners. The initial development of these models were done in the U.S.A. during the post-war era of development and economic growth. These initial developments led to a transportation model of trip generation and trip distribution and was first used in the case of the Chicago Area Transportation Study (Weiner, 1997). In this study the model used land-use projections and economical evaluations of the Chicago area to give a preview of the future travel on proposed facilities. Since the first application in the CATS the model has evolved fairly quickly into the now familiar four step model. The FSM has been modified and improved since the first applications but still uses the fundamentals set out in the early 1950s. This fundament is a trip-based transportation model in which trip generation, trip distribution, mode choice and route assignment are the four main steps (McNally, 2007). The first step, trip generation, determines how many trips each zone will produce or attract. In the second step, trip distribution, determines for each origin zone the destinations of the trips. The third step, mode choice, determines which transportation mode, car, bicycle, by foot, mass transit or other means, will be used to make the trips. In the final fourth step, route assignment, determines which route over the transportation network will be used when making the trips. The four step model has its limitations and weaknesses (McNally, 2007):

1. Demand for trip making instead of demand derived from activity participation.
2. Focus on individual trips and ignoring relationship between all trips and activities from an individual's activity pattern, so trip chaining is not properly modelled.
3. Do not reflect linkages between trips and activity.

4. Sensitive to aggregation errors. The misspecification of individual choice sets resulting in the inability to establish distinct choice alternatives.
5. Limited type of policies that can be analyzed.
6. The model is based on concept of utility maximization, thus ignoring the alternative decisions strategies of household dynamics, habit formation or choice influences.

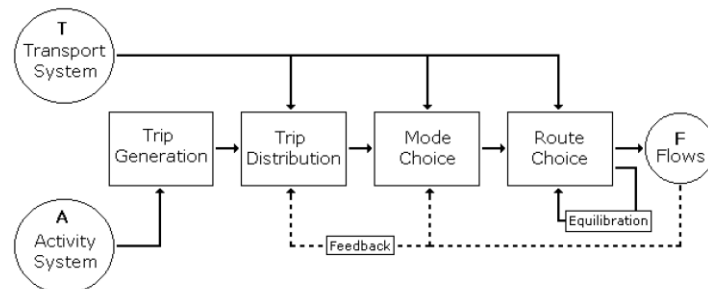


Figure 5. Four step model (McNally, 2007):

3.2. Tour-based Models

Tour-based models were developed to address the limitation that trip-based models do not consider the linkages between trips. These models group trips into tours based on the fact that all travel can be viewed in terms of round-trip journeys based at the home location.

The first tour-based models were published in the late 1970's and 1980's. The majority of these models have been developed in a European context such as The Netherlands (Gunn et al., 1987; HCG, 1992; Gunn, 1994), Italy(Cascetta et al., 1993) and Sweden(Algers et al., 1995). But there are also some models made for the American context for US city as Boston (Bowman and Ben-Akiva, 2000) or Portland(Bowman, et al., 1998).

All these models has some differences among each other but there are a few elements shared by the models. These are that they have reliance on a form of "tree logit", simplified definition of construction of tours, the models have an assumption of a main mode and explicit assumptions of car availability instead of car allocation.(Miller, et al., 2003)

The modelling of tour-based decisions provides an improvement over trip-based model systems as FSM, incorporating an explicit representation of temporal-spatial constraints among activity stops within a tour. However, in this tour-based approach has a missing link between multiple tours taken in the same day. This meaning that the tour-based approach failing to simulate the effects of inter tour temporal-spatial constraints.(Bowman, 2008)

Although the tour-based models help to solve some limitations of the FSM, this model has its own weaknesses and limitations (Sivakumar, 2007). The tour-based models suffer from a lack of behavioural realism on several points; these models:

1. often neglect trips made specifically to serve passengers
2. do not consider potential trade-offs across travel purposes
3. do not consider the effects of household interactions on travel.
4. do not consider the effects of in-home activities on travel.

3.3. Activity based models (ABM)

The conventional trip and tour-based models of travel demand forecasting have their weaknesses and limitation. Since the early 1970s brought a change in urban, environmental and energy policy, more advanced activity-based models were developed. The activity-based approach is based on the principle that travel demand is derived from activities spread out over time and space.

The works of Chapin and Hägerstrand form the basis of many of the research on activity based analysis. Chapin(1974) stated in his papers that the travel patterns and activity demands exists not only for their own rights but they are motivated by human desires, such as survival and social encounters. Hägerstrand(1970), emphasized that several constraints, capability, authority and coupling, strongly affects people's behaviour and limits individuals activity options. This translated into a concept of time-space prism in where the constraints of an spatial distribution and activities in space and time influence the individuals activity participation. These works implies that activity and travel scheduling decisions are made in the context of a broader framework. So an individual's activity pattern is influenced by both in-home and out-of-home factors as the household and other social structures. But also environmental and transportation constrains influences the individual's travel and activity behaviour (Sivakumar, 2007). Also, activity and travel decisions made by one individual are influenced by other people since people interact with each other. Therefore an individual's activity-travel pattern is influenced by those of other individuals within the population, and particularly by the activity-travel patterns of other household members (Bowman, 2008). Thus the choice process of any travel decision can only be understood and modelled within the whole context of the population and their agendas. Since the beginning of developing ABM attempts were made to broaden the range of forecasting models to incorporate activity and travel decisions spanning an entire day.

The first model that started to incorporate the activity based approach were published in the late 1970's and early 1980's. Lenntorp (1976) published the PESASP model which is a constraint-based model based on the theory of Hägerstrand(1970). This model uses all possible activity sequences for a defined activity program. These sequences are used in the model to generate a spatial choice set with a predefined set of environmental constraints. Using the PESASP model as a base, the constraint-based models of CARLA and BSP are developed. Jones et al (1983) developed the CARLA or Computational Algorithms for Rescheduling Lists of Activities. This model was one of the earlier scheduling based models. It uses a list of activity patterns and schedules to identify all the feasible schedules and activity patterns based on a certain set of constraints. Next, the model generates a feasible schedule of activities in time and space. BSP (Huigen, 1986) evaluates all possible sequences of activity-destination combinations.

Influence by the previous mentioned models STARCHILD was developed by Recker et al (1986). STARCHILD or Simulation of Travel/Activity Responses to Complex Household Interactive Logistic Decisions is a scheduling model which generate feasible activity patterns. The model assumes that the individual's decisions generates the activity patterns, based on

constraints such as travel and activity availability and feasibility. This model uses the concepts of utility maximization within a constrained environment.

During the mid 1990's, the development of activity patterns models continued and several of these models were made public with a wide variety of techniques.

In 1994 the SCHEDULER-model was developed by Garling et al(1994). This model is a computational process model (CPM) in where the scheduling process take into account the individual choices for activities, destinations for their agenda. The individual selects a set of high priority activities which is stored in a long-term calendar. These activities are then sequenced according to their priority and their locations and duration. The sequences of locations is done by using a nearest-neighbor heuristic procedure. After that the open time slots in the schedule is filled with lower priority activities derived from a short-term calendar.

Simulation Model of Activity Scheduling Heuristics of SMASH (Ettema, Borgers and Timmermans, 1993), is a CPM model in which is continues on the previous described SCHEDULER and STARCHILD models. SMASH starts with an empty schedule and step-wise, the activity schedule is adjusted by adding, deleting, rescheduling or stopping the scheduling process. These adjustments are based on the available alternatives and are repeated until a satisfactory schedule created.

COMRADE, COMpeting Risk model of Activity Duration and Execution (Ettema, et al., 1996) models the activity patterns in a continuous decision-making process to forecast the activity duration and timing of trips. The model specifically aims at the execution phase of activity patterns. Recker(1995) developed The Household Activity Pattern Problem or HAPP model. This model is a variant of the pickup and delivery problem with time window where it addresses the elements of ridesharing and vehicle-switching within a household.

PCATS or Prism-Constrained Activity-Travel Simulator (Kitamura et al., 1996) is a model system simulate the individuals activity and travel movements. This model uses the concept of Hägerstrand time-space prism and constraints. The simulation can be dived into two periods types: open periods where the individual has the option to travel or engage activities and blocked periods where the individual already committed to an activity. In this model it is assumed that the activity decisions are made sequentially, conditions and based on the past activities.

GISICAS (Kwan, 1997), is a simplified, operational version of the SCHEDULER model in which the difference lies in the incorporation of a geographic information system (GIS) to define the feasible opportunities with respect to their spatial context.

MASTIC or Model of ActionSpace in Time Intervals and Clusters((Dijst, de Jong, & Ritsema van Eck, 2002)) is a model in which the actions and activities of individuals are constructed within a number of temporal and spatial constraints. This model has similarities with the previous mentioned constraint-models as CARLA and BSP. This model differs with the others in the fact that it includes a travel-time ratio. But also that it works with a cluster algorithm instead of shortest route algorithm.

Another scheduling model is AMOS, Activity-MObility Simulator developed by Kitamura (1996). This model is a adaptation simulation system which simulates the changes in the daily travel patterns influenced by the change in the travel environments and the individual's choice

behaviour. Bowman and Ben-Akiva(2001) was published an integrated activity-based discrete choice model of individual's activity and travel schedules. This model is used these schedules and transforms them to an activity patterns with a set of tours. This activity patterns are used to forecast the urban passenger travel demand of a region.

Also in same period as of the late 1990's the technique of the microsimulation models continued to be developed. One of the first models to include microsimulation in its model was ORIENT-model, This model developed by Sparrmann (1980) simulates traffic flows based on individuals activity patterns with outputs the working-day passenger traffic within a predefined area. the model has been used in optimization of public transport networks and extension of retailing hours.

In 1995 the TRANSIMS (TRansportation ANalysis SIMulation System) was developed at Los Alamos National Laboratory. This model simulates individual travellers and their transportation behaviour. The model is based on a data-driven cellular automata microsimulation in which is can create and analyse a synthetic population, generate individual activity schemes and generate routes on a predefined network. (Barrett et, al., 2003)

ALBATROSS (Arentze and Timmermans, 2000) was the first computational process model of the complete activity scheduling process that could be fully estimated from data. ALBATROSS (A Learning-BASed TRansportation Oriented Simulation System) is an activity-based model of activity-travel behaviour that is based on choice heuristics that consumers apply when making decisions in complex environments. The model predicts which activities are conducted when, where, for how long, with whom, and the transport mode that is involved.

From ALBATROSS some additional models were developed in order to support or to additional analysis of this model. These are PATRICIA (Predicting Activity-Travel Interdependencies with a Suite of Choice-Based, Interlinked Analyses),a model was developed by (Borgers, et al. 2002) to help assess the performance of ALBATROSS and AURORA(Timmermans, et al., 2001) a complementary model of ALBATROSS in which the activity-travel rescheduling behavior is done with a utility-based model.

In SIMAP (Kulkarni & McNally, 2000)the foundation is made by dividing the population into groups of similar individual activity-travel patterns called, RAP(representative activity patterns). These RAPs together with activity attributes, as location and duration, are used to create a full-day activity patterns.

TASHA (Miller and Roorda, 2003) is a scheduling microsimulation model that simulate and generate activity and travel patterns for a twenty-four hour weekday for all the persons within a household. This model uses a rule-based method to organize activities into schedules for household members.

Another microsimulation that uses an underlying econometric models in order to simulate the individuals daily activity and travel patterns is the CEMDAP model (Bhat et al, 2004). This model is based on land-use, socio-demographics, activity systems and transportation level of service attributes which results in a complete daily activity patterns for each household member in the selected population.

The Florida activity mobility simulator or FAMOS (Pendyala et al., 2005) is a model that is based on two modules of previous developed models: HAGS and the previously described PCATS. HAGS is primarily used as a population synthesizer. Here zonal socio-economic and household travel survey data is used to generate the households and their members. Next to that HAGS also generate the agenda of fixed activities that the individual household member must accomplish within their agenda or schedule. In this model is also a location choice model included to identify the spatial location of the fixed activities. These two modules of HAGS and PCATS have been put together to form a microsimulation model system for the simulation of activity and travel patterns at the level of the individual decision-maker. By focusing on the individual decision-maker this model can analyze the travel demand in a region along a continuous time axis.

In the microsimulations also evolved with incorporation with land use and travel behavior. The Regional planning Model Based on the microsimulation of daily Activity Patterns, RAMBLAS by Veldhuisen, Timmermans and Kapoen, (1999) is one of these new models. RAMBLAS uses the given daily activity patterns and spatial distribution of dwellings are used to simulate to predict traffic flows in a transportation network for different times during a day. Thus help analyzing the likely effects of new land-use and transportation plans.

Another model that incorporate land use and travel behavior is the model by Salvini and Miller (2003). This model the Integrated Land Use, Transportation and Environment (ILUTE) simulates the evolution of an integrated urban system of people and their activity patterns, transport network, dwellings and commercial buildings and the job market over an period of time.

UrbanSim (Waddell, 2002) is the next step after the two previous mentioned models ILUTE and RAMBLAS in which there are attempts to build a combination of the integrate activity-based model with a microsimulation model of land use and transportation.

3.4. Multi-state supernetwork model

As previously mentioned, transport demand modelling has gradually shifted from single trips, via tours to daily activity-travel patterns. Still, there is the need for incorporating an increasingly larger share of multi-purpose multi-stop trips. This shift in perspective has led to the development of the multi-state supernetetwork model. This model is able to represent comprehensive activity-travel behaviour.

The multi-state supernetetwork model is based on several studies in network developments. Beckmann et al (1956) provided the framework for the analysis of transport between origins and destinations over networks. Further contribution was made by Dafermos(1972, 1976) who demonstrated, through a formal model how an abstract traffic network could be used to model multi-modal transportation. Later Dafermos(1981) included congestion in this traffic equilibrium model. This abstract network became later, with the integration of transit and road network into a new network called 'hypernetwork" (Sheffi and Daganzo, 1978). This hypernetwork was later renamed as a 'supernetetwork' by Sheffi (1985) in which the supernetetwork was constructed by adding transfer links at locations where people switch transport mode (see r and s in Figure 6). In this supernetetwork the mode and route choice is modelled simultaneously. In a study by Carlier et al (2003) the unimodal networks of transport mode and transfer locations are combined into a multimodal supernetetwork, see Figure 7.

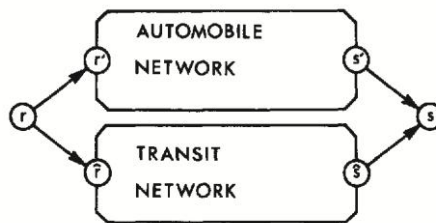


Figure 6. Supernetetwork representation (Sheffi, 1985)

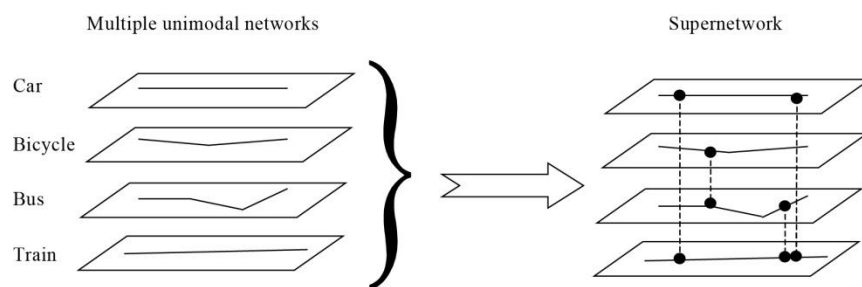


Figure 7. Supernetetwork representation (Carlier et al., 2003)

These were followed by other studies Nagurney et al (2000) where the option of telecommunication as a new virtual transport mode was proposed within the equilibrium framework of a multi criteria network proposed by Nagurney and Dong(2000). Although in this model the multi-modal trip chaining was not taken into account. However, all these supernetetwork models were only trip based therefore limiting their relevance for the activity-based approach.

Arentze and Timmermans(2004) took this idea of a trip-based supernetwork and transformed this into a supernetwork representation allowing to model tours as least-cost path through a network. This concept is represented in a multi-activity multimodal tours in a new multistate network (MSN).

A multi-state supernetwork for an activity-based program has been built by interconnecting an integrated land-use multi-modal transport network across every possible combination of activity and vehicle state. In the multi-state supernetwork, nodes are represented as real locations in space. The links between these combination consist of travel, transition and transaction links. (Liao, Arentze, & Timmermans, 2013). The supernetwork model is not yet a full-fledged activity based model. The model does not predict activity programs of individuals but rather consider this as given input.

Liao et al. (2013) took the basic concepts of the MSN-model developed by Arentze and Timmermans(2004) and continued developing and improving the multi-state supernetwork representation in which the network scale is considerably reduced without compromising the representation power of the previous versions. In this new representation the network is split into two types of network, a private vehicle network (PVN) and a public transport network (PTN). This split removes redundant nodes and links. It gives a more clear representation of the transition among activity-vehicle states. A further reduction was made by using a heuristic approach to generate the personalized PVNs and PTN.

These two personalized networks are based on the individuals activity program. From this activity program the persons activities are located within the network starting with the fixed activity locations followed by the location option of the flexible activities. Based on these locations the public transport connection, the parking locations and bike connections are selected. This all resulting that only a small set of locations are of interest to the individual. In Figure 8, the activities of these personalized network integrated in the supernetwork are represented in regard to the individuals activity program.

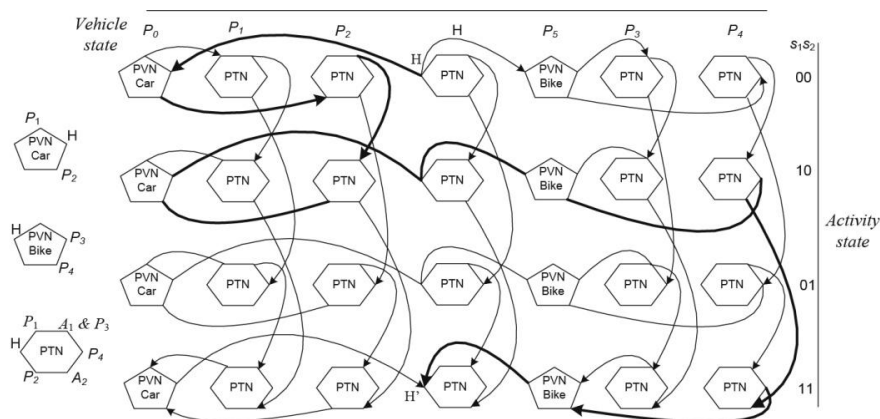


Figure 8. Multi-state supernetwork representation (liao et al., 2015)

Furthermore Liao (2013) extended the individual multi state supernetwork for the use of a two-person's joint activity program. Another feature that was added and integrated into the multi-state supernetwork model is the use of several new modalities such as ICT, E-bike and PT-bikes. These new modalities can expand the action space of an individual and thus potentially result in new types of activity-travel patterns.

Model limitations

The developments and applications of a multi-state supernetwork for ABM are still in an early stage and so this model developed by Liao(2013) has its limitations. Components that can be added to the supernetwork are a space-time constraints which can be embedded into the process of selecting the relevant locations in order to remove infeasible and inferior locations and thus removing unnecessary travel connections in the multi-state supernetwork representation. Another component is the duration or search-time and disutility profiles of activity participation and parking.

Datasets

In the multi-state supernetwork different datasets are used for this study, see Table 1. The road network is derived from the NWB, the Dutch national road database. In this are distinguished, namely local, regional and national roads. In this dataset the average speed is not included but these are assigned according their road type and information from open street maps.

Time table tables of public transport are also taken into account. These tables are derived from the 9292 organization, the Dutch PT route planner. The time tables includes bus, trams, metro and train connections. Also from this dataset the locations of the stops and connections are derived.

Table 1. Overview Datasets

No.	Dataset
1	Road network - Nodes and Links
2	PT timetable - Connections and Stops
3	Land use
4	Activity program
5	Individuals' profiles
6	Individuals' parameters
7	Home profile

The population of the study area comes from the MON/OViN database (Dutch annual survey for movements). People older than 12 years and with at least one trip are selected from this database to from the synthetic population of the area. Also from MON/OViN database the individuals activity patterns are extracted including the activity type, activity location and transport mode. Also from this database the individual profiles which personal details as gender, income and education level and the home profiles with postcode and location are generated.

In the land use dataset includes the available location for the activity are based on the information for the BAG-database (Dutch building geo-data). This dataset provides for each building in the study area the function and the available floor space. These factions are then converted into activity types and the floor space is use as an indication to measure the attractiveness of the site. Also in this land use dataset the parking locations and cost are included.

Application

With the application of the multi-state supernetwork approach the integrated land-use and transport scenarios on individuals travel patterns can be analyzed. From the previous mentioned datasets the supernetwork can extract the real locations. These are represented by the nodes from the road network dataset. The links of the road network dataset represents in the model as three categories. 1) *Travel links*: connecting different nodes representing the movements. 2) *Transaction links*: connecting the same nodes of different activity and 3) *Transition links*: where there is no change of location but change of transport mode or activities (Liao et al., 2015). For the whole network, a standard shortest-path routine is used to identify the most preferred path. With this routine some attributes may be time-dependent as factors such as congestions may influence the travel time of cars and the public transport. Finding the preferred path can be done on a personalized level since the data input as the activity program is on the individuals level and there are personalized parameters used in the model.

With the input of the daily activity patterns and the synthesizes population of the study area can the model generate the personalized PTNs and PVNs. In these personalized network the connections are derived depending on their specific network and attributes. The PVN connections are derived through a shortest travel time patch in a time-dependant road network for the entry node to the exit node. In the same way, the PTN connections are derived through a least-cost path in a time-expanded PT-network (liao, et al., 2015). With these generated networks the multi-state supernetwork module can find the optimal activity-travel patterns for a specific scenario. The effects of this scenario can then be analyzed and compared to the results of other scenarios. In the following flowchart (Figure 9) represents the application of the multi-state supernetwork approach in order to analyze planning scenarios (liao, 2013).

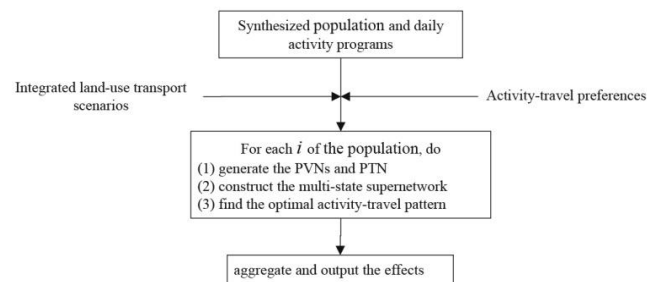


Figure 9. Flowchart of the application

3.5. Summary

The need for integrated land-use transport models to make accurate estimates of travel demand and to predict the effects of policies on travel demand has been long aware by local authorities. From the 1970s onwards these models gradually expanded from a four step model covering individual home based trips to a current state-of-the-art model that gives a representation of individuals' activity programs. This is caused by developments in available technology and the desire to counteract and solve the weaknesses and limitations of the earlier models. As one of these state-of-the-art models the multi-state supernetwork will be used in this thesis to analyse different scenarios. This because it is one of the state-of-the-art models and it integrates land-use, a multi-modal transport network, activity programs and individual characteristics.

Chapter 4

Study area

The study area of this study encompasses most of the Metropolitan region of Amsterdam in the Netherlands. The selected area includes the municipality of Amsterdam and the surrounding municipalities. Also the main connections to the major cities in the Netherlands such as The Hague, Rotterdam and Utrecht and also to the north of the province of North-Holland have been taken into account.

Prior to running a simulation with a transport model the study area will be described. As discussed in chapter 2, the transportation network is a main element of TOD. So in this chapter an overview of the current transport network is given. In addition, the current and future urban developments in Amsterdam are being discussed. Also an overview of the current major nodes in the network is given in this chapter. This is followed by an overview of the possible TOD locations within the study area. One of these locations will be selected as the focus area of this project.

4.1. The Amsterdam Metropolitan Area

The study area is the major part of the Amsterdam Metropolitan area. This metropolitan region consist of the surrounding municipalities around the city of Amsterdam as well as the cities of Almere and Lelystad. Also the Airport Schiphol is part of the region. The region has also its own administrative organization: the "Cityregion Amsterdam". This organization develops and approves policies and agreements which are important for the whole region. In this region there are several corridors in which commuters travel to and from Amsterdam. These corridors are the Ring Amsterdam A10, the Zaancorridor Amsterdam-Alkmaar, Schiphol-airport corridor, Amsterdam-Almere-Lelystad and the Amsterdam- Utrecht corridor (Figure 10).



Figure 10, The study area

The transport network of the Amsterdam metropolitan area consist of a range of different transport links for car, train, metro, bus and bicycle. In Figure 10 is clear that the main network is south of the river IJ, which crosses the city from east to west and divides the city in a Northern and a Southern part. The Figure shows that almost all of the infrastructure is located in the southern part. This is because of the historical development of Amsterdam that started on the south bank of the IJ. Another factor is that Amsterdam has connections to the other main cities in the Randstad and these cities are mainly south of Amsterdam.

The car road network (Figure 11) in Amsterdam shows a clear functional hierarchy. A primary network: motorways to approach the city and especially lead through traffic along the city. A secondary network, containing the Ring A10 which is particularly used for local and destination traffic, with transfer points for transition to urban public transport. Finally a tertiary network, with traffic streets within the city for local access completes the road network.

Next to the car road network there is an extensive bicycle network, see Figure 11. This network is according the Municipality of Amsterdam (2011) one of the fastest ways of transportation within the city centre. Especially in the city centre the bicycle network is very dense. Furthermore, each railway station has PT-bikes that can be used as an additional travel mode.

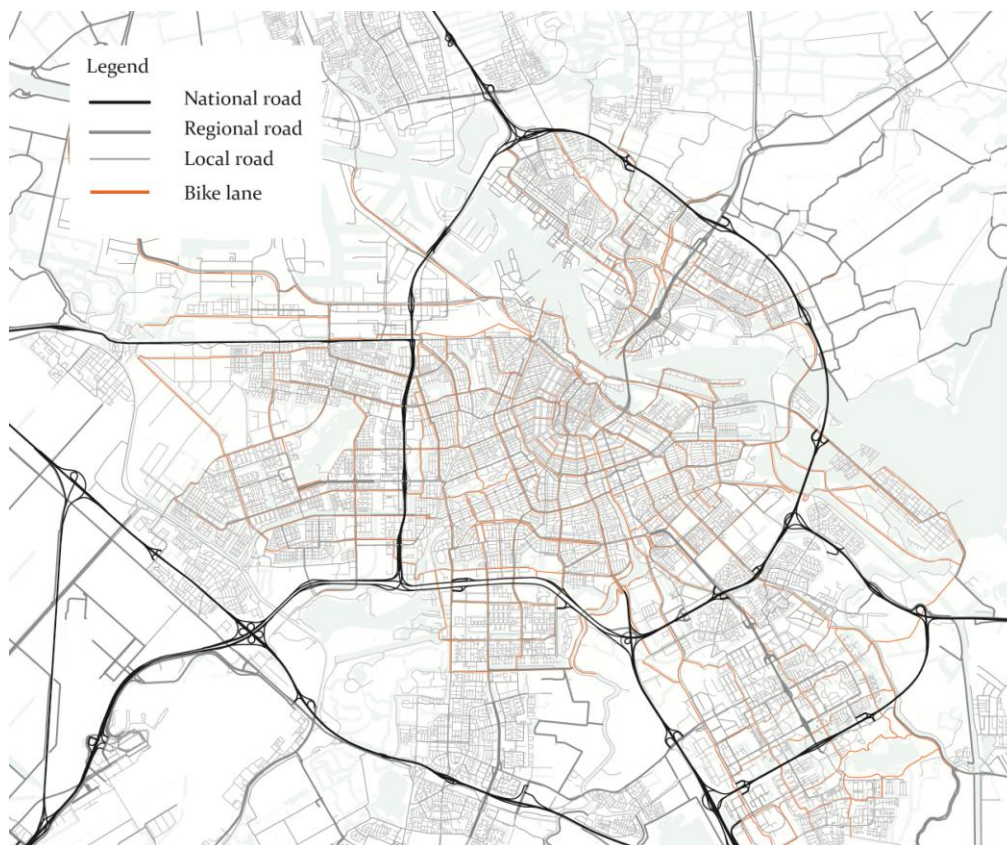


Figure 11, The Road and bicycle network of Amsterdam

Next to the private vehicle network there is an extensive public transport network. This network consists of different transport modes as train, metro, tram, and bus that focus on both the city and the entire region. In the inner city, public transport consists mainly of lines with frequent stops every few hundred meters. This is because there is a high residential density in the area. Further away from the centre the stops are further apart, what is to be expected in a more suburban area. This regional public transport is part of the R-NET, a public transport network especially developed for high end and fast transport within the Metropolitan area. The frequency of these regional lines are lower than in the downtown area where up to every five minutes one of the PT services departs from a station. Another regional and national public transport mode that connects Amsterdam with other cities is the train network. This network of Intercity-trains and stop trains connects Amsterdam with almost the whole of the Netherlands. In Figure 12 the public transport network of metro, tram and train is shown. The buses are left out because they use the road network.

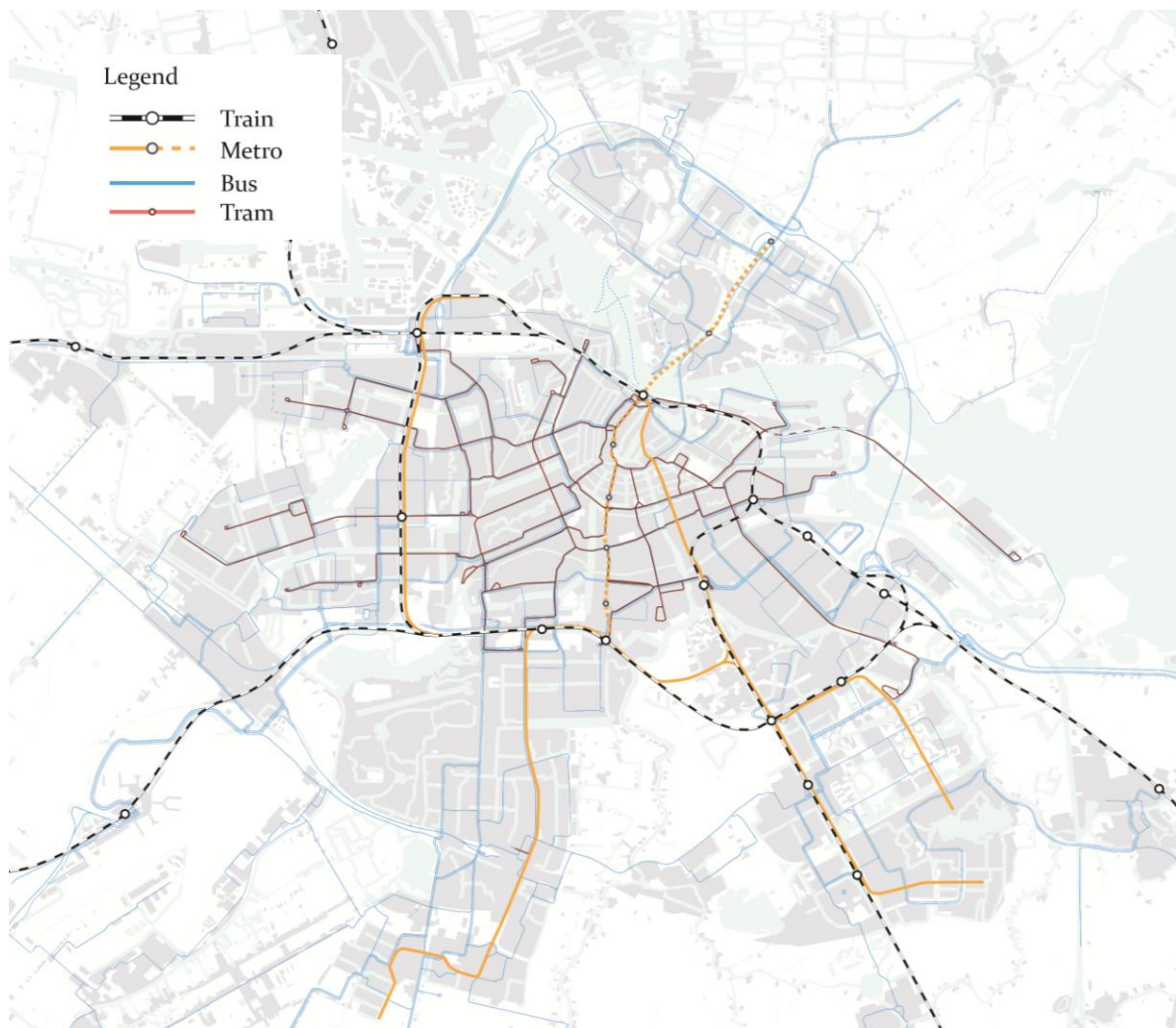


Figure 12, The public transport network of Amsterdam

4.2. New Developments

In the Amsterdam Metropolitan Area there are several developments going on. These developments are necessary in order to cope with the changing population of the city of Amsterdam but also with the change of the use of public transport and car in the future. Also the current infrastructure needs to be maintained en redeveloped. To be able to cope with these changes and developments several policy documents suggested different strategies.

The general vision of the whole metropolitan area describes a strategy for the next thirty years (vision 2040) to keep Amsterdam economically strong and sustainable (Gemeente Amsterdam, 2011). In this vision, intensifying land use in the city is one of the main policy measures. With this intensifying of the land-use further development and integration of the public transport network at metropolitan scale is required. Also the regional road network has to be adapted to the future growth of the Metropolitan Area, but within the city centre the options to expand are limited. These new developments consist of creating new and redeveloping high quality public transport lines and upgrading and expanding the rail and road network.

For the mid-long term the municipality has proposed a mobility policy which is based on the vision 2040. This mobility policy mainly focuses on traffic safety, traffic management, parking and the main routes (Gemeente Amsterdam, 2013). Recent developments in the city mainly cover changes in mobility needs. In the last decade the transportation within the ring has changed. The proportion of cyclists has grown from 40% to 60%, at the expense of public transport and mostly the car. In the city centre the use of the bicycle has grown from 15% to 25% at the expense of the car. Another trend is the decline of car use in peak hours and a growth in off-peak hours. To accommodate these trends, so called “plusnets” have been created for different transportation modes.

Besides the new policies, the municipality has already invested in big projects around the city (Gemeente Amsterdam, 2014). Some of these project are already in development. Among these projects that are currently in development are the North-South metroline, the redevelopment of the Amstelstation and the ZuidasDok.(see Figure 13)

4.2.1. North-South line

The North-South metro line (Noord-zuidlijn) is currently the biggest infrastructure project in the city of Amsterdam. The project entails the construction of a 9.7 kilometer long new metro line running from the Amsterdam-North district, underneath the river IJ via Amsterdam Centraal station to the Amsterdam Zuid station, which is planned to become the second biggest transport hub in the city (see also section 4.4). The line consist of a mixture of bored tunnels and immersed tunnels under the river IJ. The line is expected to be completed in 2017 and will transport around 185.000 people a day. The trip from north to south will take around 16 minutes which is substantial faster than the 31 minutes that it takes today (Amsterdam, 2014).

During the construction there have been several difficulties, mainly at Amsterdam Central Station which resulted in the project running over budget by forty percent. Also there was the risk of damaging the historical and UNESCO protected buildings in the inner-city of Amsterdam. These problems were partly caused due to mistakes made during the construction process (Amsterdam, 2014). In the future this line will be expanded to the south with the new Amstelveenlijn, a redeveloped metro line running from Amsterdam Zuid station to the south of Amstelveen. This last expansion of the metro system is currently on hold due to financial reason.

4.2.2. Redevelopment Amstelstation

The Amstelstation is now one of the major stations within the Amsterdam network with over 60000 daily commuters and with almost all the types of transport available at the station. The area itself consist of a mix of residential and offices with 10.000 jobs available. But this current situation of the Amstelstation is inconvenient and inefficient and also not sufficient enough to cope with future developments. This reason gave the municipality to plan major redevelopment of the Amstelstation. This redevelopment is more than only upgrading the station itself, the plan also include the development of office, community services and residential buildings within short distance of the station. Next to the buildings also the infrastructure will be redeveloped with new roads and bike lanes. But also the bus and tram stops will be relocated to form a new station. The construction of this plan is started in early 2015 and expected to be finished without any delay in 2023 (Gemeente Amsterdam, Projectbureau Wibaut aan de Amstel, 2010).

4.2.3. ZuidasDok

Next to the North-southline and Amstelstation, The ZuidasDok is a planned infrastructure project that involves a complete redevelopment of the Zuidas, the southern axis of Amsterdam consisting of highway, train, metro lines and a major business park and other facilities. These redevelopments have to ensure the accessibility of the Amsterdam South Axis and the northern part of the Randstad, both by public transport and by road. This will be obtained by expanding the Amsterdam Zuid station and the integration of regional and local public transport.

Also the highway A10 will be expanded from 2x2 lanes to 2x6 lanes. This expansion will realized by means of a tunnel in order to improve air quality and to reduce noise pollution at the centre of the South Axis. This creates opportunities for new residential developments right next to the business district of the South Axis. Currently this project is on hold due to financial problems. The construction of the plan is expected to start around 2017 if there are no further delays and problems.



Figure 13. North South metro line, Amstelstation and ZuidasDok

4.3. Nodes of Amsterdam

In the transport network there are several nodes, places where different modes of transportation meet. These nodes can be categorized according to their level of importance and connectivity. These typologies have been discussed in chapter 2. In the Amsterdam area there are 4 different types of nodes according to the classification by the Cityregion Amsterdam (2012), see Figure 14. The City Region came this classification depending on local importance, function and location within the city.

The first type is the A-location which are the internationally know locations. In Amsterdam there are 2 A-locations: Amsterdam Centraal station and Amsterdam Zuid station. Secondly, there are five B-locations, these are location that are the more important destinations for work or education within the city. Thirdly, the C-locations which are the remaining important infrastructure hubs in the city network. Finally, the D-locations which are the remaining important locations in the city.

As seen in the classification several locations are P+R (Park and Ride) facilities. This means that visitors who come to Amsterdam by car can park their car further away from the city centre and can travel to the city centre by public transport. These facilities help to relieve the already stressful inner city of additional car traffic. This also reduces car-use in the inner city.

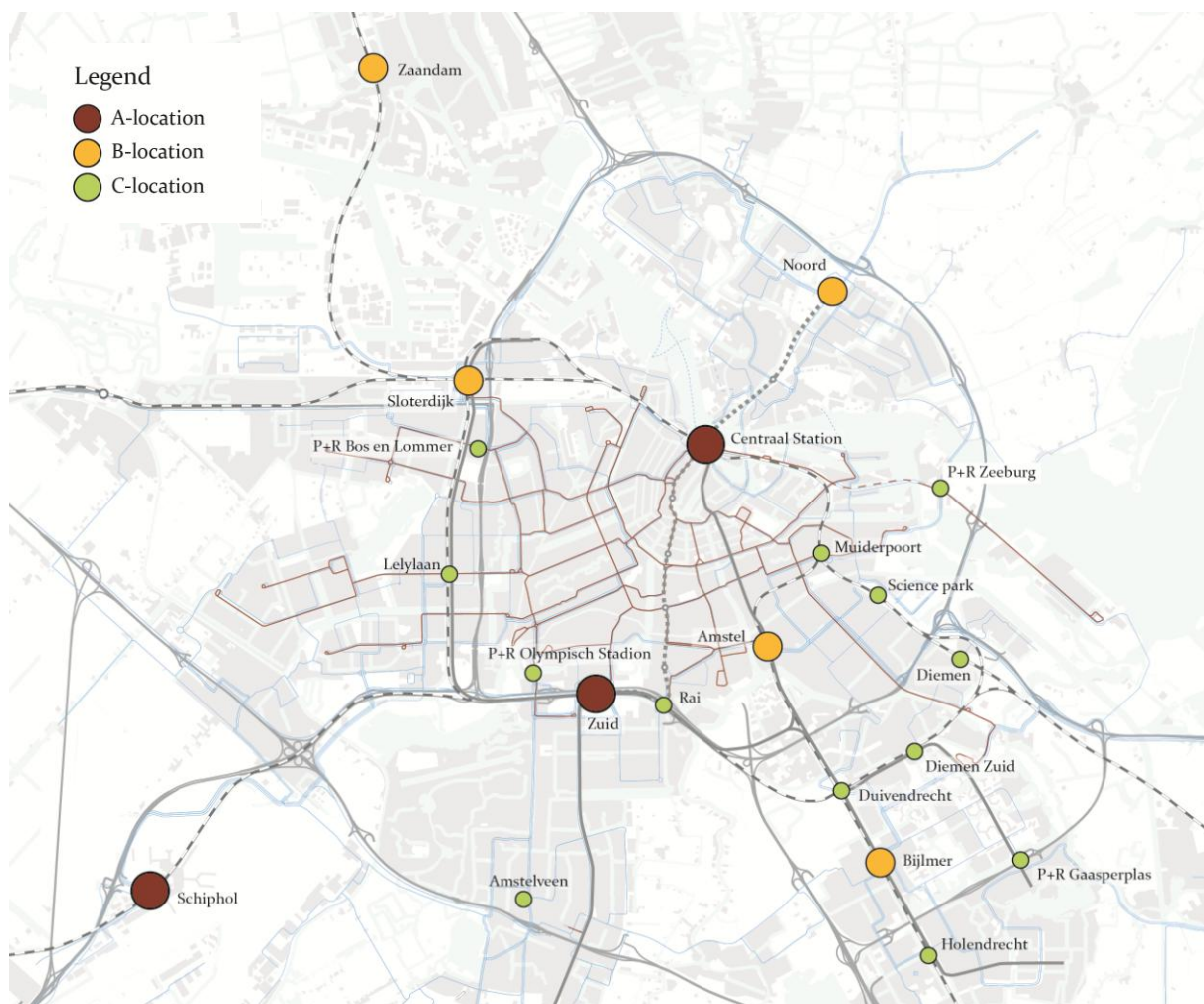


Figure 14, The classification of the nodes according to the City Region Amsterdam.

4.4. Focus area

As stated in the beginning of this thesis the research is about what the effect is of a new node in the transport network of the Amsterdam Metropolitan Area. This chapter discussed the transport network of the area. In order to choose a location to implement TOD related scenarios in Amsterdam, a selection of interesting locations was selected. The current infrastructure network of Amsterdam has a few areas that can benefit from further development. By applying the typologies of Kamruzzaman et al. (2014), see section 2.3.1, on the classification of city region, Figure 13, there several areas or nodes that are qualified for further TOD.

The potential TOD are the nodes proximity of a transit service but there is still need to increase facilities also there can be a need for more dwellings. In the Amsterdam area these are the area around the Amstelstation and Amsterdam north around buikslotermeerplein.

Next to the potential TODs there are some existing TOD. These existing residential TOD and activity TODs are areas where there is already some development but still room for future developments. In Amsterdam these area are the area of Bijlmer and Arena, Schiphol area, the Zuid-as and the Sloterdijk area. The rest of the nodes qualify as a TOD non-suitability, since there is less demand for further developments or a lack of infrastructure.

From the potential TOD locations, the area of Amsterdam North is the most suitable for the focus area of in this thesis(Figure 15). This because the area lacks a lot of infrastructure and is only connected by a few bus lines and roads. Taken into consideration that the old industrial areas in Amsterdam North have to be redeveloped, this area offers great opportunities for new transport oriented development. In addition, the Amsterdam local public transport company GVB and the municipality are developing and constructing a new light rail metro line to this area. This line will improve the accessibility of the Amsterdam North area. This is an essential condition for TOD. Therefore Amsterdam north is chosen to be the focus or study area of this study.



Figure 15, Focus area: Amsterdam North

4.5. Summary

The study area of the thesis is the Amsterdam Metropolitan Area. This metropolitan area consist out of the city of Amsterdam and the surrounding municipalities. The area has an extensive car network and bicycle network. Also there is an extensive public transport services with both local and regional bus, metro, tram and train services. Also in the area there are several developments going on in order to cope with the changing population and of the city and the change of the use of public transport and car in the future. Within the Amsterdam network there are several areas or nodes that are qualified for further TOD. From these potential TOD locations the focus area of Amsterdam North is chosen.

Chapter 5

Data collection

In a previous chapter the multi-state super network model has been discussed. In this thesis this model is used for the simulation of traffic flows on the transport network of the Metropolitan Area of Amsterdam. In order to run this model several databases are required to run the model. To assess the likely effects of different scenarios for the development of the Amsterdam North area, these databases have to be adapted according to each scenario. The databases contain information about amongst others the road network, public transport network and land use. Table 2 provides a full overview of the required data. Available databases have to be modified in order to serve as input to the MSN model. The adaptation is done with the help of several programs (see Liao, Maas, 2015).

Table 2. Overview of the Datasets and their sources used in the Super network model

No.	Dataset	Data source	Description
1	Road network <ul style="list-style-type: none">• Nodes• Links	Nationaal Wegen Bestand (NWB)	Road network in the study region, selected and transformed with the help of TransCAD into nodes and undirected links.
2	PT timetable <ul style="list-style-type: none">• Connections• Stops	9292 data	Timetable of all the buses and trains in the study region, selected with the help of SPSS.
3	Land use	BAG data, with tagged postcode [6]	Locations of all activity buildings in the study area; dwellings and disused buildings were left out by means of TransCAD.
4	Activity program	MON/OVIN data	For each individual, an activity program is extracted from MON/OVIN data with help of a python script.
5	Individuals' profiles	MON/OVIN data	For each individual, attributes are stored, extracted from MON/OVIN with help of a python script.
6	Individuals' parameters	Already available	Individuals' preferences on travel time, costs and additional parameters.
7	Home profile	MON/OVIN data	For each individual, the home location is extracted from MON/OVIN data with help of a python script.

In the following sections, the databases will successively be discussed.

5.1. Data

As mentioned the database are subject to changes in order to able to be used them in the super network model. The first action for almost all datasets is the selection of the study area, since most of the databases consist of the whole of the Netherlands. Thus the databases need to be reduced to fit the Amsterdam metropolitan area. After the first reduction of the databases the data need to be adapted to the format required by the model. This section starts with a few methods and attributes used with working with the data. This is followed by a description of the datasets that are used in the model with their respective preparations.

5.1.1. Methods

Most of the databases consist of files that created and stored by geographical information systems (GIS). GIS is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data related to position on the Earth's surface(Longley et al., 2011). This technique enables to analyze and understand patterns and relationships of geographical elements.

Coordinate systems

The multi-state super network model uses a coordinate system to locate objects. Geographical Information Systems uses coordinate systems as well, however, several coordinate systems exist. These systems are, amongst others: EPSG:28992, ITRS, ETRS89 en WGS84

ITRS and WGS84 (Figure 16) are international coordinate systems which are developed since the early 1980s. the International Terrestrial Reference System (ITRS) played an important role in the development of the coordinate systems use around the world. The ITRS is unfortunately not suitable for use as a European geo-referencing system, since the ITRS-system does not account for the movement of the European plate. For this reason the European Reference Frame (EUREF, the sub commission for Europe of Commission 1.3 of the International Association of Geodesy (IAG)) realized ETRS89 which moves with the European plate. The ETRS89 served in the last decades as a base for national coordinate systems in Europe and it is now de facto the European reference system.

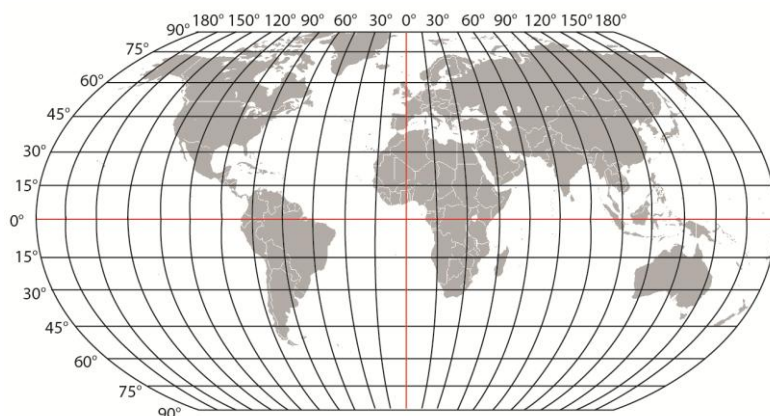


Figure 16, WGS84 Coordinate system

In the Netherlands, the Rijksdriehoeksmeting (RD, see Figure 17) and the Normaal Amsterdamse Peil (NAP) are the most commonly used reference systems (Nederlandse Commissie voor Geodesie, 2005). In the RD coordinate system the church "Onze lieve Vrouwetoren" in the city of Amersfoort is the center of the system and has for its x and y coordinate both a positive number where as the x-coordinate always larger is than the y-coordinate. The latest version of this coordinate system is the EPSG:28992 where the church in Amersfoort has the coordinate (155000 m, 463000 m).

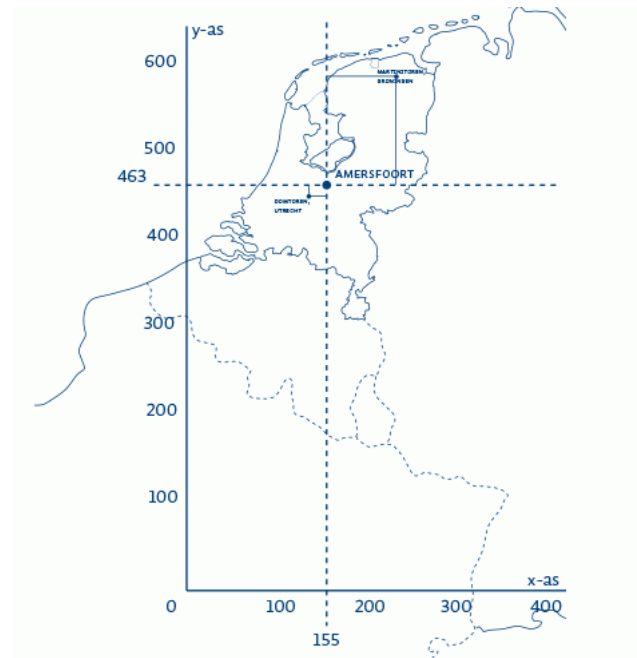


Figure 17, Rijksdriehoeksmeting, Kadaster 2015

The chosen study area encompasses several municipalities. In the data preparation these municipalities can be selected by their own identification code. This code is determined by the Dutch Bureau of Statistics (Statistics Netherlands, CBS). The code is made up of 4 digits. In international settings the code is preceded by the letters 'NL'. If a municipality is dissolved also the code of this municipality is withdrawn. The codes are unique and therefore the codes will never be re-used if municipalities merge, for example. If municipalities merge, the new municipality gets a new code with prefix number 1. In the case of annexation, the code of the main municipality will remain the same if the name remains the same. The municipalities are divided into districts and neighborhoods. The district and neighborhood code consists of eight digits; four of the municipal code, two for the district and two for the neighborhood.

5.1.2. Road network

The multi-state super network model uses road network stored according to the principles of GIS environments. In a GIS environment, a network is defined as 'a series of nodes connected by segments or links (Longley et al., 2011). For each segment and link attributes can be attached that represent the characteristics of the network. These attributes can be used in a range of applications like traffic analysis, routing, mode choice modeling. Examples of these attributes are presence of traffic light for the nodes and length, direction, average speed for the links.

In the super network model the road network is transformed into two files, a node file and a link file. Each of the links are associated with two nodes or two records which are determined in the node file. The nodes and links are derived from the NWB, the national road database in the Netherlands. The organization National Database Traffic Data (NDW) maintains and updates the NWB-database of all the roads in the Netherlands managed by road authorities and central government, provinces, municipalities and district water boards, but only if they are provided with a street name or number. In total the NWB Roads cover about 145,000 kilometers digitized road sections (+/- 825 000 in number) and is updated four times a year (Rijksoverheid, 2015).

Data preparation

In order to collect and restore the data for the Amsterdam metropolitan area the GIS program TransCAD has been used. The nodes and links have been selected from the NWB database with the use of municipality codes and other attributes such as road number and road authority. Some roads were picked manually if they represent major road to cities outside the study area. In total there are 43284 nodes and 119782 links.

When preparing the data a number of decisions were made. It was decided that to connect the major cities around the study area with the study area by means of a single highway or link. This was done to accommodate the flows of commuters between the study area and other cities or regions.

Also the decision was made that all road will be considered as two-way streets. This is done because of the scale of the study area and the scenarios. Although many streets in the Amsterdam centre are one way streets, the addition of a direction to these roads will make almost no difference hence it is not implemented in this dataset.

Another decision was made concerning the road type. The road types are categorized according to their speed limits and function. It was decided to use the four most dominant and most common road types encountered in the Dutch road system, also because these types match most of the speed limits. The four road types that are being used are: Local road with a speed limit up to 30 km/h, Urban roads with a speed limit between 30-50 km/h, Regional roads with a speed limit between 50 and 80 km/h and finally National roads with a speed limit between 80 and 130 km/h. The types have been stored as a link-attribute. Speed limits were partly extracted from the Open street map database (OpenStreetMaps, 2015) and set manually for the remaining streets. Because the dataset does not contain information about travel speeds, an estimated average speed will be used based on the different road types and time of day as shown in Figure 18. The average fuel consumption is assumed to be 0.17, 0.15, 0.125 and

0.10 €/km for the four different road types. In order to be able to geo-locate the different nodes and links the NWB uses the international coordinate system WGS84 with longitudes(X) and latitude(Y) for the study area around 4.3 and 52.0. These coordinates are used in other dataset to cross reference with the Dutch national coordinate system RD (see chapter 5.2.1). Finally the data is exported to two files, one node file and one link file (Figure 19).

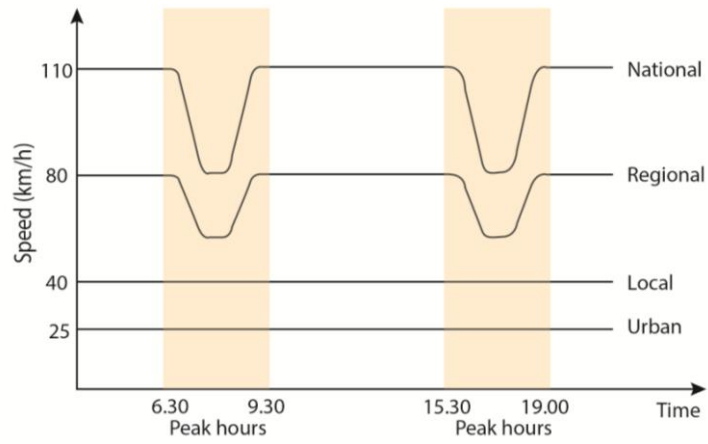


Figure 18, Average speed during a day

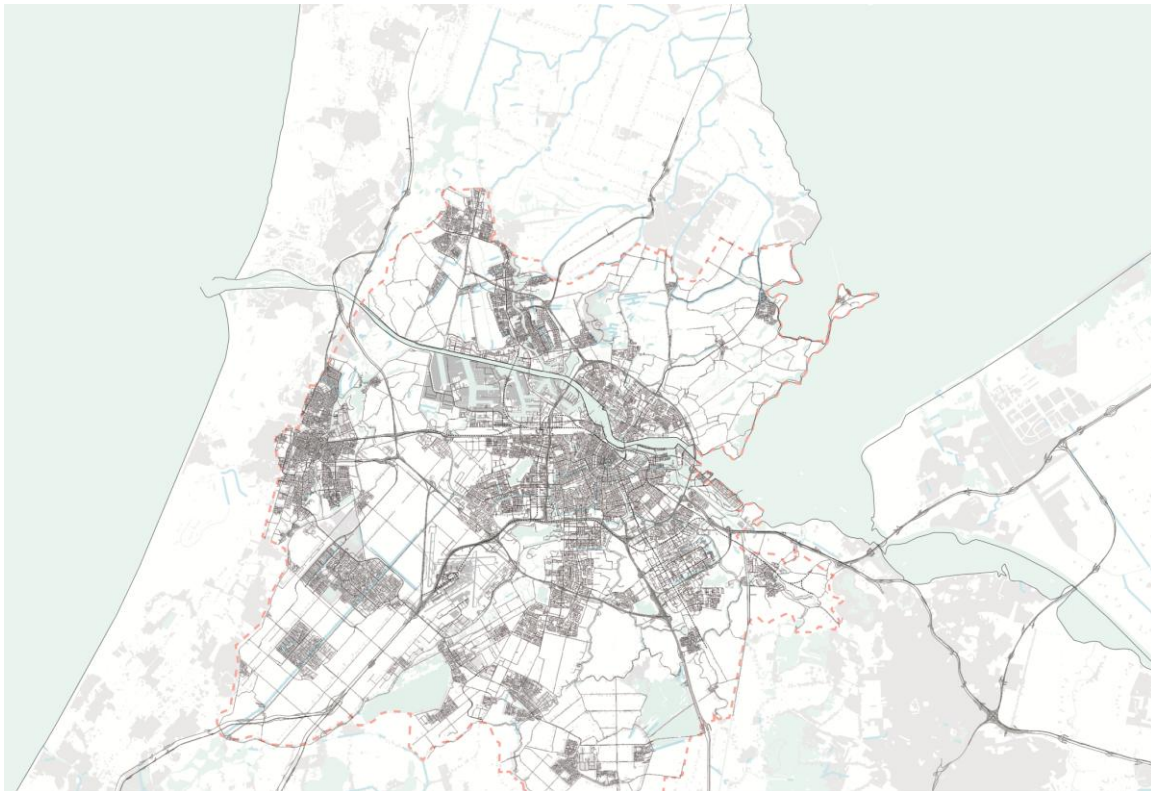


Figure 19, Road network

5.1.3. Public Transport

As people may travel by public transport (PT), it is necessary to know which public transport lines there are. The timetables of the public transport modes in the study area are taken into account, including buses, trams, stop trains and intercity trains. In the Netherlands the public transport is divided into 39 regions or concession areas and 16 specific PT-lines or routes. Each of these concessions are operated by commercial transport companies.

The study area consist of the PT-concession areas the city of Amsterdam, the Zaanstreek, Amstelland Meerlanden, Waterland and Haarlem-IJmond. In these areas the transport companies GVB, EBS and Connexion provide the bus, tram and metro connections, while the NS provides the railway connections (see Figure 20).

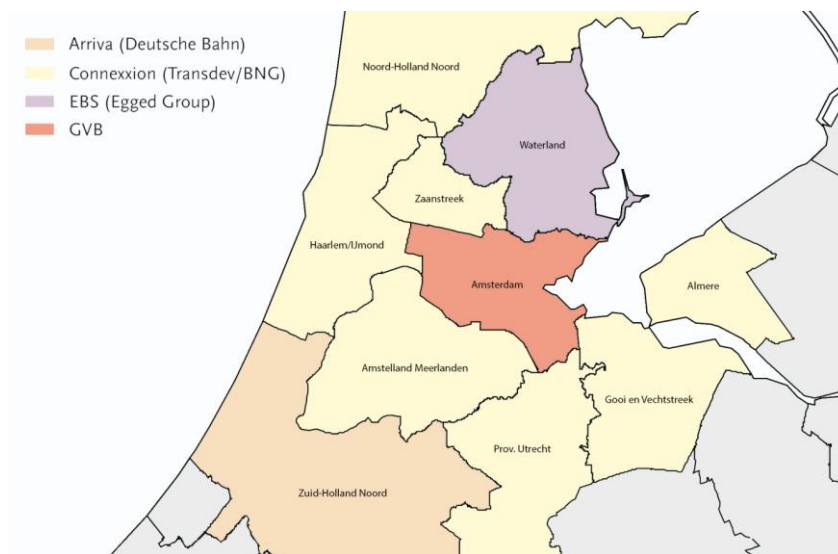


Figure 20, PT concession areas

The public transport dataset for the super network is timetable-based, not frequency-based. This means that waiting, transfer and travel time can be truly reflected for any route. The data for this dataset is collected from the Dutch PT planner 92920v for the year 2013. For the model the PT-dataset consist of one file with the stops and another with the connections for each transport mode. The dataset is created with SPSS. The initial selection of the PT-system in the study area is made by selecting the concession areas and manual editing. In total, the study area contains 4311 stops and 711986 connections in the case of the base scenario. The fares for PT bus/tram, stop train and intercity train are assumed on base of distance. In the supernetwork model a margin of at least one minute is assumed for transfer at a same PT stop and four minutes for transfers between different neighboring PT stops.

5.1.4. Land use

Travel is derived from the need of households and businesses to interact with their environment. So another dataset that is necessary contains information about land use. As individuals want to participate in activities such as work, education, shopping and leisure (Sivakumar, 2007). This means that the spatial distribution of land-uses is required. For this purpose, the national database BAG is used. BAG (Basic registration of addresses and buildings) is part of the Dutch governmental system of basic registrations. This database includes the attributes status, surface geometry, x-y coordinate, built and purpose for five types of objects: houses, residence objects, track designations, public areas and place of residences. The BAG database contains details of all properties in the Netherlands. The information of the database is collected by the national facility BAGLV which makes the data available to various parties and buyers.

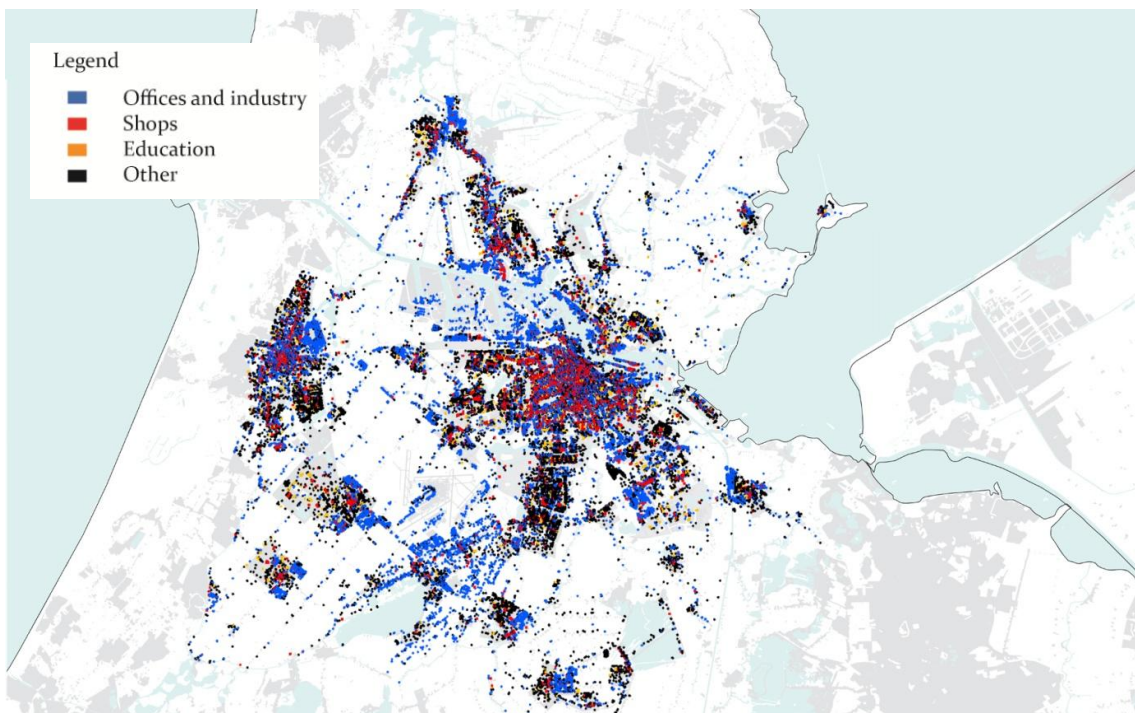


Figure 21, Land use locations

Data preparation

The first step in preparing the land use dataset (Figure 21 and Table 4) is reducing the number of land use types as not all of these land uses are relevant in this thesis. Only the most common and relevant land uses have been selected: Office, Shop, Industry, Meeting/social facilities, Healthcare, Hotels, Education and Sports.

Next, the attribute 'parking costs' needed to be defined (Table 3). A base cost and a unit cost per minute for car parking is taken in to account. The total parking cost (c) is calculated as $c = a + b * x$ (Euros) with a being the base cost, b the unit cost per minute and x the number of minutes. In the entire study area there are around 25 different parking fees. In order to streamline the dataset the parking fees are subdivided into four categories depending on the price and location within the different municipalities in the study area. Within each category an average price is calculated for both the base and unit costs.

Table 3. Parking costs

Category	Base Cost	Unit Cost
1 Centre High	€ 0.00	€ 3.90
2 Centre Medium	€ 0.00	€ 2.00
3 Centre Low	€ 0.00	€ 1.00
4 No cost	€ 0.00	€ 0.00
5 Airport	€ 18.00	€ 0.00

All locations have been assigned to one of these types of locations. Type 1 is represented by the center of the city of Amsterdam. Type 2 is represents district centers or TOD locations. The other types are the Airport location (type 5), and other locations (type 4). Extra parking time is added to land use locations in order to accurately represent the real parking times. The parking time includes searching for a parking spot and travelling from the parking spot to the destination. The time that is added ranges from 2 minutes in the more suburban areas up to 15 minutes at the airport.

Finally, the number of land use location has been reduced by aggregating locations into 4 digit postcode areas with the same activity type. With this aggregation the floor spaces of the each activity type are being summed up. For parking costs and extra parking time, the highest value within the postal code area is selected.

Node ID	X.Y coordinates	Activity Type	Floor Space	Parking Costs. Base and Unit costs	Postcode	Position in network Extra parking time
27880	122093 487121	1	107158	0 0 65	1011	1 10 1
27245	121496 487471	1	152604	0 0 65	1012	1 10 2
27421	120746 489000	1	529961	0 0 65	1013	1 10 3
26056	118648 489438	1	229459	0 0 65	1014	2 5 4
25523	120712 487952	1	38087	0 0 65	1015	1 10 5
25504	120574 487123	1	102516	0 0 65	1016	1 10 6
26966	121264 486277	1	352839	0 0 65	1017	1 10 7

Table 4, Sample of the land use dataset

5.1.5. Activity program

Since the multi-state super network is an activity-based model it is necessary to know how people move. The need to travel are determined by an individual's need to participate in activities spread out in time and space. The activity program database contains activities per person per day. The information for the individuals' activity programs is collected by means of the Dutch national travel survey MON/OViN. Linked to the activity program there are individual profiles and attributes which are required to calculate the utility of choice options. Also linked to the activity program is the home locations of each individual.

The Travel Survey

Since 1978 the Dutch Government investigates the mobility of the Dutch population on a yearly basis. The objective of the surveys, with household as unit, is to investigate and describe the travel patterns of the Dutch population. This investigation is done by collecting information about origins and destinations, time of day, transport mode, distance travelled, travel time and purpose of the trips. The survey provides much useful information on travel behavior in the Netherlands. Until 2003 the study was named 'Onderzoek Verplaatsingsgedrag' (OVG) and conducted by the CBS. Then it was taken over by DVS, restructured and named 'Mobiliteitsonderzoek Nederland' or MON. In 2010, the survey returned to CBS and named 'Onderzoek Verplaatsingen in Nederland or OViN. (CBS, 2015)

From 1978 until 1984 the survey was conducted by the aid of interviewers. Each month 1500 household were visited and the sample was equally divided over the days of the week. During this period the data was gathered for each household member older than 12 years. In 1985 the first major redesign took place; the interviewers were replaced by telephone-interviewing in combination with a self-completion questionnaire which was send by mail. More detailed information was collected in the questionnaires at lower costs. However, the redesigned surveys are not comparable with the old surveys. A follow-up change in 1994 is the incorporation of children younger than 12 years in the sample. Also from this year the sample size has been expanded from 10000 in 1993 to around 60000 household in 1995,. Another major redesign was in 1998 when the response rate dropped to 30% which led to the decision of the government to alter the program, see Table 5. Now, the survey includes a written questionnaire for the household and a written questionnaire for each individual within the household. The MON/OViN data covers about 80% of the mobility in the Netherlands.

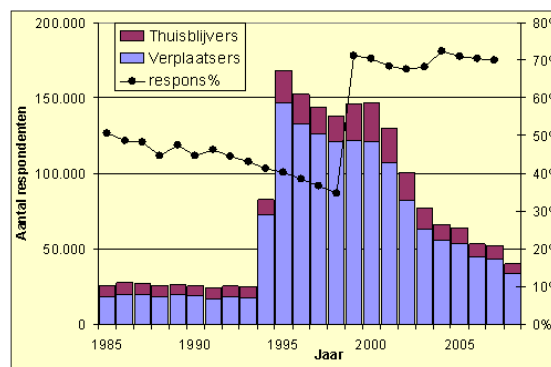


Table 5, Response MON/OViN Surveys, 1985-2008, SWOV

As mentioned the survey asks people for their travel patterns during day. This is specific for each individual in each household, so people can stay at home during the day or travel a lot; both cases are useful to know concerning traffic modelling. A travel pattern can look like the imaginary case shown in Figure 22.

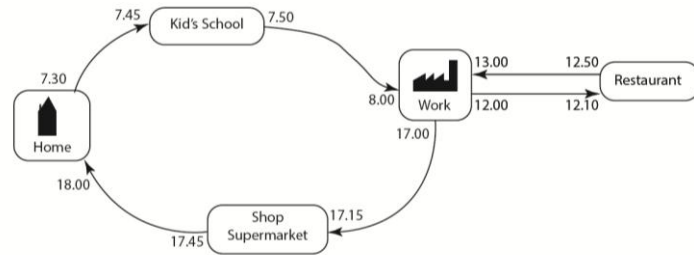


Figure 22, Example of an individual activity program

A female leaves the house at 7.30 and arrives at 7.45 at the kid's school to drop of her children. After that she drives to work where she arrives at 8.00 and stays there until 17.00 and only leaves the work location for a lunch break for one hour. After work she goes shopping and after that back to home. In this case the travel pattern consist of six trips, each with its own length, duration and transport mode. In total, five activities have been performed at different locations. More information about the individuals is gathered such as level of education, income, sex, ownership of a car or bike, frequency use of public transport.

The OViN data has to be transformed in order to use the activity patterns in the MSN model. For example, for each activity location the recorded postcode has to be transformed into coordinates matching the road network. Furthermore the OViN is transformed in to a Home address profile in which the geo-location and other information about the home address is stored and finally an individual's profile is made in which all the information about the individual is stored, such as home address profile, age, car or bike ownership and income.

Data preparation

Respondents younger than 12 years were not taken into consideration as children younger than 12 years usually travel together with one of more adults, usually their parents. This means that these trips are not unique and therefore not included in the dataset.

In the original MON/OViN the total surveyed population of the last five years is around 8000 respondents. This number is small compared with the 800.000 inhabitants of the city of Amsterdam. The population extracted from the MON/OViN consist of the inhabitants of Amsterdam and the surrounded municipalities but also the people commuting from and to Amsterdam are selected. In order to get a larger population of agents in the model, data is extracted from MON/OViN databases collected during the last five years and applying the population factor which resulted into an increase of agents up to 26500. The distribution is comparable to the average of the Netherlands (CBS, 2015). The populations consist of 51% female and 49% male.

Next to the population the attributes of the activity locations need to be addressed. In the supernetwork model the activity locations can be set as fixed location or a flexible location. Table 6 shows the classification of the activities and their respective frequencies in the activity programs. The activities are labelled as 1 for a fixed activity and as 0 for a flexible activity. This means that with a fixed location the activity is always at the same location given in the travel survey with their respective coordinates and other attributes. On the other hand a flexible location is considered flexible if an activity can be done at different locations within for example the same postal code area. In this case an activity location choice model will be applied to select a location from the set of alternative flexible locations. The fixed activities in this case are work, business, education and sports. This because these activities take most of the times place at the same location.

The model connects activities to corresponding land use locations using the 4-digit postcode. Since in MON/OViN destinations are known at the level of 4-digit postcodes and as mentioned in the land use data the locations of the activities are derived from the BAG data and aggregated into 4-digit postcodes. The activity types are different in the two datasets. This means that the BAG data has to be recoded to use the same activity types in both files. Also the duration of the activities are being adjusted from the MON/OViN data. This is done because in several cases there are duplicates of certain entries. To reduce the number of cases and thus reduce the running time of the model several cases are summed up when the activity, agent and location are the same.

Table 6. Activity Distribution

Activity	Work	Business	Pick & send	Education	Service	Shops
Percentage	19,3%	2,1%	4,7%	5,3%	2,4%	11,7%
Activity type	1	1	0	1	0	0

Activity	Leisure			
	Lodging	Hiking	Sport	Recreation trip
Percentage	6,3%	3,4%	3,4%	6,1%
Activity type	0	0	1	0

In this application only two types of vehicles are considered, the car and bike. In the application is assumed that every person that owns a bike or car keeps being the owner during the simulation. The distribution of the private vehicles are given in Table 7.

Table 7. Possession of private vehicles

Vehicle	Bike	Car
Percentage	73%	50,3%

Car ownership

About 51% of the households in the Amsterdam metropolitan area owns a car and 75% of the people have a driving license (Gemeente Amsterdam, DIVV, 2010). The majority of the households possesses 1 car and about one third owns 2 cars; a small percentage has 3 or more cars, while a 22% has no car at all (Table 8).

Table 8. Cars per household

Number	0	1	2	3	4 or more
Percentage	22,0%	50,7%	23,9%	2,7%	0.06%

Bike ownership

The bike is the most popular choice for transportation within the Amsterdam area with a share of 47%. About 73% of the household owns a bicycle. For the Netherlands this is about 86% (Gemeente Amsterdam, DIVV, 2010). Within each household the number of bikes varies from zero up to six and more (Table 9).

Table 9. Bikes per household

Number	0	1	2	3	4	5	6 or more
Percentage	5,9%	16,8%	25,6%	17,1%	16,6%	8,9%	9,2%

Modal split

The choice of transport mode in the study area is between three types: Bike, Car and Public transport. In the study area the current modal split of the trips is derived from the OViN survey 2013. From this dataset the modal split of the study area for bike, car and public transport the shares of 32,3%, 54,5% and 13,2% respectively.

Education

Education levels range from elementary school up to University. In the study area the distribution of the highest completed educational level is shown in Figure 23. This distribution entails that around 50% of the people finished high school or the MBO and around 40% with a degree of the higher education. This distribution for the study area is comparable with the average of the entire Netherlands (CBS StatLine, 2014).

Income

In Figure 24 the distribution of the income of the people in the study area is shown. This is necessary to know because from these number it is possible to deduct if certain people can afford to use or own a car instead of a bike and vice versa. The average income of the study area is: €42400. This is almost similar with the average of the Netherlands, which is €43600 (CBS StatLine , 2014).

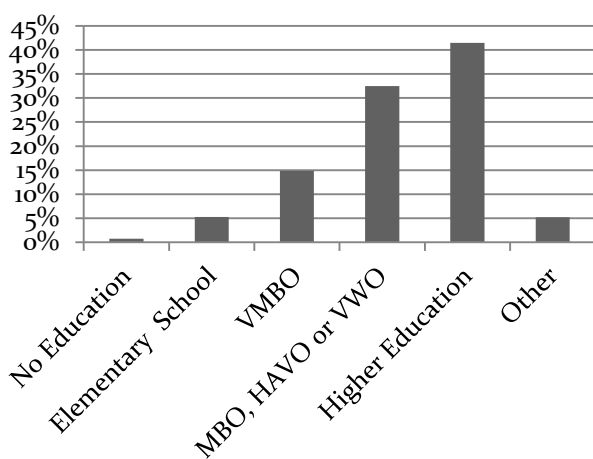


Figure 23, Education distribution

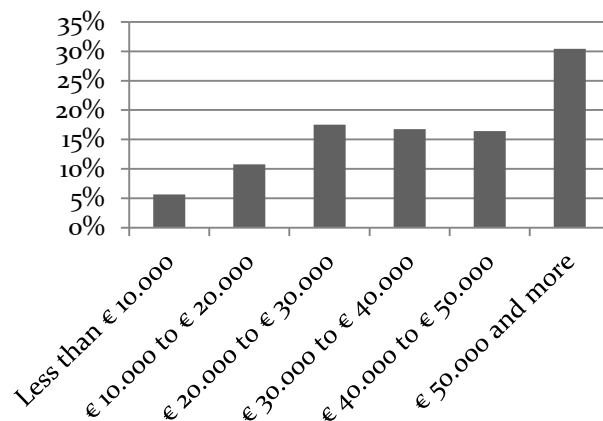


Figure 24, Income distribution

5.2. Summary

The multi-state super network model requires several datasets in order to run the model. These datasets contain information about the links and nodes of the road network, public transport network timetable, stops and connections. The land use dataset with information of the locations activity type, available floor space and parking prices. Furthermore the datasets of the individual activity program, home profile and personal information. These datasets have to be modified in order to serve as input to the MSN model. These adaptation is done with the help of several programs.

Chapter 6

Model estimation and Scenarios

In the previous chapter the data which are required in order to run the model have been discussed. In this chapter the model calibration and the different scenarios to be analyzed are described. When the model is calibrated the developed scenarios can be analyzed. These scenarios consist out of land use, infrastructure and parking policy interventions. At the end of this chapter the results for the different scenarios will be summarized.

6.1. Model calibration

The base scenario (scenario o) has been used to calibrate the model. This scenario consists of the current state of the study area. This means that nothing has changed in the focus area. This scenario is used to calibrate parameters of the MSN model in order to get an accurate representation of the real world. Only if the MSN model is able to simulate the current situation of the modal split and trip length, the model can be used to assess the likely effects of other scenarios. The base case scenario simulation consist of a simulation of 52456 trips from 26514 agents. This means an average of 1,97 trips per agent during a day. The results of the base case scenario with the modal split, average distance and average travel time is shown in Table 10.

Table 10. Distribution

		Base scenario	Ovin 2013
Modal split	Bike	32,2%	34,3%
	Car	49,7 %	46,8%
	PT	18,1%	18,9%
Average distance (km)		17.81	17,5
Average travel time (min)		46.01	35,4
Total distance travel (km)	Bike	11254	16264
	Car	66051	71811

In order to calibrate the model, the outcomes of the base case scenario are compared with data from the OViN survey in 2013 (Table 10). After the comparison certain parameters can be changed to better represent the current situation. These parameters settings concern peoples preferences for the different transport modes and parameters for travel time and transfer times for each transport mode. These parameters (see Appendix A, Parameters for Individual's preferences on activity-travel patterns) that are used in this case are derived from an earlier study at the Rotterdam area (Arentze & Molin, 2013). With these parameters there are no changes made since the outcomes of the Amsterdam case are about at the same level. The average trip length and travel time in the model are: 17.8 kilometer and 46 minutes, while the OViN shows that these are: 17,5 kilometers and 35,4 minutes. Here the average distance travelled is at the same level while the average travel time has a considerable deviation.

This inaccuracy of the travel time lies in the way the locations are being used. The locations are centered in each of the 4-digit postcodes which can cause a slightly longer travel time for certain routes. Also the assumed travel speeds on the network may cause some bias. For the modal split the model shows for bike, car and public transport the shares of 32,2 %, 49,7 % and 18,1%. In the OViN these are 32,3%, 54,5% and 13,2%. This means that they are almost at the same level. The differences between the OViN and the model are mainly because of the inaccuracy of the model. Thus the model can be used for further analysis of the scenarios.

6.2. Policy measures and Scenarios

The supernetwork model will be used to simulate traffic flows under different scenarios. These scenarios are combinations of proposed policy measures around a transit hub in the northern part of Amsterdam, concerning transport node, parking pricing and land-use developments.

As mentioned in Chapter 4 the focus area or study area is Amsterdam North. The new node is located around the new station of the north south line called Amsterdam north. This station is close to the local centre of Buikslotermeerplein. Along this square the shopping mall Boven't Y and the municipality district centre are located and it is the main location providing basic facilities for the people living in the Amsterdam North district. With the new metro line and several other interventions this node will become the northern hub of Amsterdam and will be seen as a new gateway to enter the city from the north.

Scenario_o : Base case

As mentioned in the previous section, the base scenario reflects the current state of the study area, where nothing has changed in the focus area. This scenario has been used to calibrate parameters of the MSN model and will be used as a base to compare other scenarios.

The scenario consist out of 59686 road links and 43284 nodes. The public transport in the study area consists out of bus, tram, metro and train routes which consist out of 4311 stops and 711956 connections. In the base scenario the activity patterns of 26514 agents are analyzed. The activity patterns cover 1331 activity locations which are divided into eight different types of activities. In the focus area these activities occupy floor space according to Table 11.

Table 11. Scenario o: Activities in focus area

Work	31620 m ²
Lodging	0 m ²
Healthcare	12874 m ²
Sports	6525 m ²
Shop	61877 m ²
Education	77224 m ²
Community	20654m ²

Policy measure_1: Land use developments:

The policy measure of land-use developments will consist of two options. The first option is to aim at a high density of functions developed in the area around the Buikslotermeerplein and the metro station North. The total new developments covers an area of around 45 ha. In this option the density of residential environments is 120 units/ha and will have a 60% - 40% split of residential and the other functions (see Table 12). This will increase the floor space the other functions by around 35% compared with scenario 0. This density is comparable with the highest density in the city of Amsterdam, which is located in the district "Centrum".

The second option is a medium dense development. This option is on the lower end of the development at the same location as the first option with 80 units/ha and will have the same split of residential and other functions as the first option (see Table 13). This will increase the floor space of the other functions by around 20% compared with scenario 0. The density in this option is slightly higher than the average density in the city of Amsterdam with an average of 50 unit/ha but matches with the higher density developments of the city.

Table 12. Policy measure 1A "High"

Work	+26754 m ²
à 18 m ² /job	1450 jobs
Lodging	+7377 m ²
Shops	+3688 m ²
Community	+3688 m ²
Residential	
à 120 unit/ha	+ 5500 Dwellings

Table 13. Policy measure 1B "Medium"

Work	+16230 m ²
à 18 m ² /job	900 jobs
Lodging	+4215 m ²
Shops	+2107 m ²
Community	+2107 m ²
Residential	
à 80 unit/ha	+3500 Dwellings

In both options the development is directly situated next to the new station North, which is part of the new North-South metro line. These developments will take place within 100-500 meters radius from the station (see Figure 25). The split of land-use functions is based on other Transit oriented developments around the world, in particular the ones from Portland, USA, Vancouver, Canada and Brisbane, Australia. However the majority of these plans were developed before the financial crisis and therefore adjusted. The floor space for the work activity is compared to the predictions of the Plabeka monitor (2014), an organization which predicts, analyses and give advice about work and industrial locations in the Amsterdam metropolitan area. For the work activity the total number of new jobs is calculated based on the new floor space. According to DTZ Zadelhoff (2014) the average workspace is around 18 m² per person. This translates for both sub-scenario to 1450 and 900 new jobs respectively (Table 12 and 13).



Figure 25, Location land use interventions

Both options of the policy measures have to be implemented in the datasets concerning public transport and land use. In addition the activity program needs to be adjusted to accommodate the increase of floor space and functions in the designated postcode. This increase will be done according to the split for each option and are assigned according to a scale which is based on the ratio of agents compared with the total population.

Home profiles

The development of new dwellings in the focus area will affect the home profile for a number of persons in the home profile dataset. For each new residential unit in the area, a person's home profile has to be reassigned to the new area. The selection of persons to move will be based on the current location of their homes. These current home locations will be divided into three different areas. The first area consist of the postcodes directly adjacent to the focus area. The second area consists of the rest of the city of Amsterdam. The third area will consist of the cities and towns that surround Amsterdam. From these selected zones different proportions of people will move to the new area. These proportions are higher for people living in the first zone and decrease in the second and third zone. Within each zone, the movers are randomly selected by assigning a random number between 0-1 to each of the profiles. If the random number is less than τ (see Table 14), the person (and household) will move. With this method the people living closer to the focus area are more likely to move to the new location than people living further away from the focus area. The total number of movers is in scale with the ratio number of agents : total population which is equal to 1 : 50. The residential location of the selected movers has to be adjusted in the home profile file. For each of the sub scenarios the number of people and τ are different, because the number of new homes differs. This results in a larger share of people that are going to move in option 1A and a lower share in option 1B (Table 14)

Table 14. Reassigned mover to focus area

Zone	Policy measure 1A		Policy measure 1B	
	τ	Agents	τ	Agents
1	0.11	55	0.08	35
2	0.002	33	0.0015	21
3	0.0016	22	0.0012	14
Total		110		70

Activity Program

Also with the reassignment of home profiles the activity program and the locations of the fixed activities need to be reassigned. Since the people move to another part of the study area, the work and education location may be different. This means that within the activity program these attributes have to be changed. For some of the inhabitants, new working locations need to be assigned. This is done by selecting people from 3 different groups. The first group are the movers, it is likely that a proportion of those moving to a new area are going to work in this area. From this group a random selection of around 25% of the movers will be assigned a working location in the focus area.

The rest of the new jobs will be filled by people currently working in the rest of the study area (see Table 15). With this last group it is possible that a person finds a new job in the study area or that a business will move to the study area and the employees will move with this business. From these groups different proportions of people will have their job in the new area. The workers from this last group are randomly selected. Similar to the home profile the number of new workers is in scale with the ratio agents : total population = 1 agent : 50 people, this means that the previous mentioned number of jobs in Tables 12 and 13 will be adjusted accordingly. Next to these three groups there are also the current workers that remain working in the study area.

Table 15. Reassigned jobs to the focus area

	Policy measure 1A	Policy measure 1B
Movers	9	6
Workers from Study Area	20	12
Total	29	18

For the education-activity changes occur only for the people that move to the focus area. Since the current schools of children in these families are likely too far away in order to remain their location they need to change school. This change is done by replacing the fixed location with another location closer to the new home. The school location is determined by postcode. When the current school is within the new home profile postcode, there is no change. But when the current school is not within the postcode, the new education location will be a school within the postcode area of the new home. For other activities, no change is required as they are already flexible in location. The supernetwork model will select the corresponding locations.

Policy measure _2: Public Transport infrastructure

This public transport infrastructure policy measure will consist of two different types of interventions where new public transport infrastructure will be introduced. The first intervention is the addition of a new metro line to the current public transport network. This metro line is called the North-South metro line. This metro line will be an extension of the current infrastructure network to further improve the accessibility and connectivity of the northern part of Amsterdam. The new metro line will run once every 5 minutes with a total travel time of 16 minutes from the North to the South, see also chapter 4 for more information about the North-South metro line (see Figure 26).

The second intervention is an investment in the current bus network. This intervention is derived from the local policy (Stadsregio Amsterdam, 2015) in which is stated that all the current bus lines coming from Waterland and Zaandam going through Amsterdam north will get a new stop or will end at station Noord (see Figure 26). These bus lines are part of the greater R-Net, the rapid bus transit system of Amsterdam. With these improvement the frequency can be increased and travel time can be reduced but also the connectivity of and accessibly to the North-South line and Amsterdam North increases. These policy measures will affect the PT data sets: there will be additional connections and stops representing the new metro line. In addition, the changes in the bus network have to be implemented.

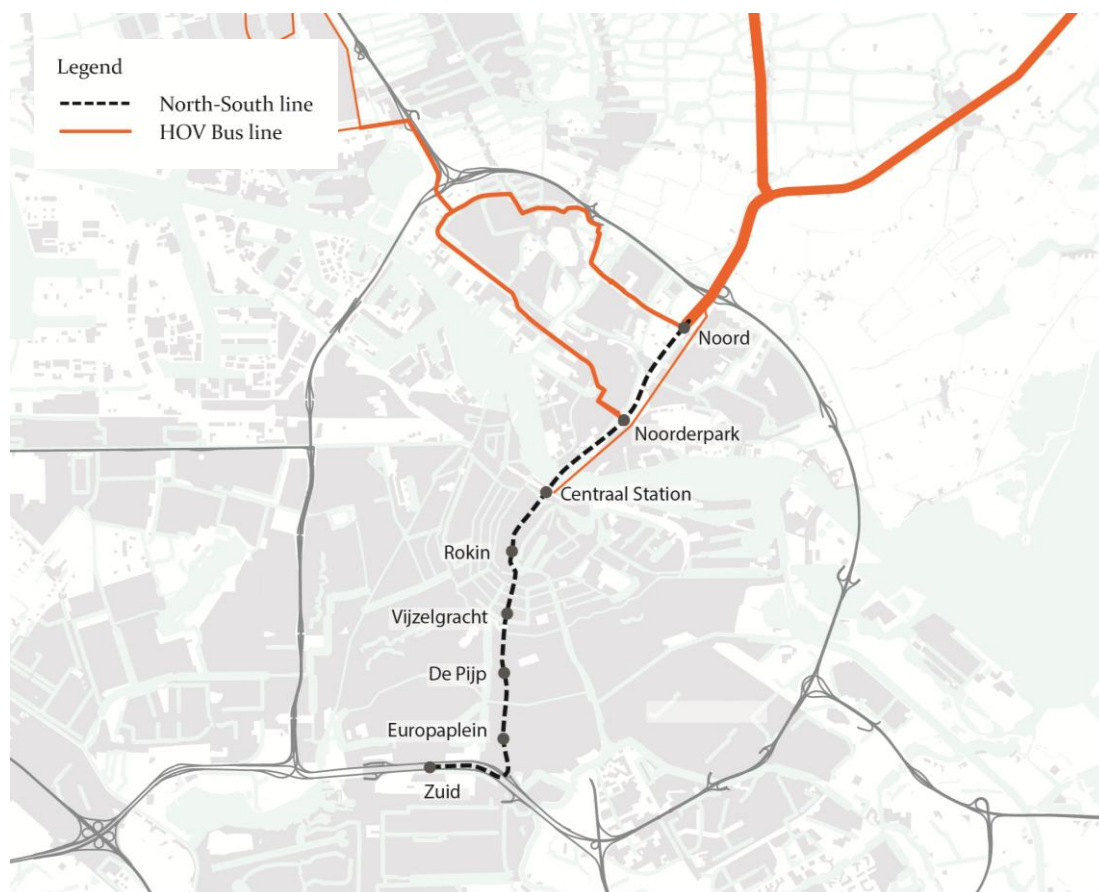


Figure 26, Transportation interventions

Policy measure 3: Change in parking costs

According to the third policy measure parking prices will be changed. This policy measure consists out of two options. In the first option (3A) the parking prices will increase, while the prices decrease in the second option (3B). These parking price changes will have an impact on the focus area and the surroundings but also at the new Noorderpark station of the new metro line. The categories in which the areas are classified are categories 1, 2 and 3 (Table 16). Prices in these categories will be increased or decreased compared to the base scenario (see chapter 5). These are the zones with relatively high residential densities and a high share of car use. This translates in the prices shown in Table 16. The increase in parking costs is supposed to promote the use of bike and public transport facilities and to reduce the ever growing amount of car use in the city.

Table 16. Increased parking cost

Category	"Base case"		Policy measure 3A - Increase		Policy measure 3B - Decrease	
	Base Cost	Unit Cost (per hour)	Base Cost	Unit Cost (per hour)	Base Cost	Unit Cost (per hour)
1 Centre High	€ 0.00	€ 3.90	€ 0.00	€ 5.00	€ 0.00	€ 3.00
2 Centre Medium	€ 0.00	€ 2.00	€ 0.00	€ 3.00	€ 0.00	€ 1.00
3 Centre Low	€ 0.00	€ 1.00	€ 0.00	€ 1.00	€ 0.00	€ 0.50
4 No cost	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
5 Airport	€ 18.00	€ 0.00	€ 18.00	€ 0.00	€ 18.00	€ 0.00

Application

The described policy measures are being analysed in combination with each other. First, the land-use development policy measures (1A and 1B) will be ran separately. This generates scenarios s1 and s2. The Public Transport policy measures will be added to both land use policy measure. This results in scenarios s3 and s4. The Public Transportation measures will be analysed as a separate scenario as well (s5). This in order to test if the measures of the new R-net and North-South line are effective on its own. After that, all three policy measures will be combined. However, for the land use development, only the lower density option is considered, yielding scenarios s6 and s7. The 7 scenarios (Table 17) will be compared with the base scenario of the current situation with no changes.

Table 17. Overview scenarios

s0	Base scenario
s1	Landuse 1A
s2	Landuse 1B
s3	Landuse 1A + PT
s4	Landuse 1B + PT
s5	PT only
s6	Landuse 1B + PT + Decrease parking cost (3B)
s7	Landuse 1B + PT + Increase parking cost (3A)

6.3. Results

The results of the multi-state supernetwork model provides information on the effects of integrated pricing, location and transport planning scenarios on travel patterns. The results of the different scenarios are analyzed and interpreted with the help of several indicators. These indicators are the modal split, total travel distance or VMT, average travel time, average travel distance and the public transport travel time. Furthermore the usage of the road network can be analyzed through the node usage of each trip since the outcome files specify the exact route for each trip.

One of the indicators that can be analyzed is the modal split of the trips. In the base scenario the modal split for the bike, car and public transport is 32,3 %, 49,6 % and 18,1% respectively. In scenarios s1 and s2 where only the available floor space is increased, this does not have a significant impact on the transport mode split. In these scenarios the split is almost at the same level as in the base case. This means that there are probably not enough people going to live or work in the focus area to have an influence on the modal split. In the scenario where both the land use developments and Public Transport interventions are simulated (s3 and s4) there are some differences noticeable (see Table 18). In both scenario s3 and s4 the use of the bike increases. This increase of the bike has impact on the public transport usage which decreases. In both scenarios the car share is at a lower level than in the base case. This can be explained due to the fact that the differences are caused by the people that move to and work in the focus area no longer need to use public transport but take the bike since they live closer to their activities. With only the PT developments (scenario s5) the modal split shifts toward the public transport at the cost of both bike and car. Scenarios s6 and s7 where the parking prices are changed in the focus area, show the strongest effect on the modal split. When the prices will be increased (s7), the share of the bikes increase at the cost of the car in comparison with scenario s4. But on the other side when the parking prices are decreased (s6) the share of bike decreases in favour of the car. In both scenarios (s6 and s7) the share of the public transport stays at the same level, just below the level of scenarios s0 and s4. This is to be expected since the PT has the lowest share in the modal split and therefore the effect is less profound.

Overall the difference in the share of the different transport modes over all scenarios is minimal. There are some differences noticeable but for the whole region these differences are marginal because these interventions are on a small scale compared with the Amsterdam Metropolitan area.

Table 18. Modal split distribution

Scenario	0	1	2	3	4	5	6	7
Car	49,61%	49,58%	49,59%	49,59%	49,59%	49,57%	49,64%	49,57%
Bike	32,28%	32,31%	32,30%	32,32%	32,30%	32,25%	32,25%	32,33%
PT	18,11%	18,11%	18,11%	18,09%	18,11%	18,18%	18,10%	18,10%

The average travel time for each trip is shown in Figure 27. With the average travel time the largest impact is noticeable in scenario s3 where the extreme land use developments and public transport take place. The largest difference between the scenarios is between s3 (High density land use + PT) and s5 (PT only). This difference between these scenarios is caused by the people moving to and working in the focus area: they cause a lower travel time in s3. But in s5 there is only the PT measure with no people changing homes or work location. This still causes a lower travel time compared to the base case scenario s0, but less strong.

To assess the effects of parking prices in the less dense and possible more realistic developments, scenarios s6 and s7 have to be compared with scenario s4. The effect is minimal and is around 0,1 minutes. This difference can be explained because people tend choosing the bike as their transport mode more often in S7 (higher parking prices) than in s6 (lower parking prices). This mode choice in favour of the bike can be the reason for the shorter travel time for s7 compared with s6. This because travelling in the city centre by bike tends to go faster than travelling by car. Overall the scenarios do not substantially impact the average travel times of the region.

Figure 28 shows the average PT travel time per trip. On average commuters spend less time on PT travel in the scenarios s3-s7, compared to s1 and s2, about half a minute less. This can be explained due to the fact that the new metro line and HOV bus lines which provide new links in the city are faster than the older connections in the city. Compared to the base scenario, the only difference in scenario s5 is an improved PT-system: it shows a decrease in both the overall average travel time (Figure 28) and PT average travel time (Figure 29). However, as PT has the lowest share in modal split (Table 18), the effect is less profound in the overall average travel time.

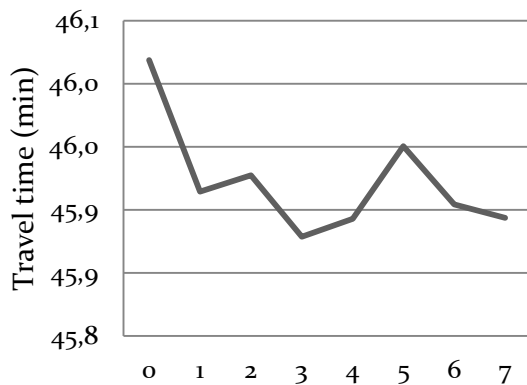


Figure 27, Average travel time

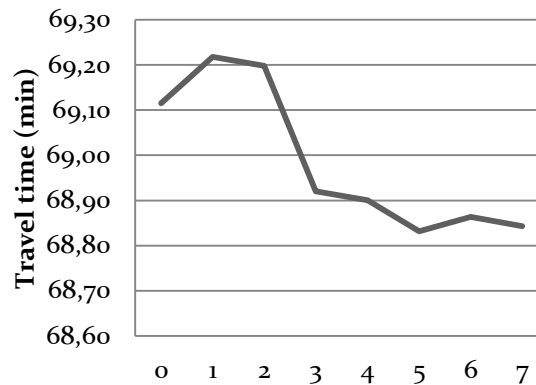


Figure 28, Average PT travel time

Figure 29 shows the effect of the VMT or vehicle miles travelled. As with the shares of the transport modes the different scenarios do not have a great impact on the VMT of the whole region. The strongest effects are seen in the scenarios where the parking prices in the study area are changed. In scenario s7 with the increase of the parking costs the total distance travelled by car is less while the total distance by bike increases. In scenario s6, it is just the other way round. When parking prices increase, people tend to use alternative travel modes to reduce travel costs.

Regarding scenarios s1-s4, it becomes clear from Figure 29 that total distance travelled by car is somewhat less than in the base case (s0) and that the distance travelled by bike is somewhat more. This is as expected because the bike may be a faster travel mode for the agents who moved to the focus area. However, it is not clear why the distance travelled by bike is higher in the medium density scenarios (s2 and s4) compared to the higher density scenarios (s1 and s3). The effect of an improved transport system on distance travelled by car and bike seems to be neglectable.

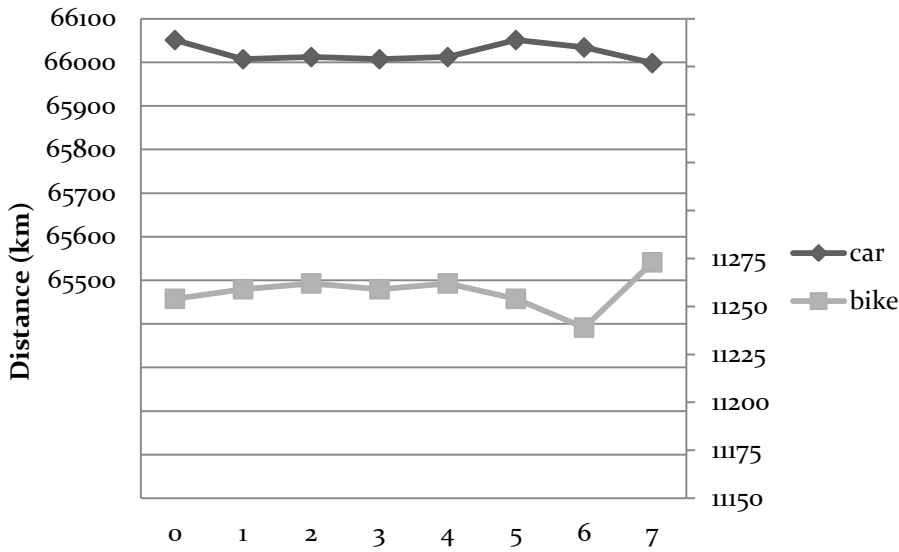


Figure 29, VMT

The average travel distance of all transport modes in the study area is shown in Figure 30. The results show that the average distance only changes marginally. The biggest changes are seen when the high land-use developments are combined with an improved Public Transport infrastructure (s3). The small differences can be explained due to the fact that most of the people in the study area still make the same movements and only a small percentage of the total population will change their home or activity location to the new focus area.

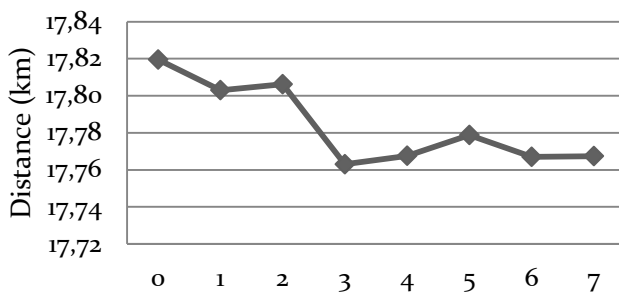


Figure 30, Average distance

In the usage of the road network, including both car and bike movements, there are definitely changes in certain nodes and road segments noticeable (see Figure 31). In multiple areas there is an increased use of the road network. In Amsterdam North these increases mainly occur around the Noorderpark station, especially between the station and the focus area. Also along the HOV-lines from Zaandam to Amsterdam and in the focus area there are changes in the usage of the road network. In these areas the usage increases in certain segments up to a threefold of the base case usage. Other areas where there is an increase are along the new north south line around the stops CS, Rokin, Vijzelgracht, de Pijp and Europaplein. Another increase is noticeable around the Muiderpoort station. Most of the changes were to be expected since the new metro line attracts more travellers. Although the increase around the Muiderpoort station is a little surprising since it is not connected to the new metro line. The increase at this station could be because of the shifts in travel patterns to Amsterdam north from travellers from the east of the city.

The areas where there is a major decrease are in the inner city, Amsterdam South district and in Amsterdam West district. There is also some decrease in the Amsterdam North area, mainly along the main road from north to south between the two new metro stops. Furthermore there are some changes in the usage of the A10 ring road (Table 19). At the ring, the intensities will decrease in the southern parts along the segment between the node Amstel, Duivendrecht and de Nieuwe Meer. In contrast intensities at the ring will increase in the northern parts, especially at the segments close to the study area and between Zaandam en Amsterdam.

Table 19. Usage of Ring road A10

		0	1	2	3	4	5	6	7
North	Zaandam	7150	7600	7300	7300	7300	7150	7300	7300
South	De Nieuwe Meer	22600	22200	22500	22550	22500	22600	22500	22500
	Amstel	17350	17850	17400	17350	17400	17350	17400	17400
	Duivendrecht	30500	30700	30400	30500	30400	30500	30350	30400

In almost every scenario the changes in the road network are at the same locations. However the percentage of the change of usage compared with the base case is different. In scenarios with the medium density land use developments (s2, s4, s6 and s7) the difference is less than with scenarios with high density land use development (s1 and s3). This difference is to be expected since in the lower density land use developments less people move to the focus area compared with the high density developments.

Overall, the changes in the scenarios (s1-4, s6-7) with land use developments are as expected since there is an increase of people living, working and shopping in the focus area; there should be an increase of the road usage in the focus area. Also noticeable is that the new metro line connecting the north with the rest of Amsterdam is clearly working since almost at every stop usage increases.

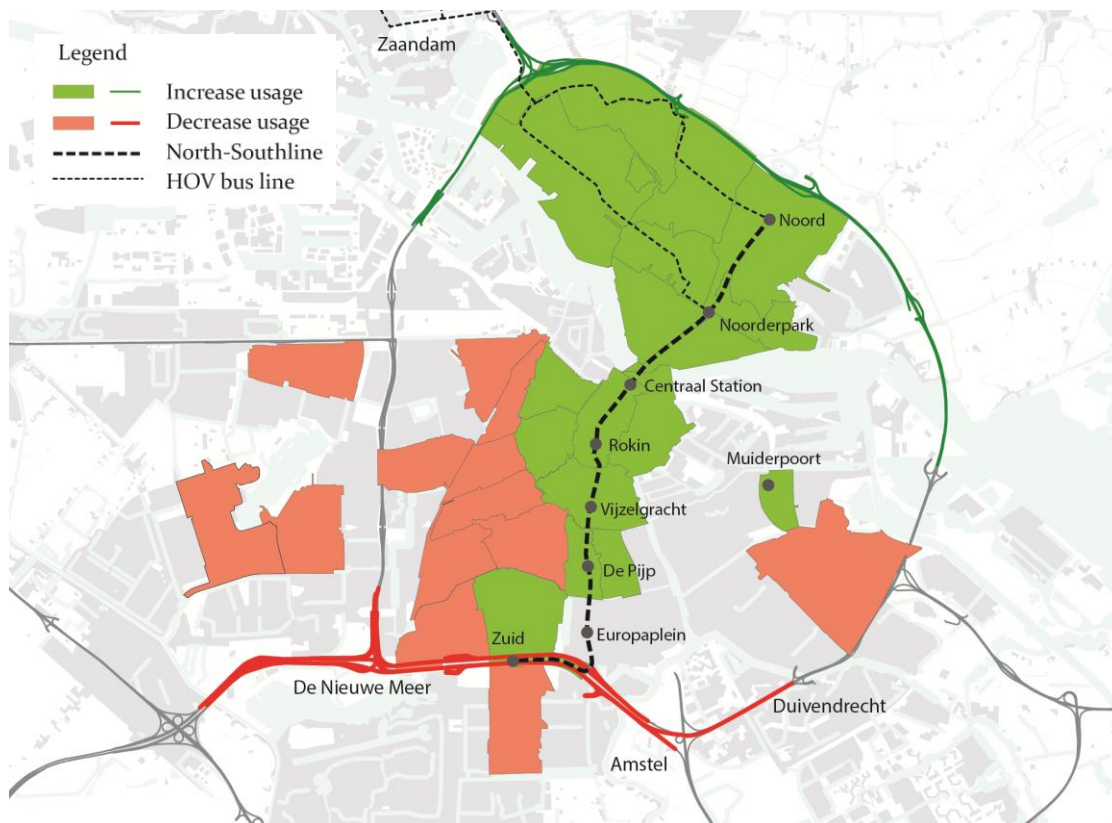


Figure 31, Locations of the changes in the road network usages

As mentioned before, major changes occur in the Amsterdam North area. As shown in Figure 32 and Table 20 both new metro stations are main points to enter the district. Especially the use of the station Noord increases. In the scenarios with the PT improvement, the use of this station increases up to three times compared with the base scenario (actually the PT-stop 'Buikslotermeerplein' which is currently the main stop at the same location in the focus area). The land-use developments has minor effect on the PT-usage in the focus area in comparison with the PT improvements. The effect are an increase of 53 and 30 agents for the high and low developments respectively. The new Noorderpark station is less popular but still used quiet often. With the developments suggested in the scenarios s3-s7 the usage of the new Noorderpark station is around or just below the level of Station Noord in the base case. This may be expected as in the scenarios most bus lines end at station Noord and only a few continue to the central station via the Noorderpark station.

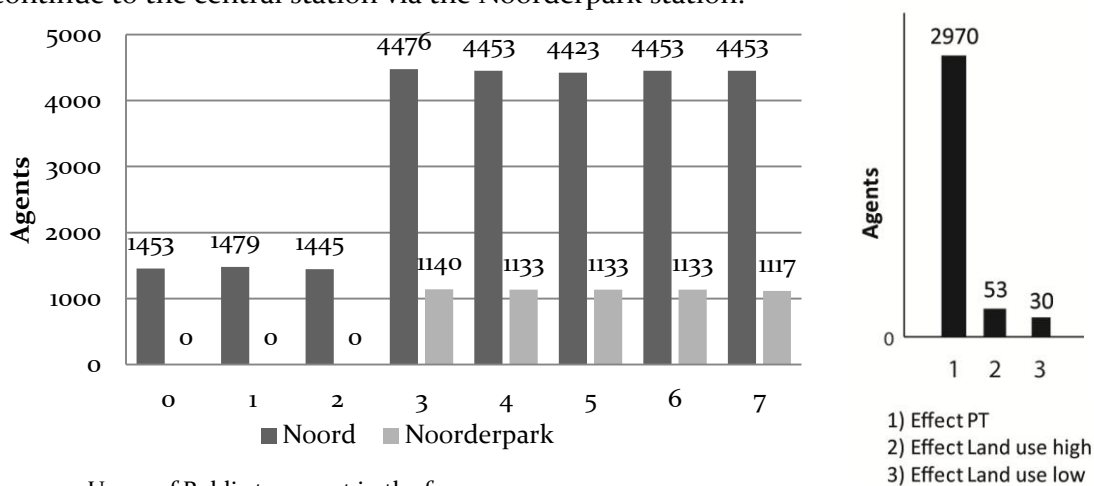


Figure 32, Usage of Public transport in the focus area

Table 20. Usage of PT in the focus area

Stop		0	1	2	3	4	5	6	7
Noord	Agents	1453	1479	1445	4476	4453	4423	4453	4453
	Travellers	72650	73950	72250	223800	222650	221150	222650	222650
Noorderpark	Agents	0	0	0	1140	1133	1133	1133	1133
	Travellers	0	0	0	57000	56650	56650	56650	56650

When looking at the PT usage at the new central transit hub station Noord the use of public transport increases in all scenarios with improved PT (see Figure 32). This is because of the introduction of the new metro line and additional bus stops in the focus area. In these scenarios the increase is up to 300% compared with the base scenario. This increase was to be expected, but with these changes improvement of the PT can be considered as a successful policy measure. In the case of scenarios s1 and s2, with only land use developments, changes are minor. PT use increases a bit in s1 but decreases somewhat in s2. Given the fact that PT usage in scenario s5 is only a fraction less than in the scenarios s3, s4, s6, and s7, it can be concluded that the people moving to the focus area do not affect PT usage in the focus area.

With the road usage of the major roads in the focus area, where both car and bikes are included, there is an increase in most of the scenarios (Figure 33 and Table 21). In these scenario the increase is due to the both infrastructure and land use development. With these developments there are more people travelling around in the focus area. In the case of the other scenario (s5), the road usage stays at a similar level as in the base scenario, since there are no changes to the road network and no new developments in the focus area. The changes in parking costs (scenario s6 and s7) result in an increase of 7 agents and a decrease of 4 agents respectively, which means that this is an effective tool to influence people's behaviour.

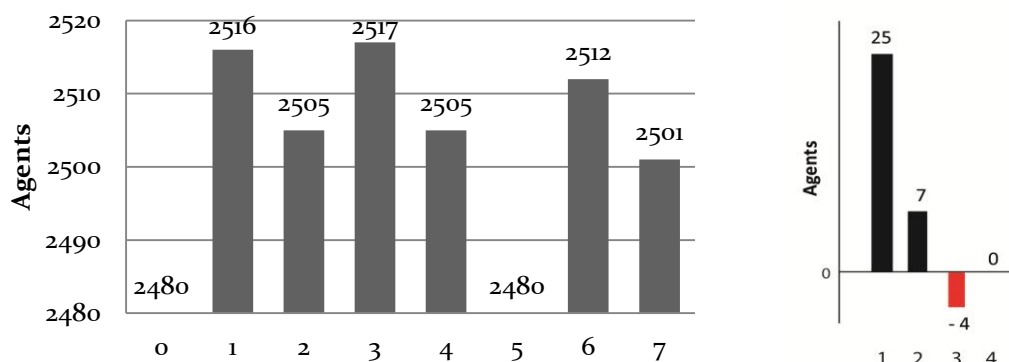


Figure 33, Usage of the Road network in the focus area

- 1) Effect land use (s4)
- 2) Effect Decreased parking prices
- 3) Effect Increased parking prices
- 4) Effect PT

Table 21. Usage of the Road network in the focus area

Roadnetwork	0	1	2	3	4	5	6	7
Agents	2480	2516	2505	2517	2505	2480	2512	2501
Population	124000	125800	125250	125850	125250	124000	125600	125050

When looking at the average travel distance of the people living in the focus area, these are lower than the average of the whole study area. Whereas in the Amsterdam Metropolitan Area the average travel distance is around 17.5 km. For the people living in the focus area the average travel distance across all transport modes is 15,2 km. For the different transport modes the mean trip length of the car is between 12 and 14 km. and for the bike the mean trip distance is between 6 and 10 km (Figure 34). This for people living in the focus area.

The differences for the car and the bike in the scenarios s1-s4 lies in the fact that there are more people living and working in the focus area in scenarios where there is any land development. Where in s1 the effect of the average bike distance is higher than others. This effect can be because more people need to cycle longer distances for example to get to the other side of the river IJ. For s5 there is no change as to be expected since there is no change in the road network. As for s6 where more people take the car instead of the bike. This means that people use the car even more for short trips which results in a lower average car distance. In s7 it is the other way round, where people use more the bike instead of the car for the shorter trips and therefore the bike average is lower and the car higher since people used them more for the longer trips.

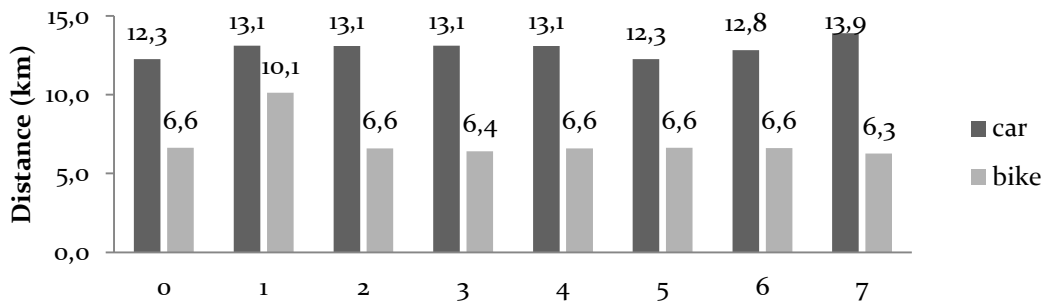


Figure 34, Average travel distance per mode in focus area

The use of facilities in the focus area is affected by the policy measures (Figure 35 and Table 22). For the activities work and education there are several differences noticeable. These differences are related to the number of people moving into the area and the available jobs. Thus in scenario s1 and s3 the use of facilities is the highest. This effect is also noticeable in the scenario s2,s4, s6 and s7 where there is a lower land use development which results in a smaller increase. For the activity shopping there are no changes across the different scenarios although the floor space and therefore the attractiveness was increased. Only in scenario s7 with higher parking prices, the number of people shopping in the focus area is decreased. For the other activities, such as sports or meeting/community services participation stays around the same level. This can be explained because of the relative small amount of agents living and working in the focus area.

Table 22. Activities in the focus area.

Agents	0	1	2	3	4	5	6	7
Work	15	44	33	44	33	15	33	33
Shopping	13	13	13	13	13	13	13	12
Education	5	16	12	16	12	5	12	12
Population								
Work	750	2200	1650	2200	1650	750	1650	1650
Shopping	650	650	650	650	650	650	650	600
Education	250	800	600	800	600	250	600	600

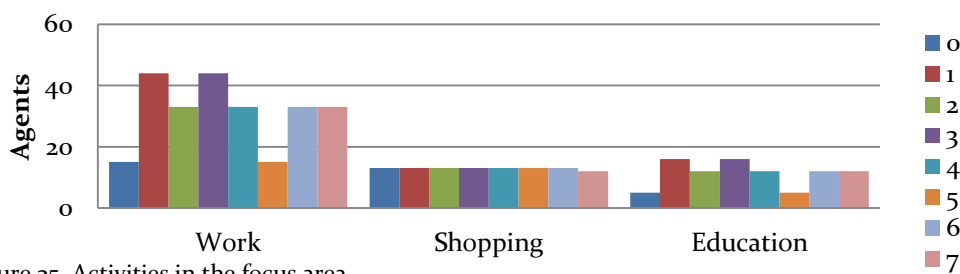


Figure 35, Activities in the focus area

6.4. Conclusion

The effects of three policy measures, combined in seven scenarios, have been assessed by means of simulation. The policy measures are: land use development in a high and medium high density, improved PT and increase and decrease of parking prices. According to the results, the policy measures have a relatively small effect on the indicators considered since these changes take place at a relatively small scale compared to the whole study area and the daily urban system of Amsterdam. The indicators used are average distance, travel time and pt-travel time. These indicators only marginally differentiate between the scenarios. The biggest impact occurs when all policy measures are combined.

When the focus area is connected with a new metro line and HOV bus lines the model shows an increase of the usage of both stations Noord and the Noorderpark, with the biggest increase for station Noord. In addition, usage of the road connections between these two stations in the focus decrease. These changes in the focus area can be explained by the usage of the new metro line and because of the way how the model determines the route (least-costs) and the fact that the activities are considered to be located at the centre of each 4-digit postcode area.

In the area around the new North-South metro line there are more movements on the roads to the stations Rokin, Vijzelgracht, de Pijp and Europaplein. In contrast with the areas around the metro line, the other areas in the inner-city and west and south districts the road network usage decreases. This decrease is because a part of the population moved to the new focus area therefore less car and bike movements in the west and south districts are required.

The new metro line is clearly working and is mostly used by people living within the ring road A10. Use of the metro line decreases around the station Zuid, which is one of the main transfer point for the commuters from outside the city to go into the city. This effect is plausible because people will transfer more at the central station instead of station Zuid. Furthermore the use of the ring road A10 shifts to the Northern part. This is due to the fact that people from outside the city use this road to travel to the focus area. The use of the northern parts of the ring road A10 increases while it decreases in the southern half of the ring. This is because of the previous mentioned new metro line, but also because of the changes in the activity patterns with the new destinations for people living or working in the focus area.

To influence an individual's travel behavior, parking prices seem to be the most effective way to affect car usage in an area. If the parking prices are changed, increasing the parking prices will reduce car usage and decreasing the prices will increase of car usage. This confirms the principles of TOD.

Chapter 7

Conclusions and discussion

7.1. Summary and conclusions

During the past decades the theories and applications of transit oriented development has evolved from a simple metro line connecting the inner-city with the suburbs to a complex system taking into account infrastructure, typologies of transit hubs, mix of land use developments, and parking regulations.

In the same period the development of transportation research has seen a shift in the models. From the 1970s onwards researchers try to develop transportation forecast models that gradually expanded from a basic four step model covering home based trips via tour-based models and activity-based models into a current state-of-the-art model that gives a representation of individuals' activity programs. As one of these state-of-the-art models the multi-state supernetwork is used in this study. This model with its integrated land-use multi-modal transport network combines a person's activity pattern and transport modes into individual trips.

This study investigates the question : "What will be the effects of TOD development at a node in the Amsterdam transportation network?" In order to investigate the question a focus area around the Buikslotermeerplein in the district Amsterdam north is selected. Different policy measures including land use and public transport infrastructure developments and parking prices policies have been considered. These policy measures have been combined into scenarios for the focus area and the likely effects of these scenarios have been assessed by simulation with the multi-state supernetwork model.

The results show that the individual public transport and land use policy measures have relatively small effects on the indicators considered for the entire Amsterdam Metropolitan Area. These indicators concern the modal split, total distance travelled, average distance of all transport modes, travel time and public transport travel time. However, there are changes noticeable in these indicators for the focus area in the Amsterdam North area.

The new North-South metro line and improved HOV-bus lines the Amsterdam North area generate more movement in and usage of the area. Next the use of the areas around the stops along the new metro line increases which is a result of the new metro line providing better connections with the inner-city and northern district of Amsterdam.

The results show that separate measures like increasing land use or improving public transport infrastructure have their effects. Combining these measures according to the principles of TOD, however, generates a stronger effect. Therefore, when the municipality of Amsterdam wants to plan to develop Amsterdam North into a new transit hub according to the principles of TOD around the Buikslotermeerplein and Station Noord there is need to develop a plan that consist of a combination of infrastructure, housing, and other developments. These developments need to be of a sufficient but realistic size in order to attract people, businesses

and enterprises to this part of the city. Of course, the decision to implement Transport Oriented Development not only depends on land use and transport policies, but also on stakeholders willing to invest in such developments.

7.2. Discussion and future research

During this project, several decisions have been made concerning the data preparation and the development of the scenarios. These decisions may affect the results of this project.

The selection of the area can be different, as mentioned the Amsterdam Metropolitan Area was chosen for this research. The larger the study area, the better likely effects can be assessed. However, indicators may be rather insensitive in the case of large study areas. Therefore, considering the indicators at different scales may give a better assessment of what this means for the city of Amsterdam itself and for the focus area around the new TOD. In this study, indicators were only considered at the level of the entire metropolitan area and at the level of the postal code area covering the TOD.

In this study approximately 80% of the daily urban system is taken into account both in terms of area and people using the area. When the entire western part of Netherlands and all people living, working, and moving around in this area would have been taken into account, more accurate outcomes would have been generated. In order to limit running time, the number of agents used in the simulations was limited to a small percentage of the population. When more agents had been taken into consideration, the results would have been more accurate as well.

In this project, the impact of only one TOD in the Amsterdam Metropolitan Area was assessed. A more rigorous test of the concept of TOD would be implementation of multiple transport oriented developments in the AMA or even the whole province of North-Holland. Such assessments may give a base for an integrated regional or provincial strategy on urban development. Existing transport nodes may be considered as the core of new TOD's and may facilitate the increasing number of people living and/or working in metropolitan areas.

Finally, simulating likely effects of TOD is just the first step of a long lasting process. Many other effects have to be investigated and policy makers and stakeholders have to agree on implementing developments. Once such a decision has been taken, a plan has to be designed, integrating all aspects of urban development.

So far, the newly developed multi-state supernetwork model has been tested in a few test cases. The model is still under development and therefore rather user unfriendly. In future extensions of the model, features like ride-sharing could be added as a travel mode. Also, a more user friendly interface would be welcome.

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Appendix A

Parameters for individual's preference on activity-travel patterns (Arentze & Molin, 2013)

Part 1	First line indication: no		memo
Part 2	Field explanation		
	1 st	Parameter for the time of waiting somebody or an activity	0
	2 nd	Parameter for the time of waiting and boarding PT	0.0925
	3 rd	Parameter for travel time with the mode walking (avg)	0.12
	4 th	Parameter for travel time with the mode bike (avg)	0.08
	5 th	Parameter for travel time with the mode bus (short/avg)	0.058/0.063
	6 th	Parameter for travel time with the mode bus (long)	0.07
	7 th	Parameter for travel time with the mode inter-city train (short/avg)	0.06/0.052
	8 th	Parameter for travel time with the mode inter-city train (long)	0.049
	9 th	Parameter for travel time with the mode car (short/avg)	0.043/0.045
	10 th	Parameter for travel time with the mode car (long)	0.079
	11 th	Parameter for the time of parking a car	0.079
	12 th	Parameter for the time of picking-up a car	0.03
	13 th	Parameter for the time of parking a bike	0.02
	14 th	Parameter for the time of picking-up a bike	0.01
Part 3	Field explanation		
	15 th	Parameter for the money spent on fuel	0.098
	16 th	Parameter for the money spent on tickets	0.201
	17 th	Parameter C- PT	0.113
	18 th	Parameter C- Bike (main/long)	0.741
	19 th	Parameter C- Acc Bike	0.438
	20 th	Parameter C- Egg Bike	-0.055
	21 st	Parameter C- Car for P+R	0.5
	22 nd	Parameter C- Bus/Tram	0.747
	23 rd	Parameter C- Train	0.968
	24 th	Parameter C- Acc PT	0.888
	25 th	Parameter C- Egg PT	0.165
Part 4	Field explanation		
	26 th	Parameter FromDist 4	1.78
	27 th	Parameter FromDist 81	1.35
	28 th	Parameter FromDist 81 82	1.4
	29 th	Parameter FromDist 83	1.65
	30 th	Parameter FromDist 84	1.67
	31 st	Parameter Size 4	0.000023
	32 nd	Parameter Size 81	0.0000232
	33 rd	Parameter Size 82	0.0000157
	34 th	Parameter Size 83	0.0000314
	35 th	Parameter Size 84	0.0000101
	36 th	Set as 0	0
