PARKING IN BALANCE:

A Geospatial analysis of efficiency of the parking system of Enschede, The Netherlands

MITAVA CHATURVEDI

February, 2012

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.

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ABSTRACT

Parking policy is one of the important means urban planners and policy makers can use to address problems related to travel demand and traffic congestion in a city. Parking constantly demands valuable space in the city and if its distribution is not properly planned it can have negative impacts on the traffic flow and order of the city. Thus it becomes important to strategically design parking lots in locations where not only the system is efficient but also where user's utility is maximized. A tool is thus required which is flexible enough to examine effects of a wide range of possible parking policy interventions, including various supply mix of parking spaces, varied tariff structure and so on and so forth.

The research presents such a tool which has the capability to investigate the effects (considered as efficiency of the system in spatial, demographic and economic terms) of parking policy intervention by considering various factors, which the users take into account while choosing a parking location in the case of the city of Enschede, The Netherlands. A model is developed which simulates the choice of parking lot using five location factors (namely: parking charges, noticeability of the facility, condition of parking surface, type of winter provision, safety of the driver and driver's vehicle- assumed to concern vandalism and ease of searching a parking lot) and allocates trips entering a zone (i.e. the parking demand) at morning and evening peak hours to parking locations (considering the trip purpose, the walking distance from parking location to destination and the parking location choice).

The results show the spatial balance of the parking system in the city as well as presents in detail the problem areas and parking lots which are over utilized or underutilised.

Keywords: Parking policy, efficiency, parking balance, Geospatial analysis, parking modelling, parking choice, parking allocation

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Mitava Chaturvedi

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1. INTRODUCTION

As the title of the research suggests the study aims to develop a methodology for a Geospatial analysis of the parking system focusing on testing parking policy interventions. In order to develop such a methodology primarily it is required to have sufficient background information of the context and significance of the subject so as to define the scope of the research.

In this chapter first a general introduction to the topic of the research is presented, providing justification for the study to be conducted. Further it continues to discuss research objectives and the questions defining the scope of this research. The chapter concludes with setting up a conceptual framework for the study.

Vehicles must be parked before the occupants can use it to undertake any activity. Parking is thus an essential component of any trip. Car parking has risen as an issue in local and strategic planning and policy (Hensher & Button, 2000). In the mid 80's competition increased between parking and other land use needs. Due to the increasing social environmental consciousness, the growing environmental pollution in urbanized areas and the worsening financial position of many municipal authorities, parking has changed from being an issue of building regulations to an issue for town and traffic planning(GFIVT, 2009) . Considering the case of Enschede, there are 66,091 passenger cars ("Statistical Yearbook," 2011), hence, there is a requirement of approximately 90 ha of area in the city at all times for all of them to be parked (assuming standard parking bay size of 2.5*5 m^2).

It has been recognized in literature that the amount and location of parking can influence the condition of traffic on roads in the city, demand for public transport in the city, the form and functioning of the area and the environmental quality of the city (Rye, 2007; Stubbs, 2002). Hence there is a need for more understanding of the implications of parking policy interventions. Thus a tool is required so as to investigate potential strategies for dealing with parking, including a mix of supply of parking, differentiated tariff structure etc. Such a tool would present us with the opportunity to assess the effectiveness of the parking system which can help to achieve the above mentioned purposes.

1.1. Background

1.1.1. Potentials of a parking policy

"Parking policy acts as a link between land-use and transport policies"(Marsden, 2006). Parking constantly demands valuable space in the city and if not appropriately planned it can have negative impacts on the traffic flow and order of the city in general (Bates & Bradley, 1986). There are multiple objectives related to transport and land use strategies that a parking policy addresses, the three specific parking policy objectives that Marsden (2006) perceives to be in conflict have been discussed below:

- "Regeneration" of a specific part of urban area
- "Restraining" vehicular traffic
- "Revenue" generation from the parking operation

The above mentioned objectives confirm that appropriately designed parking policies, in various ways, can contribute to the promotion of a more efficient use of the transport network, lower emissions, higher densities and more inclusive urban design (Rye, 2007; Stubbs, 2002).

1.1.2. Complexities of studying the parking policy interventions

Parking policy instruments are very complex in terms of their interpretation and implications as they are interwoven with each other and also with other land use policies. Feeney (1989) in his study of "a review of the impact of parking policy measures on travel demand" discusses certain factors that make the interpretation of the findings of parking studies problematic, particularly with regards to determining elasticity estimates of parking policy interventions (for e.g. the parking price elasticity):

- "Inconsistent definition of the demand variable (e.g. is it total car use or parking at a specific site);
- Possible substitution between different elements of parking demand (short vs. long-stay);
- The consideration of the non-monetary costs of parking; the money and time costs for competing travel options; and
- Possible supply effects where there are reasonable competing alternatives" (Feeney, 1989).

Also the qualitative and quantitative assessment of the effectiveness of a particular intervention can be a tedious exercise as the policies are interwoven. A change in one intervention can affect the other; for example "Minimum parking requirements increase the supply and reduce the price of parking" (Shoup, 1999) and increase in price of parking can lead to a decrease in the demand factor.

1.1.3. Limited empirical evidence on performance of parking policy measures

Most of the articles on transportation literature have drawn attention to the fact that there is relatively little formal analysis of parking measures. For more than 50 years, traffic engineering has focused primarily on traffic flows and congestion. However, the study on pricing parking has received some attention from a number of authors who claim that optimal parking policies effects travel behaviour (Marsden, 2006; McCahill & Garrick, 2010; O'Flaherty, 1996).

There are only a limited number of empirical studies on the economic (or other) impacts from parking policies. Although, some stated preference research on the impacts of road pricing and parking have been undertaken by Collis and Inwood (1996) in the case of Bristol city centre. The results illustrated that both reducing parking spaces and increasing costs were although unacceptable but parking restraint would encourage use of public transport (Collis & Inwood, 1996; Still & Simmonds, 2000).

1.1.4. Need of a GIS model to study parking policy system

The basic feature of a parking system involves movement and storage of vehicles in space. Thus analysis on parking systems involves the study of spatial systems (Young & Taylor, 1991). Spatial GIS analysis would give an opportunity to assimilate, integrate, and present data collected and stored of the parking system (Waerden & Timmermans, 1997). Also GIS allows the illustration of the exact site of each data record and thus the capability of testing policy impacts on the system (Young & Taylor, 1991).

1.2. Research Problem

The main problem of the research is to develop a methodology to assess parking policy interventions geospatially, while also ascertaining the assessment criteria. Thus the problem related to the study of parking policy interventions are discussed, which provides us with the challenges involved in the research. Also a description of the general problems that are related to planning of parking policies are discussed, which gives an idea of problems that the research may address by providing the methodology.

1.2.1. Problems related with the study of parking policy instruments

Firstly, there seems to be an inconsistency in the definition of the parking demand variable. Literature on parking suggests plenty of ways to determine parking demand (Hensher & Button, 2000; L.R.Kadiyali, 2007; O'Flaherty, 1996) and it is not very clear whether the demand is the total car use or utilization at a particular site. Research by Carter Burgess suggest that "estimating parking demand is more of a value judgment, rather than a technical exercise" (CarterBurgess, 2004).

Second is determining assessment criteria for the evaluation of parking policies. The literature does not provide of any such defined standard of evaluation criteria. Although Litman in his book review of "Parking Management: Strategies, Evaluation and Planning" (Litman, 2006) discusses the need of parking system to be efficient spatially, user group wise and economically, while not providing any method to calculate such measures. Thus measuring efficiency of the parking system is another challenge of the research. Quantification of such efficiency parameters presents us with the problem of inconsistency of the definition of efficiency. Also from theory of planning (Cullingworth & Nadin, 2002; Unwin, 1994) it is well noted that these efficiency measures may consist of plenty of qualitative indicators and the quantification of these is another challenge, while also determining the data requirements for these indicators is a tedious exercise in itself.

Finally measuring the scale of the impacts of parking policy instruments presents us with another problem. As already mentioned due to the interwoven nature of the parking policies estimating the impact from one particular intervention is difficult. Parking measures like changes in parking capacity, parking tariffs etc. will affect the efficiency of the parking system. To measure independently the effect of a particular measure is often difficult while also measuring to what extent they impact the whole system is also a problem (Topp, 1993).

1.2.2. Problems arising from poor planning/management of parking

Ample literature and parking policies of different cases (Bedford's Parking Strategy, 2010; CarterBurgess, 2004; Draft Parking Policy for Birmingham, 2008; Essex parking policy, 2007; Lee & Kwon, 1999; Spratt, 2007) discuss the problems a city faces due to poor planning and management of parking. The common problems can be summarised as imbalance of parking supply and demand, on street parking problems, urban design problems and future demand problem.

An imbalance of supply and demand can be seen daily in cities as parking excess where plenty of empty parking spaces are available at certain locations especially in residential areas or outskirts of a city, or insufficient parking at certain locations especially during the peak hours resulting in demand spilling on streets, adjacent properties or neighbourhoods especially in city centres, areas where there has been any land use change or intensification and areas where uses compete for parking. These problems are mainly because of inaccuracies in assessing appropriate level of parking.

On street parking problems is more acute in areas which are major trip generators especially the industrial estates, stations and hospitals. On street parking often leads to congestion on streets while vehicles enter or exit the parking lot while also it is a nuisance for the pedestrians. This also leads to an urban design problem where on street parking leads to reduced open spaces especially in residential areas.

Increased vehicle ownership and the new developments in urban areas lead to an increase in parking demand in future. Assessing the demand for future and planning for an efficient distribution over the city is a problem that most of the local authorities face.

1.3. Objectives and Research Questions

The aim of the research is to devise a GIS model to compute the efficiency of parking areas, simulate the working of parking policy interventions, and estimate future parking problem areas in the city of Enschede.

Objectives and Research questions

Table 1.1: Objectives and research questions

S.No.	Objective	Research Question
1	To set up a GIS model incorporating parking supply (tariffs, location, capacity) and parking demand (peak hour, off peak hour and holidays) to test the efficiency of parking system and test the functioning of parking policy interventions	How to measure efficiency of the parking system? How to devise a GIS model to measure efficiency?
2	To study efficiency (spatial balance, demographic and economic) of existing parking lots (in peak hours)	Where (in the study area) are bottlenecks present in terms of parking excess or demand spilling?
3	To construct scenarios of how changes in parking tariffs/ supply (increase/decrease) will affect the efficiency of the system	Which factors (parking tariffs/supply) affect the efficiency to what extent?
4	To study the impacts of future land use development on parking areas • Study changes in occupancy rates • Identify major bottlenecks in terms of parking excess or demand spilling	Which areas will be affected by new land use developments?

1.4. Conceptual Framework

By studying the interactions of land use, travel demand and parking and considering the problems identified, this research uses traffic demand (to measure parking demand) and parking supply to develop a tool so as to study the efficiency of the parking system (Refer to figure 1.1).

The conceptual framework consists of 3 main tasks:

- Attractiveness of the parking lot- based on which the choice of parking lot is defined
- Parking allocation- the demand of parking needs to be distributed to the existing supply based on attractiveness of the lot
- Efficiency- is further defined on three scales; spatial, user group and economic

The other 4 components discussed in the conceptual framework are:

- Supply: parking supply which is given
- Demand: which is calculated from travel demand
- Parking policy interventions: to be tested which effects the supply side
- Land use developments: to be tested which will affect the demand side

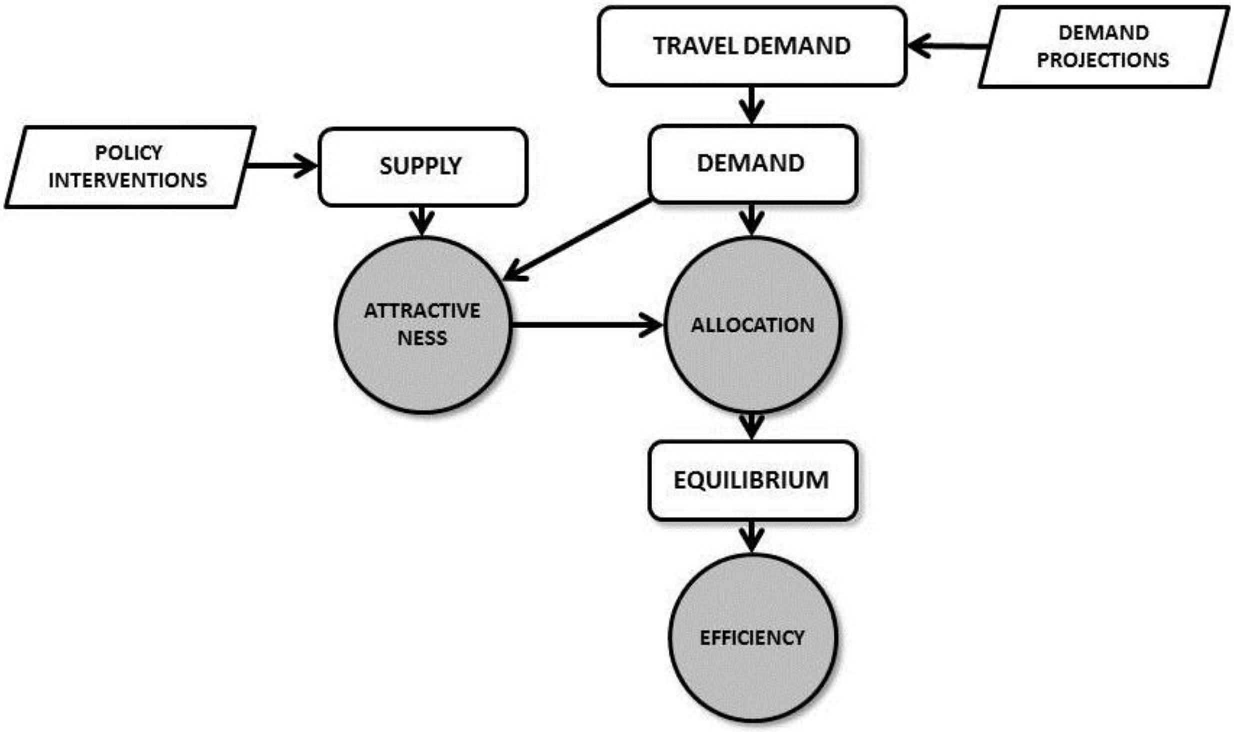

Figure 1.1: Conceptual Framework

1.5. Thesis structure

The research is composed of six chapters. The structure is as given in figure 1.2.

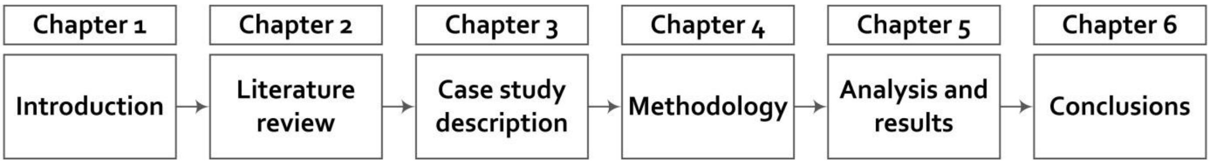

Figure 1.2: Thesis structure

Chapter 1 provides a background of the research in terms of a brief introduction to the topic of the research, describing the research problem. It defines the scope of the research by identifying the research objectives and questions and sketches a conceptual framework for research which also outlines the concepts that need to be studied in detail from literature.

Chapter 2 addresses various concepts related to parking policy in literature and previous works done on the subject in order to establish a theoretical framework for the research to be conducted. It discusses the principles of parking modelling techniques and a framework for the assessment of parking policies.

Chapter 3 discusses briefly the case study which has been selected for the research. Providing general introduction to the city and further specifically the current parking supply and demand information.

Chapter 4 details out the methodology that has been established for the research considering the concepts as discussed in chapter 2 and providing a sequential step wise procedure for achieving the research objectives as defined in chapter 1.

Chapter 5 presents the results attained after implementation of the methodology in terms of the efficiency maps and figures explaining the results obtained.

Chapter 6 provides with the conclusions of the research discussing the main achievements and the limitations and shortcomings of the research conducted. It further discusses some ideas for further improvements that can be made in the presented research and further research required in the subject.

2. LITERATURE REVIEW

This chapter explores the scientific knowledge on parking studies, particularly focussing on parking modelling techniques. The purpose of this chapter is to identify a theoretical framework for accomplishing the objectives defined for the research, based on previous works done on the subject.

2.1. Land use and Transport Interactions

The figure 2.1 represents the interactions between Land use, parking and travel demand. By observing these interactions both the parking supply as well as the parking demand can be designed in a manner compatible for the town and environment.

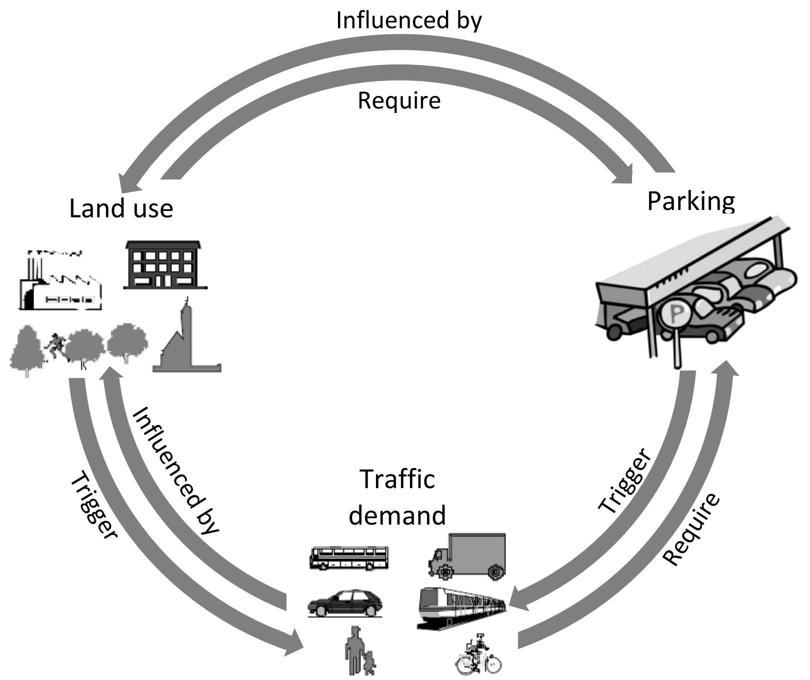

Figure 2.1: Land use and Transport interactions

Source: (GFIVT, 2009)

The research uses these interactions to model parking efficiency. Traffic demand is used to simulate parking demand and land use to simulate parking supply. Land use characteristics have been used to calculate efficiency of the system.

2.2. Parking Policy

2.2.1. Studying the effect of parking policy

First and foremost it is essential to understand why is it important to study the effects of parking policy interventions. As observed from literature parking policy acts as glue between the implementation of land-use and transport policies. Three specific objectives of “Regeneration” of a specific part of the urban area, “Restraining” vehicular traffic and “Revenue” generation from the parking operation as discussed by Marsden (2006) confirm that in various ways, parking policy tries to contribute to the promotion of a more efficient use of the transport network, lower emissions, higher densities and better, more inclusive urban design (Rye, 2007; Stubbs, 2002). Also Hensher and Button (2000) discuss that "The amount and the location of parking affect: the level of service and congestion on access roads and internal city streets; the efficiency, effectiveness and financial performance of public transport; the amenity, safety, and environmental integrity of the city and its surrounds; and the form and functioning of the metropolitan region as a whole".

This study tries to recognize the factors that affect the performance of the parking system in effect understanding the above mentioned issues.

2.2.2. Recurring themes in literature of parking studies

Literature covers a wide range of topics and analytical techniques in modelling parking behaviour. Some research focuses on choice of parking location and others examine the effects of parking policy decisions on travel behaviour, including mode choice as well as parking location. Most recurring themes include the following:

- Parking policy analysis

J. Bates and M. Bradley (Bates & Bradley, 1986) used CLAMP model (Computer based Local area Model for parking behaviour), which is a simulation tool to examine the impacts of parking policy interventions like availability, location, type, size and price of parking lots, on parking demand in the CBD. It models the system by combining a demand model, network model and four stage transport model approach. The demand is disaggregated to destination, duration of stay and purpose of the trip. The supply is characterized by capacity, price, access distance, search distance, egress time and fines or illegal parking. The model presented a dynamic relation between travel demand and parking supply. It operated at three levels; one presenting differences in demand within each period which could explain modal split, congestion and parking lot search. The other was differences in time period within each weekday explaining how demand changes with respect to time periods and lastly differences in travel patterns by day of the week which explored short term and long term parking policy impacts on parking demand.

- Parking location decisions/ Parking choice models

G. Ergun (1971) evaluated impacts of parking policy interventions and the benefits of investment in parking facilities, in particular, location of parking facilities and parking rates. He used a discrete choice approach based on binary logit model. He used variables like parking cost, walking distance from parking lot to destination point, duration of parking and socio-economic characteristics like age and gender, to explain his model. His research reflected the trade-off between walking distance and parking price. The results presented a greater sensitivity to parking price than walking distance and socio economic factors could not help much in explaining parking choice.

D. van der Goot (1982) developed a model to simulate travellers behaviour in selecting a parking lot. He considered walking time from parking location to destination, parking duration, utilization rate of the lot, accessibility factors that account for attractiveness of the parking space. He developed a logit model to explain the choice of the parking space also considering the trip purpose. The results show that off street parking was considered more attractive by all user types; the walking time was a major factor in decision of parking location choice and the parking restrictions had a significant impact on work related trips.

The study by K. Axhausen and J. Polak (1991) examined not only the choice of parking location but also parking type. They used a stated preference approach to account for factors affecting travel behaviour. In addition to parking cost and walking time they also included factors like search time and access time. The results demonstrated a higher sensitivity to parking cost and travel time. After the breakdown of travel time to access time (in vehicle time), search time and walking time, it was noted that users are more sensitive to search time followed by sensitivity to walking time, lower sensitivity was noted towards access time.

- The sensitivity of mode choice decision to parking cost and availability

D.W. Gillen (1977) incorporated a parking variable in the mode choice model. He calculated the elasticity of mode choice with respect to parking costs and determined how changes in parking policy are likely to affect modal shift. He used a binary model that represented choice between transit and automobile. His results show that travellers were more sensitive to parking costs than to transit fares or automobile costs. Additionally it showed low elasticity of mode choice to parking costs.

- Considering parking cost in a different way than other costs such as operating costs and transit fares

M. Florian and M. Los (1980) discuss the impact of supply of parking spaces on parking choice. This research was specifically conducted for station choice in park and ride context. A generalized cost measure was assumed consisting of in-vehicle travel time from origins to the station, parking cost at station and transit fare from the station. The results compared the utilization of each lot which was observed from the license plate surveys and the one that was predicted by their model.

2.2.3. Approaches to study the impact of parking policy

Existing studies on parking policy impacts can be categorized as either empirical studies which are used to study the before and after execution of a parking policy or modelling and simulation studies, which analyse possible impacts of parking policy interventions.

Empirical studies provide us with an opportunity to monitor actual changes resulting from the implementation of parking policies. Although it is often difficult to isolate the effect of a particular intervention from other external effects and distributional effects are difficult to monitor with such an approach (Shiftan & Burd-Eden, 2000).

Examples of modelling and simulation studies include Arnott & Rowse (1999), D.W Gillen (1977) and C.T. McCahill & N.W Garrick (2010). Although such an approach lacks reliability as prediction of a particular impact under many reasonable assumptions is questionable but still such technique can be developed to evaluate new infrastructure (Shiftan & Burd-Eden, 2000).

2.3. Classification of Parking models

This section identifies the main conceptually defined parking models at various scales. Table 2.1 presents a summary of the conceptual models identified in literature discussing the hierarchy of the model and its use.

Table 2.1: Summary of parking models

Model	Hierarchy	Uses
Parking design model	Parking lot or parking site	Relationship of traffic flow and parking inconvenience Performance of the parking lot
Parking allocation model	Sub centre or regional modelling and area wide or metropolitan modelling	Distribution of parking lots Performance of parking system
Parking search model	Parking lot or sub centre	Investigate impact of parking information on route choice and choice strategy Investigate time spent in searching for a parking space
Parking choice model	Implicit at all levels of hierarchy	Study user's reaction to changes in supply, price and operation of parking facilities
Parking interaction model	Sub centre or regional modelling and area wide or metropolitan modelling	Traffic management strategies Parking policy analysis

Source: (Arnott & Rowse, 1999; Bates & Bradley, 1986; Hensher & Button, 2000; O'Flaherty, 1996; Young & Taylor, 1991)

2.3.1. Parking design model

Parking design models give an opportunity to understand the performance of the parking system at parking lot or parking site level. They have been used to calculate the delay to parking vehicles on links, the relationship between traffic flow and parking inconvenience, need for parking spaces and the possibility that a person will not find a place to park and the dynamic capacity of car parks. Also these models enable to investigate competition between the parking lots for patrons. (Hensher & Button, 2000). One advantage of such models is that working on microscopic level they have the capacity to model detailed interactions between individual vehicles thus also investigate impact of parking on a link.

2.3.2. Parking allocation model

The problem that parking allocation models focus on is of allocating a fixed number of arrivals to the parking stock. They have their application at activity centres or metropolitan or sub-regional transport level (Arnott & Rowse, 1999; Hensher & Button, 2000; Young & Taylor, 1991).

- Optimization models

The purpose of these optimization models is to ensure that the existing parking facilities are used as efficiently as possible. They present with an opportunity to determine the optimal location and size for parking facilities or "best possible" distribution of parking. One disadvantage of these models is that they don't consider the dynamics of choice nor do they recognize the driver's lack of information of the parking system. (Hensher & Button, 2000).

- Constraint model

The basic principle in these models is that the users look for a satisfactory parking space rather than an optimal one. This model offers an alternative to optimization models by considering the subjectivity of choice but this nature of allocation makes calibration difficult (Hensher & Button, 2000).

- Gravity model

These types of allocation models determine the origin-destination matrix. The problems attempted by such models include change in parking policies like those of price, time, parking stickers etc. One shortcoming of such a model is that it is rather a simple representation of reality. (Hensher & Button, 2000).

- Traffic assignment

Given an O-D matrix this model allocates the vehicles to traffic and parking network. They can investigate the level of parking along roads, the utilization of parking lots etc. This level of detail is modelled using time update macroscopic simulation. "This aggregation provides the level of detail required while still enabling the realistic computer run times"(Hensher & Button, 2000).

2.3.3. Parking search model

These models attempt to understand the parkers' behaviour recognizing the role of searching for a parking space in a parking system. According to Hensher and Button (2000) they account for drivers' preconceived perception about the system in order to making a parking choice decision. They model individual drivers or group of drivers thus replicating the temporal and dynamic aspects of choice (Thompson & Richardson, 1998). These models can be used to investigate impact of parking information on route choice, the time spent in parking search and the characteristics of parking space that attract drivers (like location, comfort, safety on route, safety in space, quality of route etc.)(Hensher & Button, 2000; Young & Taylor, 1991) .

2.3.4. Parking choice model

Implicitly parking choice is modelled in all parking models mentioned above. As Hensher and Button (2000) discuss these models generally aim in modelling parkers behaviour to changes in (supply, price, operation of) parking facilities. These are expressed in form of multinomial logit model. These models have been used extensively to model mode choice and location choice (Arnott & Rowse, 1999; Bates & Bradley, 1986; D.W. Gillen, 1977; Hensher & Button, 2000; Young & Taylor, 1991).

2.3.5. Parking interaction model

The allocation, search and choice models can be collectively used for parking policy analysis (Hensher & Button, 2000). These models can be used at any hierarchal level but are mostly used to assess impacts of regional or local parking policies. These models can use a combination of empirical or modelling and simulation techniques in different components of the study.

2.4. Parking demand

2.4.1. Supply and demand equilibrium

"In classical economics it is conventional to treat both supply and demand as a function of cost"(Hensher & Button, 2000). The cost is supposed as a 'generalized cost' which can be any variable which would affect the demand for parking such as price, travel time, walking time, security etc. The supply reflects the response of the parking system to a particular level of demand.

2.4.2. Parking demand modelling

Three ways of assessing parking demand have been identified from literature:

Vehicle ownership: All the cars should be parked before and after they undertake any activity. Thus overall demand of parking is highly dependent on the level of car ownership in an area. But this way of assessing parking demand will usually lead to an overestimation of demand and also the actual distribution of demand is unknown. This method can be used to estimate the total land use requirement for parking in a city.

Actual utilization of parking lots: Although this method of assessing parking demand is the most accurate way as the actual user behaviour is noted and also the distribution of demand is known. But still it does not account for excess/ spill overs and also this method requires extensive surveys which can be a tedious exercise.

Trips made to the zone: The demand for parking is derived from the demand for trips to a particular zone. Examples of studies which use such method to assess parking demand include R. Arnott & J. Rowse (1999), Carter Burgess (2004), G. Ergun (1971), Y.Shiftan & R.Burd-Eden (2000) and B.P. Feeney (1989). Although the distribution of trips within the zone is not known but it gives a more realistic picture of parking demand as all the cars that enter the zone at a specific time interval will need a parking space.

2.5. Parking lot Attractiveness

Attractiveness of the lot explains whether the lot will be used by the user or not. This choice largely depends on behaviour of the user. Some research use revealed preference approaches or stated preference methods to simulate this behavioural phenomenon. Others use some proxy indicators like the location and trip characteristics etc. to model it.

D.W. Gillen (1978) defined the attractiveness of a parking lot by location characteristics and socioeconomic characteristics of the user. Also J.D Hunt and S. Teply (1993) in their paper entitled " A nested logit model of parking location choice" considered 10 attributes to calculate parking choice which were a combination of social, location and trip characteristics. Most commonly used attributes have been classified in the table 2.1.

Table 2.2: Parking Choice factors used in literature

	Factors
Socio economic characteristics	• Age of the user • Sex of the user • Individual personal gross income
Trip characteristics	• Trip purpose • Difference between intended parking time and maximum permitted parking time • Distance from actual destination • Time spent waiting for a stall
Location characteristics	• Cleanliness of facility containing stall • “Noticeability” of the facility (assumed to be related to the size of the facility). • Type of winter provision • Condition of parking surface (whether smooth paved, rough paved with potholes or cracks, gravel or dirt) • Parking fee at the location • Duration of parking in hours • Occupation rate of the parking places considered as a percentage of parking places available within a certain distance
Other social factors	• Safety of the driver • Protection of the driver’s vehicle-assumed to concern vandalism

Source: (Arnott, 2006; Arnott & Rowse, 1999; Axhausen & Polak, 1991; Florian & Los, 1980; David W Gillen, 1978; Hunt & Teply, 1993; vanderGoot, 1982)

2.6. Parking system efficiency

The literature does not provide of any defined standard of evaluating effects of parking policy interventions. Although Litman (2006) discusses the need of parking system to be efficient spatially, demographically and economically, while not providing any method to calculate such measures. Thus for this research these three measures of efficiency are considered for assessment. An efficient parking system should hence take into account spatial, user group wise and economic factors (Litman, 2006):

2.6.1. Spatial balance

Spatial efficiency measure of assessment explains the balance of parking supply and demand at various scales of study. The available parking space and the parking demand should be balanced not only city level but also detailed zone level. Zones should be such that search time within the zone is optimal. Moreover, it is possible that the parking supply and demand are balanced overall but due to inappropriate distribution of parking spaces over the city some zones experience demand spilling or parking excess issues (GFIVT, 2009; Litman, 2006).

2.6.2. User group balance

The balance between supply and demand for different user groups should be achieved. For e.g. residents need parking for a longer duration thus even if enough short term parking space is available in the zone it will not be used by residents, also sometimes parking is reserved for residents which cannot be used by other users (employees, customers, visitors and service providers) (Gachanje, 2010; Spratt, 2007)

2.6.3. Economic efficiency

The concept of economic efficiency is based on the notion that the use of the available resources produces the highest value. Comparing the parking returns and maintenance charges would give an estimate of the parking efficiency measure (Petiot, 2004).

2.7. Conclusions

The chapter described the land use and transport interactions as this forms the base of the conceptual framework, discussing the influence of land use characteristics on traffic demand which induces parking demand and its effect on the land use characteristics in return. It further continued to discuss why is it important to study the effect of parking policies highlighting on the previous works done on it so as to know what is of importance in the topic. Additionally, the chapter theoretically discusses the parking modelling approaches, further focussing on parking demand modelling and methods of calculating attractiveness and efficiency of the parking system. These discussions lead toward achieving the objectives. Based on the different modelling techniques further a methodology is formulated for parking choice and parking allocation modelling. The efficiency measures as discussed have been used for analysis.

3. CASE STUDY DESCRIPTION

The chapter discusses the choice of case study and gives a brief introduction to the case in relation to parking areas available and trips made to the zone in peak hours. It also discusses the problems in the study area and the current initiatives that are being made by the local bodies to resolve them.

Considering the general problems with parking areas in cities as discussed in literature, a case which had similar problems at the local level was required. The case of Enschede was thus selected as it presented with an opportunity to explore these problems in detail. Also with the Gemeente Enschede starting to work on parking policy for the city in 2011, the recent data of parking supply, utilizations and demand was available at ease.

3.1. Case Study Introduction

The municipality of Enschede consists of Enschede city and the rural municipality of Lonnekar and expands in an area of approximately 143sq.km. The city inhabits approximately 157050 people in the year 2010. Figure 3.1 shows the increase in passenger cars over the last decade in Enschede. In 2010 the total passenger cars in Enschede were approximately 65000 i.e. approximately a car for every 2 persons. With almost 66091 cars in 2011 and assuming standard parking bay size of 2.5*5 m^2 there is a requirement of approximately 90 ha of area in the city at all times for all of them to be parked.

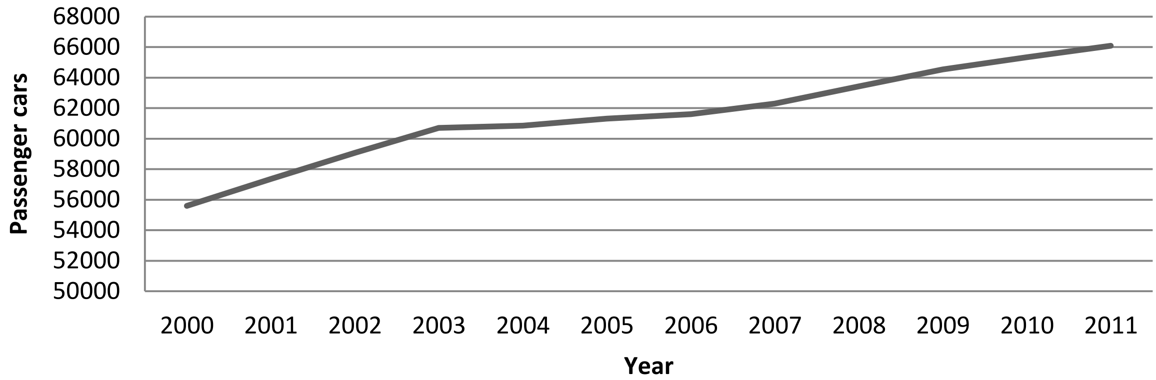

Figure 3.1: Increase in passenger cars over the last decade in Enschede
Source: ("Statistical Yearbook," 2011)

Enschede is a mixed-use community centre. Residents take advantage of the shopping, entertainment, and business destinations available. Land uses include government facilities such as City Hall, the Police Station, the Banks and commercial centre. Many service agencies operate in support of local and county government. Privately funded investment includes administrative and customer service facilities for several local and regional banks, businesses engaged in real estate, and other private business services. Several restaurants, live performance and cinema venues, and a wide variety of shopping can also be found within a few kilometres. Other attractions include several churches, an art facility providing training and sales space, and Tuesday and Saturday large open market in the city centre attracts a lot of people from the region. Thus culturally Enschede takes a leading position within the region.

The case study area is only the ring area of Enschede because of the problems of data availability. It consists of 8 parking zones with almost 22,210 parking lots available. The 8 zones comprise of the centre of the city and the surrounding neighbourhood. There are approximately 610 earmarked parking spaces (refer to figure 3.2), with over 90% as on-street parking spaces but there are 6 garage parking lots which constitute almost 18% of the total parking capacity (refer to table 3.1).

Table 3.1: Number and capacity of the parking lots in Enschede

Parking type	Number of spaces	Total capacity
Garage	6	4200
Off street	12	512
On street	592	17498
Total	**610**	**22210**

Source: I&O Research, 2011

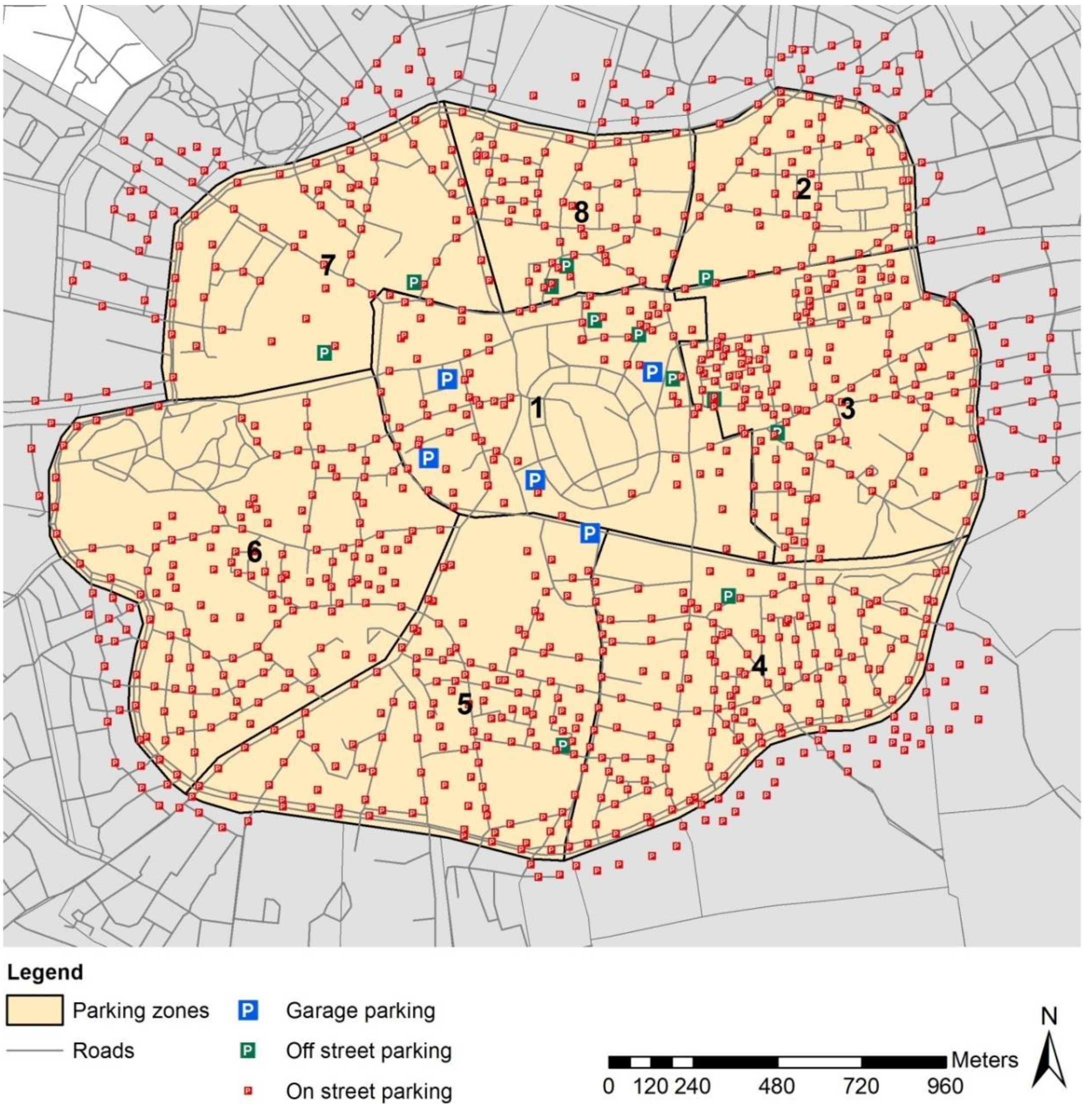

Figure 3.2: Enschede- Parking lots and zoning
Source: I&O Research, 2011

The city generates almost 9,612 and 7,930 trips in the morning and evening peak respectively on a usual working day (refer to table3.2). Almost 40% of the morning trips are destined to zone 1 whereas evening trips are more distributed (refer to figures 3.3 and 3.4).

Table 3.2: Morning and evening peak trips distribution over the zones

Zones	Morning trips 2010	Evening trips 2010	Shopping %	Work%
1- City centre	3869	2194	35	65
2- De Laares	269	358	45	55
3- De Bothoven	370	363	29	71
4- Hogeland Noord	818	440	26.5	73.5
5- Veldkamp Getfert	1467	1271	38	62
6- Horstlanden Stadsweide	1379	1094	48	52
7- Boddenkamp	690	930	44	56
8- Lasonder Zeggelt	750	1280	48	52
Total	9612	7930	39	61

Source: Goudappel Coffeng, 2011

3.2. Case specific problems

As mentioned in a presentation from Gemeente Enschede (2011) the city faces problems of:

1. Imbalance of supply and demand,
    a. Parking excess at certain locations especially in residential areas
    b. Insufficient parking at certain locations especially during the peak hours resulting in demand spilling on streets, adjacent properties or neighbourhoods especially in the city centre
2. On street parking problems, more acute in areas near station and hospital
3. Urban design problem: There are trucks and vans parking in residential areas. Also on street parking leads to reduced open spaces especially in residential areas.
4. Future demand increase: Increased vehicle ownership and the expected RO-development in Centrum will lead to more car parking. The parking demand and parking supply must remain balanced without peak dimensioning. By far the new constructions do not or only partially fulfil the requirements for parking.

These are also the general parking problems experienced in most of the cities. They arise from poor planning or management of parking policies. These are also in line with the research problem. It is to address these issues of parking that a tool is such formulated to assess impacts of parking policies so that an informed decision can be taken.

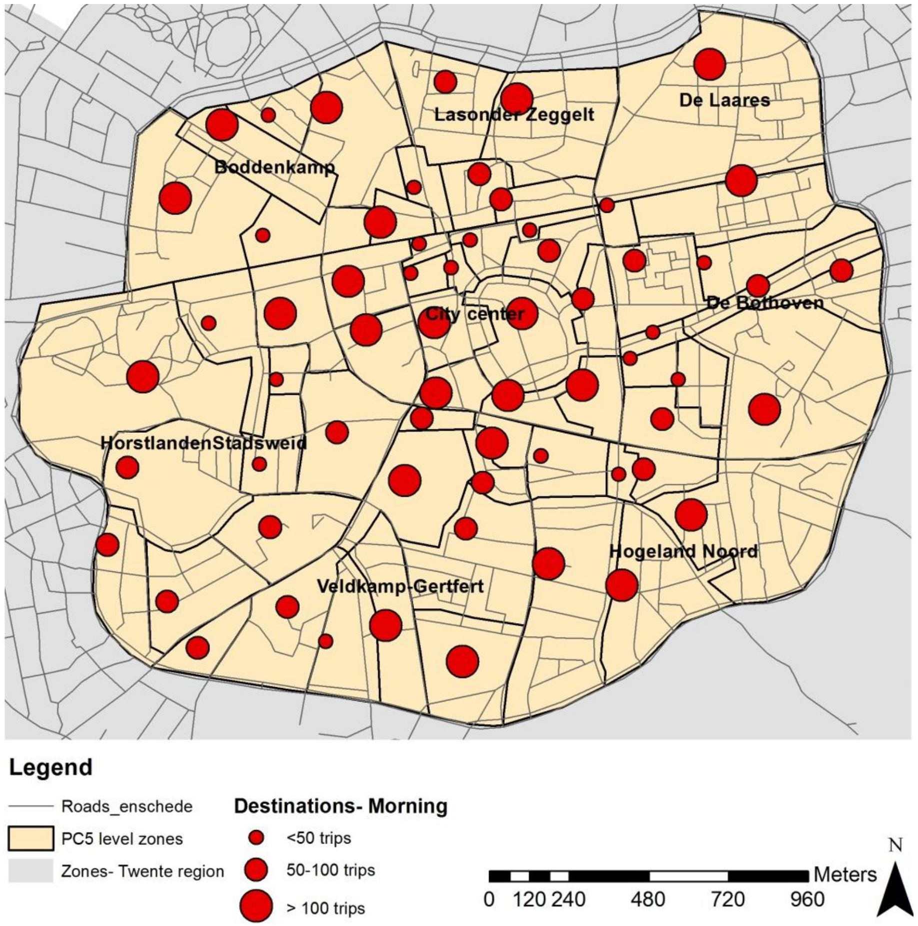

Figure 3.3: Destinations- Morning

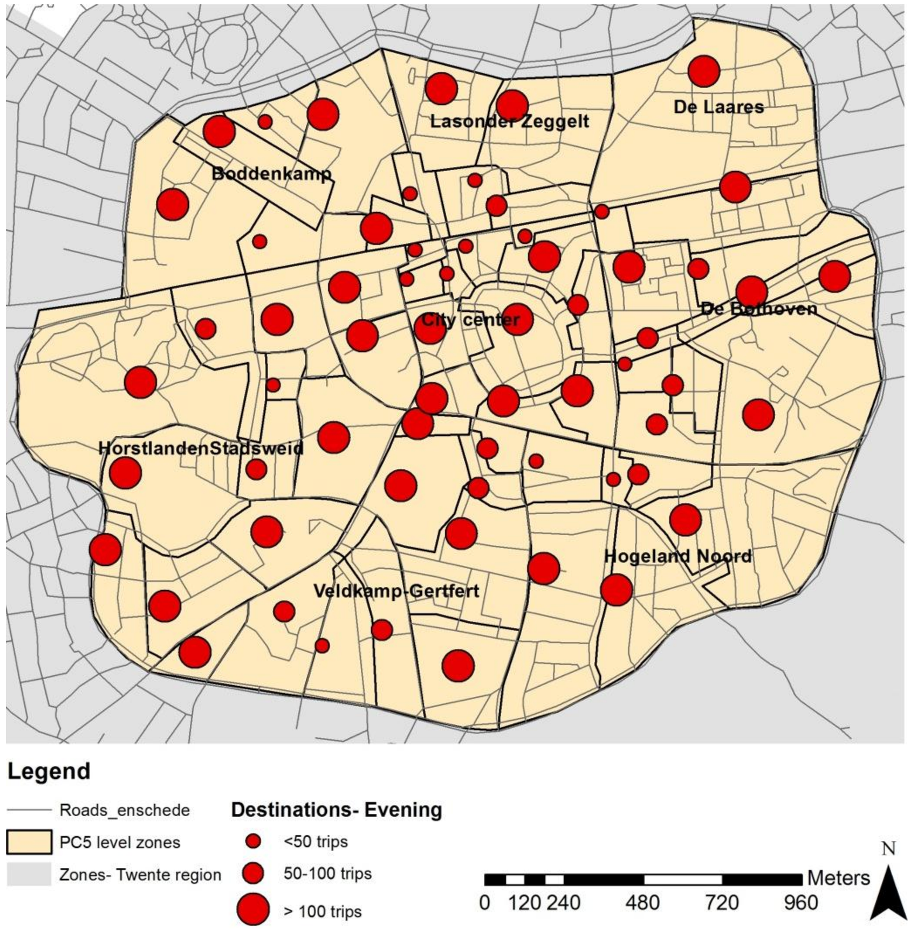

Figure 3.4: Destinations- Evening

Source: Goudappel Coffeng, 2011

3.3. Current initiatives

Currently, the Gemeente Enschede is developing a parking vision for 2012-2020. From this the Gemeente aims to get insight into current and future developments which could lead to development of plans to maintain parking balance. By updating and recording the current parking standards and research into the desirability and feasibility of, parking and accessibility, may contribute to the future parking needs. The Parking Vision 2012-2020 (Gemeente Enschede, 2011) highlights certain goals, which are as follows:

1. Improving the quality of public spaces especially with regard to streets
2. Better distribution and better use of existing parking areas and finding a balanced future parking capacity, using instruments of parking regulations and parking standards
3. Promoting sustainability through parking regulations
4. Solving urgent parking problems in residential neighbourhoods like parking trucks and vans, parking excess etc.

3.4. Conclusions

In conclusion, Enschede experiences problems that arise from poor planning or management of parking. To resolve these, a methodology is such required which can test the planning of parking policy measures and indicate the consequences of those initiatives. This is what the research aims at i.e. how to measure the consequences and how to test the parking policy interventions, which is further discussed in the methodological framework of research. This chapter also presented an introduction to the case study with respect to the parking areas available and the travel demand distribution both in morning and evening peak hours. This data is used as parking supply and parking demand in the analysis phase.

4. METHODOLOGY AND DATA COLLECTION

This chapter discusses the methodological approaches in addressing the research objectives of the study and provides with an overview of the data collected. The methodology is basically divided in six phases (Refer to figure 4.1). These phases have been discussed below:

4.1. Phase I- Concept development

The first phase of the methodology was about concept development, which involved defining the purpose of developing a GIS model for the study of parking policy interventions, understanding the factors influencing parking policy and formulating a conceptual base for identifying the requirements for parking system analysis. It was purely based on literature review. The deliverables of this phase were in terms of research justification, research problem, aim, objectives, and research questions, data requirements for the analysis and the theoretical framework for developing the research. The theoretical framework consisted of principles of parking modelling, determining an assessment criteria (or efficiency) for evaluation of parking policies and outlining data requirements for the same.

4.2. Phase II- Data Acquisition

The second phase concerns of data collection. The data identified in the first phase was then acquired through secondary sources. The main data concerning parking system analysis that was collected is as discussed in table 4.1.

Table 4.1: Data Collected

Parking Supply	Parking Demand	Parking lot Attractiveness	Other data
1. Character wise • On street • Off street • Garages 2. Attributes • Location • Capacity • Tariffs • Operating times • Maintenance costs 3. Parking zoning system • Parking zones	1. O/D data • Weekday peak 2. Actual Utilization • Weekday peak • Weekday off peak • Weekend peak	1. Any behavioral survey data 2. Trip characteristics • Trip purpose	Major activity locations/ Land use Current parking policies with special reference to pricing policies Future land use developments and/or any parking provision plans.

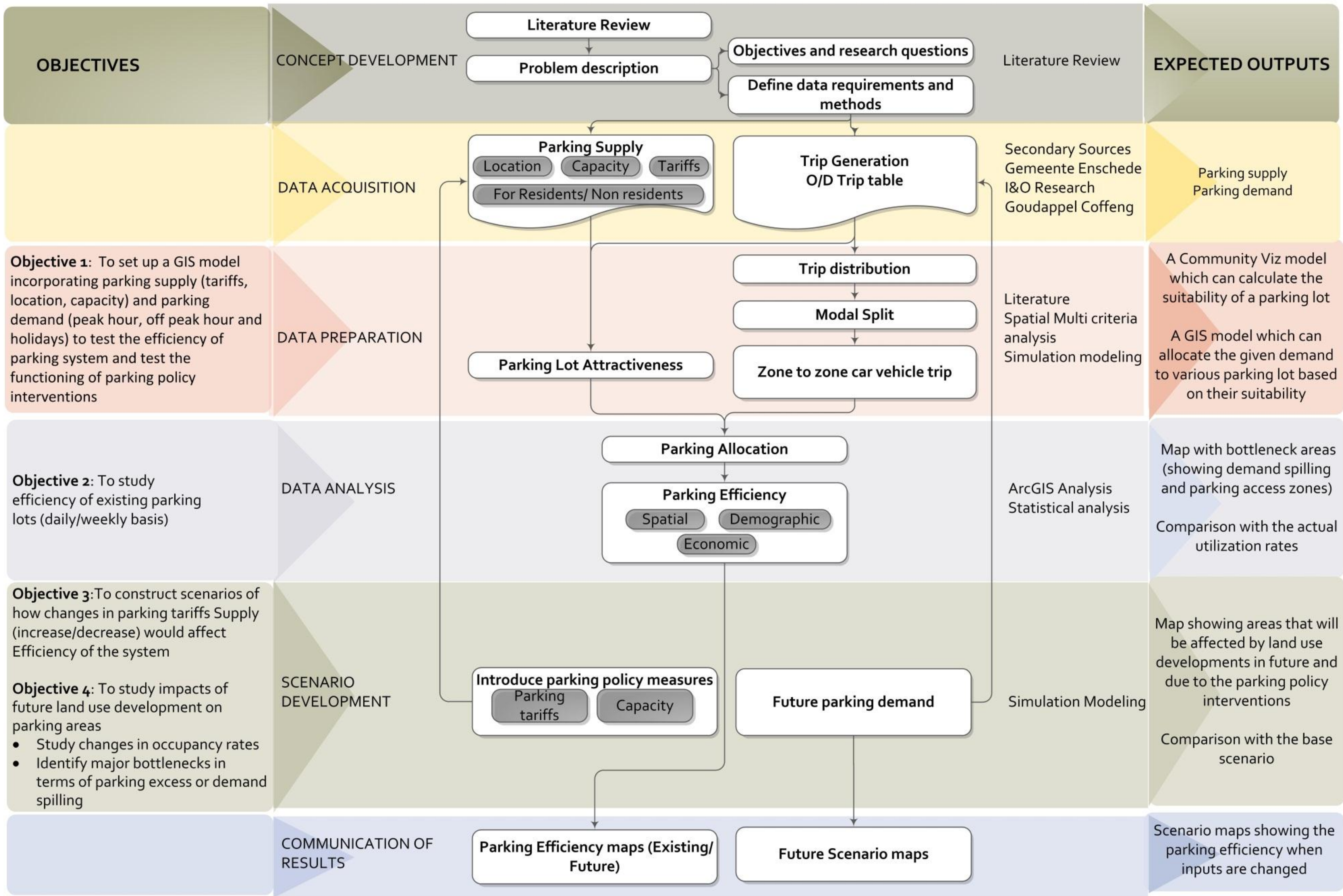

Figure 4.1: Methodology for Research

The data was collected from secondary sources, mainly from the Gemeente Enschede, I&O Research and Goudappel Coffeng.

Figure 3.1 shows the study area with parking locations divided in zones. The study area for this study is Enschede city within the inner ring road. The study area is divided in 8 parking zones. These zones constitute the centre part of the city and surrounding neighbourhood. There are currently some 19,000 public spaces split between on street, off street and garage parking lots. Table 4.2 shows the distribution of parking in Enschede zones.

Table 4.2: Zone wise total parking in Enschede

Zone	Parking
1	3902
2	1192
3	998
4	2636
5	1586
6	3412
7	3306
8	2179
Total	**19211**

Source: Gemeente Enschede, 2011

4.3. Phase III- Data Preparation

The third phase that was the data preparation phase was about constructing a model using GIS tools using the data collected in the above phases.

This phase uses the concepts of parking models as described in the literature. A parking interaction model has been used combining parking choice decisions and parking allocation modelling.

The O/D trip data was used to calculate zone to zone car vehicle trips, i.e. the demand for parking. Also the supply data and trip characteristics data was used to calculate suitability factor for each parking lot, i.e. attractiveness of the parking lot. This suitability factor describes the parking choice decision. The higher the suitability score, the higher is the probability for the user to use the particular parking lot and vice-versa. Further the parking choice decision is made use in parking allocation model, which is of the nature of a constraint model.

4.3.1. Parking Demand Calculation

As discussed in literature, demand is calculated from trips distribution (refer to figure 4.2). This research uses the O/D matrices to calculate the distribution of trips for different zones. Omni TRANS model for Twente region from Goudappel Coffeng was obtained. Two matrices one for morning peak (9:30 to 10:30 AM) and evening peak (4:30 to 5:30 PM) on a normal weekday for 2010 and 2020 and another one which was trip purpose wise model for the region for a normal weekday was available.

From the Omni TRANS model for Twente region, the O/D trip data of zone to zone car vehicle trips (number of arrivals) in the morning and evening peak for the study area was extracted to give the current arrivals to a zone. Also peak hour arrivals for 2020 were extracted from this model.

As the attractiveness of a particular parking lot will differ based on the purpose for which trips are made, the distribution of demand trip purpose wise was required. It was further used in the allocation model. Thus from the trip purpose wise Omni TRANS model percentages of trip purposes were extracted for the case study area. These percentages were used to calculate the distribution of peak hour trips. Since the land utilization data collected does not distinguish between work and business or school, only shopping and work purposes were considered. The business and school trips have been added to the work trips.

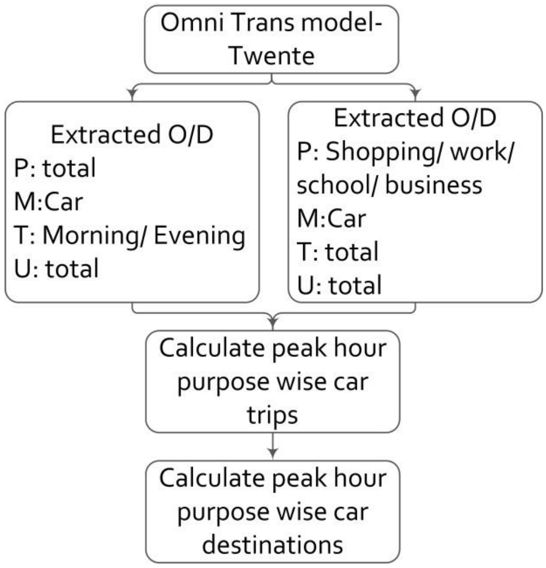

Figure 4.2: Methodology to calculate parking demand

The research focuses on peak hour efficiency of parking lots; hence morning and evening peak hour destinations were used in the allocation model, in the end comparing the efficiency of the system at these two time durations. Also hourly calculations limit the complications that would otherwise arise due to parking turnover rates.

Thus overall there were mainly 2 assumptions made in calculating parking demand. These assumptions and their justification are as discussed in table 4.3.

Table 4.3: Assumption in demand calculation and justification

Assumptions	Justification
Total parking demand- Assumed to be equal to the trip destination for an hour	All trips that end up in a zone need to be parked thus this was considered to be the full demand of parking for the zone for a particular duration.
Trip purpose- O/D data trip purpose wise for a day was available for Twente region, the same percentage distribution has been used for hourly distribution for Enschede	Based on data availability

4.3.2. Parking choice modelling

A parking choice model generally tries to model the user's behaviour pattern in order to estimate mode choice or location choice. This research uses a similar approach to model location choice using a spatial multi criteria evaluation technique.

Multi criteria analysis can be defined as a mathematical tool allowing the comparison of different alternatives according to many criteria. A criteria is a function defined on the alternative which represents the users preferences according to some point of view, they can be quantitative or qualitative. Spatial multi criteria analysis refers to the application of multi criteria analysis in spatial context where alternatives, criteria and other components of the problem have a spatial dimension (Chakhar & Mousseau, 2010).

Location factors of the parking lot and trip characteristics of the users have been used to calculate an attractiveness factor for each parking lot. The suitability score thus calculated is further used in the allocation model. The factors selected for calculating attractiveness have been chosen based on the data availability; they are as discussed in table 4.4.

Table 4.4: Factors used to calculate suitability of parking lots

Group	Factor
Trip Characteristics	• Walking time from parking place to destination (in minutes) • Trip purpose
Location characteristics	• Parking charges • "Noticeability" of the facility (assumed to be related to the size of the facility). • Condition of parking surface (whether smooth paved, rough paved with potholes or cracks, gravel or dirt) • Type of winter provision • Safety of the driver and driver's vehicle-assumed to concern vandalism • Ease of searching a parking lot (assuming that if it is on street it is well visible)

This calculation of parking choice is dealt with, in 2 phases as shown in figure 4.3 (also see annexure 7.1 for the model setup); first a suitability score for each parking lot is calculated from the location characteristics; next the trip characteristics have been incorporated in the allocation model as their value changes for different trip purposes.

The spatial multi criteria analysis is applied in a CommunityViz model. CommunityViz Scenario 360 is a GIS-based decision support software; it is an ArcGIS extension that helps to view, analyse and understand land-use alternatives and impacts (Placeways, 2012). The model has been setup using the five location characteristics as mentioned in table 4.4. The factors use attributes of the parking lots to calculate the suitability of each parking lot. Some assumptions have been made in the model in order to quantify the characteristics. The assumptions and their justifications are as discussed in table 4.5.

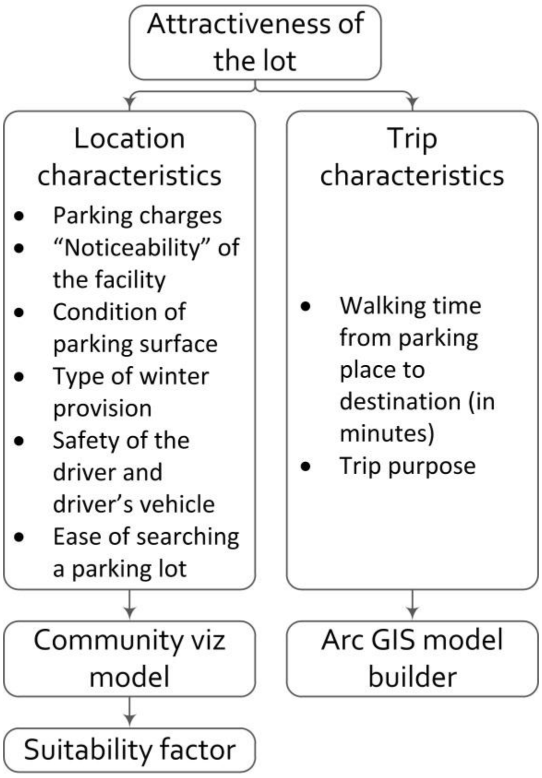

Figure 4.3: Calculating attractiveness of parking locations

Table 4.5: Assumptions in the CommunityViz model and the justifications

Assumptions	**Justifications**
The choice of five location factors and two trip characteristics	Based on data availability
Noticeability- Assumed to be relative to capacity of the parking lot	If the size of the parking lot is huge, it is easier to locate it for the users, also probability of finding an empty lot is high
Safety and winter provision- Assumed to be relative to parking type	Garage parking areas have a surveillance camera thus they are more secure and are covered thus provide winter provision unlike off street or on street lots
Condition of parking surface- Assumed to be relative to parking type	Garage parking lots are regularly maintained thus the surface is assumed to be more even as compared to on street lots
Ease of searching- Assumed to be relative to parking type	The factor describes the ease of finding the lot and since the on street lots are visible directly to the user unlike the garage lots it was considered that they are easy to search.
Weightages of the factors 1. Parking charges- 3.5 2. Noticeability-2.5 3. Ease of searching-2 4. Safety and winter provision-1.5 5. Condition of parking surface-0.5	The factors were discussed with experts from Gemeente Enschede and based on the ranking as decided by the experts they have been given a score out of 10.

4.3.3. Allocation model

The purpose of an allocation model is to allocate the arrivals to the existing parking stock. As discussed in literature they can be of 4 types; optimization model, constraint model, gravity model or traffic assignment model. Based on the data available the research uses a constraint model for allocation. The basic principle behind this model is that the users look for a satisfactory parking place rather than an optimal one (Hensher & Button, 2000). A simulation model in ArcGIS model builder was thus developed which determined a set of acceptable parking places and then allocated the incoming vehicles to them in peak hours. The set of acceptable parking places was determined by the parking choice model as discussed in section 4.3.2.

The conceptual allocation model is as shown in figure 4.4. The logic behind the model is that the trips entering a zone search for parking locations which are closer to their final destination within the zone and based on the characteristics of those parking spaces they select the one which is most satisfactory. The model is implemented in 7 steps, they are as discussed below:

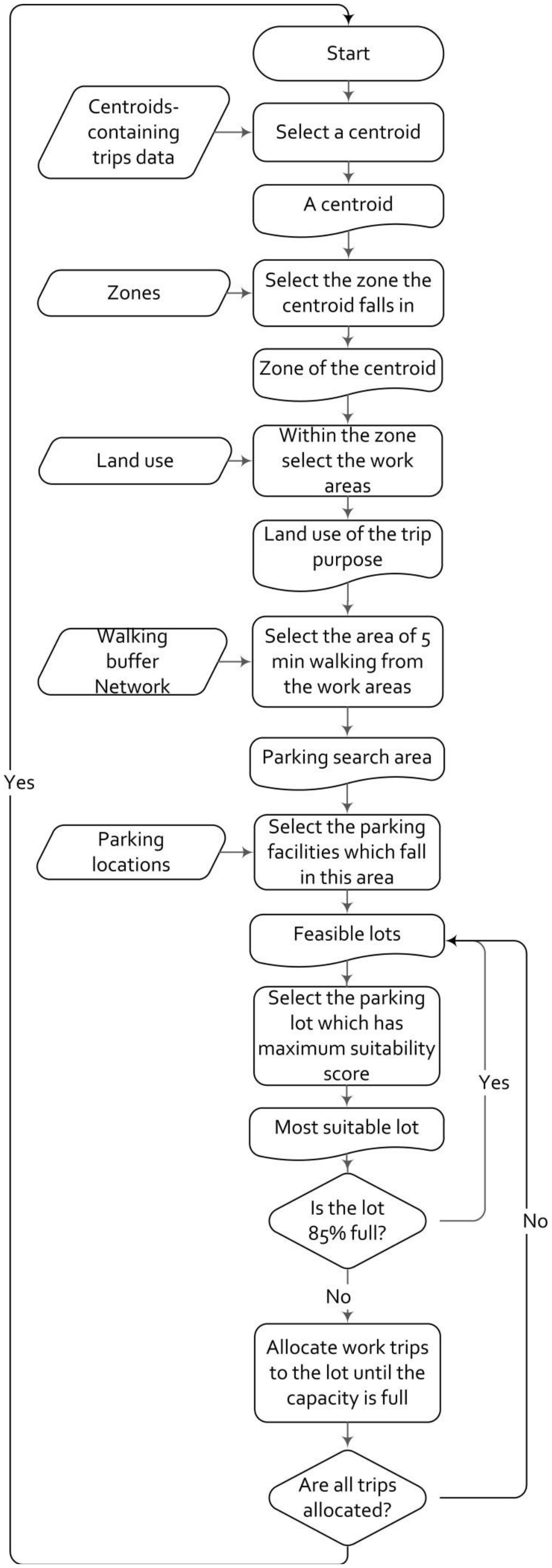

Figure 4.4: Conceptual allocation model

Step 1: Collecting the arrivals of trips in a zone. The centroids of the zone (Post Code 5 level) contain the trip data. Allocation is systematized zone wise. Thus firstly a centroid is selected.

Step 2: Selecting the zone the centroid falls in. The trips are destined to somewhere within a zone in reality; centroids are just an imaginary point within the zone made for the sake of distance calculations. Thus the zone is obtained to which the cars enter.

Step 3: Selection of the final destination of the trips within the zone. The destination of the trips is defined by the trip purpose. The data available for trip purpose is obtained from the Omni TRANS model. Only shopping and work purposes are used. In this step the final destination is assessed using the land use data, for work trips land use category industrial, public, military and private business and for shopping trips land use of category commercial is used.

Step 4: Defining the search area for the trips. After the final destination of the trips in the zone is assessed, a parking search area from that final destination is evaluated. The search area is defined as 5 minutes walking area from the final destination. The logic behind that is that the users wish to park their cars as close as possible to their destination so as to minimize the cost of walking. The threshold of 5 minutes is determined from literature. Network analysis is used to calculate walking distances from various land use areas in a zone.

Step 5: Selecting the feasible lots. Within this search area all the parking lots are thus selected. This is defined as the set of feasible lots.

Step 6: Selecting the most suitable parking lot. From the set of feasible lots the parking lot which has the maximum suitability score (the suitability score as obtained from the parking choice model) is selected.

Step 7: Allocation of the trips obtained in step 1 to the selected suitable parking lot found in step 6. This calculation is done by considering the number of trips and the capacity of the parking lot selected. If the numbers of trips are less than the capacity of the parking lot then all the trips are allocated otherwise the whole capacity of the parking lot is consumed and the remainder of the trips is noted. If there are trips remaining then from the set of feasible lots another parking lot is selected which has the next highest suitability score and the trips are allocated to it. The process is repeated until either all trips are allocated or the set of feasible lots has no remaining parking lot defined. In the latter case the remaining trips are considered to be the demand spill over for the zone.

After the allocation of trips for a centroid is complete the whole process is continued for the next centroid and so on, starting from step 1 until all the centroids trips have been allocated. The model consists of nested loops i.e. a loop within a loop, the minor loop of the allocation step 7 and the major loop of steps 1 to 7. Henceforth the model has been developed in 2 parts; the main model and the sub model (see Annexure 7.2 for the setup in ArcGIS model builder). The main model implements steps 1 to 5 thus determining the number of trips from the centroid and a set of feasible lots for that particular zone depending on the trip purpose, whereas the sub model implements steps 6 and 7 i.e. selecting the suitable parking lot and allocation of trips. After completing the loop in the sub model it returns back to the main model thus obtaining another set of trips and feasible parking lots. The model is run once for allocating work trips and then for shopping trips separately for morning and evening peak hours. Quite a few of assumptions have been made in the model to simulate allocation. The assumptions and their justifications are as discussed in table 4.6.

Table 4.6: Assumptions in the allocation model and their justification

Assumption	Justification
Vehicles park at least for an hour	To avoid consideration of parking turnover rates, thus making the model simple
Some percentage of parking is already filled up- Assumed to be a random number of actual utilization	The model allocates trips at peak hours, it cannot be considered that parking lots lay vacant at this time; they already will have some cars from previous time durations. This calculation must be made by considering average parking duration for the parking lots. Since such data was not available, it was generated as a random number between the range of actual utilization of the lot.
5 minutes of walking distance is assumed to be feasible	Frank et al. (Frank, Bradley, Kavage, Chapman, & Lawton, 2008) in their work discuss “relative contribution of urban form, time and costs in explaining mode choice for home and work related trips”. They present parking costs in terms of

Assumption	Justification
	walking as 5.4 minutes for home based work trips and 4.6 minutes for home based non work trips as a revealed behaviour in case of Seattle. An average of these two values is used in lieu of such information for the case of Enschede.
Trip purpose wise allocation- Priority is given to work trips in the morning, and shopping trips in the evening	Priority was discussed with the experts from Gemeente Enschede

4.3.4. Calculating efficiency of the system

As mentioned in literature there are 3 types of efficiency measures; spatial, user group and economic. But due to data limitations only a spatial efficiency is calculated. The spatial efficiency is calculated at three scales; parking zone level, administrative zone level (PC5) and parking lot wise.

- Parking zone wise- giving an overall picture of utilization of parking lots in each zone
- Area/ zone wise- these are the PC5 level zones, giving a further detail of efficiency within the zone of parking lots utilized within 5 minutes of walking distance from the destination, the zones where the utilization of parking lots is less than 25% and those zones which have demand spill over (i.e. the trips entering the zone but cannot find a parking lot within 5 minutes of walking) have been emphasized
- Parking lot wise- parking lots which are more than 85% utilized and the ones which are 25% or less utilized have been highlighted

4.4. Phase IV- Analysis

The fourth phase of data analysis comprises of the calculation and presentation of parking allocation and spatial efficiency of the parking system. By the model defined in phase III the parking demand is allocated to the existing parking stock i.e. to each parking lot based on the attractiveness of the lots. This information is then aggregated parking zone wise, PC5 zone wise and parking lot wise to calculate the spatial of the system.

The allocation by the model is compared with the actual utilization rates based on the statistical measure of mean absolute error (MAE) and root mean square error (RMSE). “MAE is used to measure how close the forecast or prediction is to the eventual outcome. It measures the average magnitude of errors in a given set of forecasts, without considering the direction” ("Mean Absolute error and Root mean square error," 2010) and is calculated by the given formula.

$MAE = \frac{1}{n}\sum_{i=1}^{n}|f_i - y_i|$; Where f_i is the predicted value and y_i is the true value

Root mean square error is another statistical measure to check the accuracy of the model predictions by comparing the predicted and actual values. It measures the average magnitude of error. In words, the difference of the predicted and actual values is squared and then averaged over the sample.

Finally the square root of the average is taken ("Mean Absolute error and Root mean square error," 2010; Wikipedia, 2011). RMSE is calculated by the formula given below:

$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - y_i)^2}$; Where $f_i$is the predicted value and $y_i$is the true value

The MAE and RMSE can be used together to diagnose the error in a set of forecasts. The RMSE will always be greater than or equal to the MAE; the greater the difference between them, the greater is the variance in the individual errors in the sample. If RMSE=MAE then the errors are of the same magnitude.

4.5. Phase V- Scenario Development

The fifth phase consists of scenario development. Two scenarios are tested:

- Parking policy to decongest the city center- In this scenario two parking policy interventions are tested. One is increase the parking tariff by 20% in the parking lots in the center parking zone. Using the new tariff structure the parking choice model simulates the new suitability of parking lots, based on which the allocation is done. Second is by decreasing the capacity of the parking lots in the center parking zone by 20%. Again the new suitability factor is generated and allocation done. Both of these interventions are supply side policy instruments.
- Future development- the trip distribution of the year 2020 is used to estimate with the current parking stock which areas are most affected. The policies thus formulated should focus on these areas. The same suitability as that of the base scenario is considered.

The efficiency of the system is then calculated in both of these scenarios. The results from both scenarios are then compared with the base scenario.

4.6. Phase VI- Discussion of results and Conclusion

The sixth and last phase of the methodology is about communication of results. This phase includes the visualization of maps for efficiency calculated in the fourth phase and also the maps for scenarios generated in the fifth phase. It will include interpretation of these results and finalization of the report and presentation of the whole procedure.

4.7. Conclusions

After discussing the general problems related to parking and the specific problems in the case study area, a need for a tool was felt which could test the parking policy measures and give the effects of it so that a future parking policy could be formulated. The literature suggested the parameters which should be considered in making such a tool. This chapter tries to incorporate those parameters and develops a methodology for the stated problem.

Overall this chapter forms the core of the thesis as it provides the methodology to measure impacts of the parking policies, defined here as the three efficiency measures. It discussed the calculation of parking choice and allocation of parking demand to the parking supply. A simulation model has thus been suggested.

5. RESULTS AND ANALYSIS

The previous chapter discussed the methodology to calculate attractiveness of the lots, allocate the trips entering a zone at peak hours to the parking areas available and then calculate efficiency of the system. This chapter discusses the implementation of the methodological framework for the case of Enschede.

The results have been discussed for the following scenarios:

- Base scenario using parking demand of 2010 and existing parking stock,
- Scenario of implementation of policy instrument to decongest the center by increasing the parking tariff by 20% using parking demand 2010 and existing parking stock with new tariff structure,
- Scenario of implementation of policy instrument to decongest the center by decreasing the parking capacity in center by 20% using parking demand 2010 and existing parking stock with new capacity structure,
- Scenario of future development using parking demand of 2020 and existing parking stock

5.1. Base Scenario

The CommunityViz model calculated the suitability of each parking lot based on the five location factors. Annexure IV shows this suitability for the existing situation.

Based on this suitability score and the trip characteristics i.e. the trip purpose and the walking time from parking lot to the destination the trips were allocated by the allocation model and the spatial efficiency was calculated for morning peak hour (see annexure V). The spatial efficiency parking zone wise shows that almost all the zones have excess of parking lots to accommodate for the incoming trips. Although the centre zone 1 is using more than 85% of its present parking capacity, and 2 zones in the north of the study area (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots. A further detailed zone wise analysis (see annexure V) show that 6 areas in the city centre and 1 other experience excess of parking demand and parking lots in 15 areas are less than 25% utilized.

Also spatial efficiency was calculated for evening peak hour (see annexure II). The spatial efficiency parking zone wise even here shows that almost all the zones have excess of parking lots to accommodate for the incoming trips. There is no case of demand spilling although 3 zones (neighbourhoods of Boddenkamp, De Laares and Hogeland Noord) have less than 25% utilization of parking lots available. The zone wise analysis (see annexure V) shows that 8 areas experience excess of parking demand and parking lots in 12 areas are less than 25% utilized.

Thus it is to be noted that zones 4 and 7 have an excess of parking lots in morning as well as evening peak hours (refer to figure 5.1) also there are 4 specific areas which have demand spilling and 10 areas which are less than 25% utilized in both morning and evening peak hours (refer to figure 5.2).

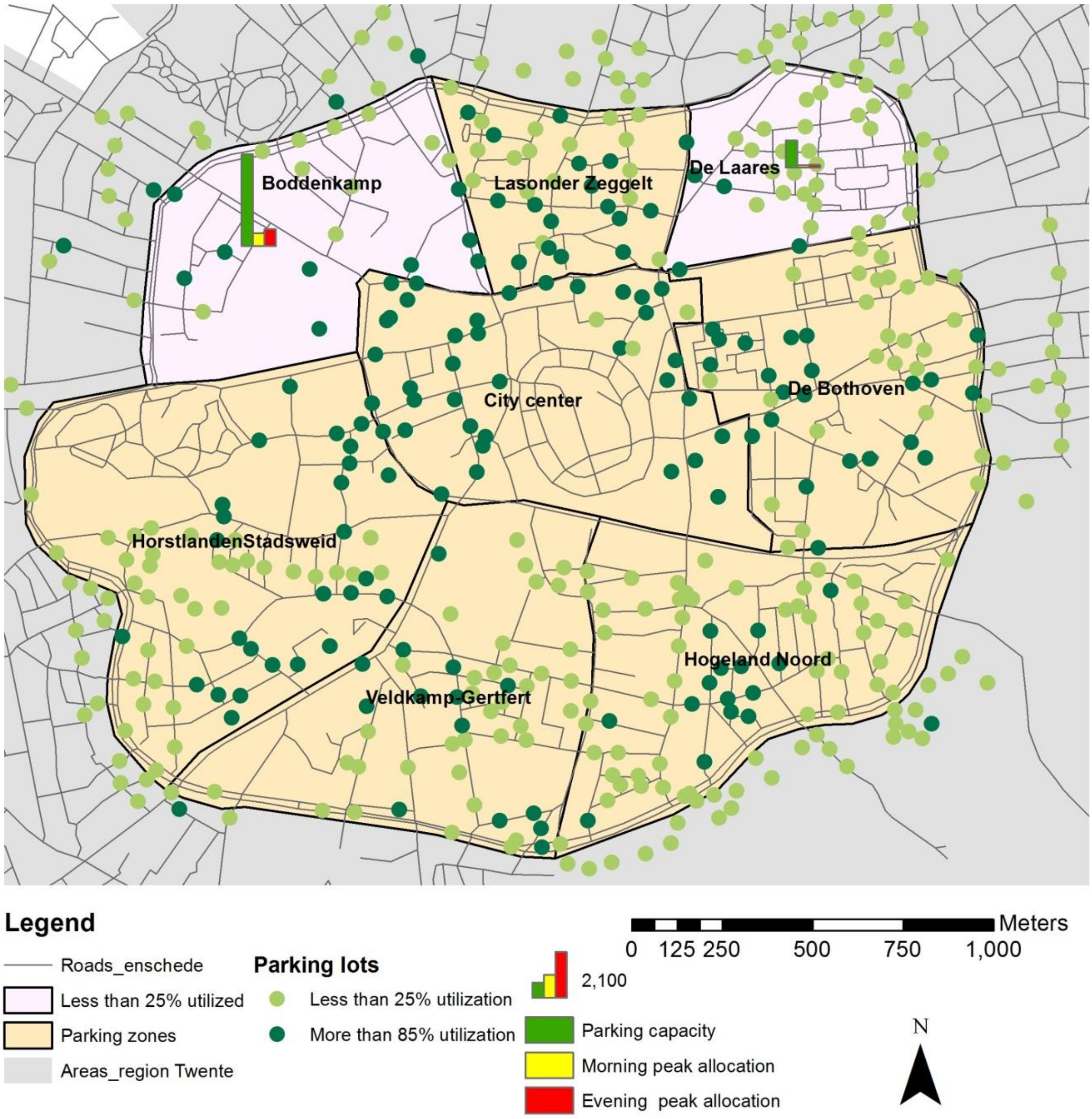

Figure 5.1: Base Scenario- Problem zones and parking lots underutilized and over utilized in both morning and evening peak

Table 5.1: Base Scenario- Number of parking lots over utilized or underutilized

	No of lots	Capacity	Utilization-Morning	Utilization-Evening
Overutilization	150	4068	4791	4807
Underutilization	301	9246	292	388

Table 5.1 shows that out of 610 parking lots almost 50% are underutilized and 25% over utilized in both morning and evening peak hours. This shows that firstly there is an overall excess of parking supply in the city and secondly the distribution of parking lots is very uneven.

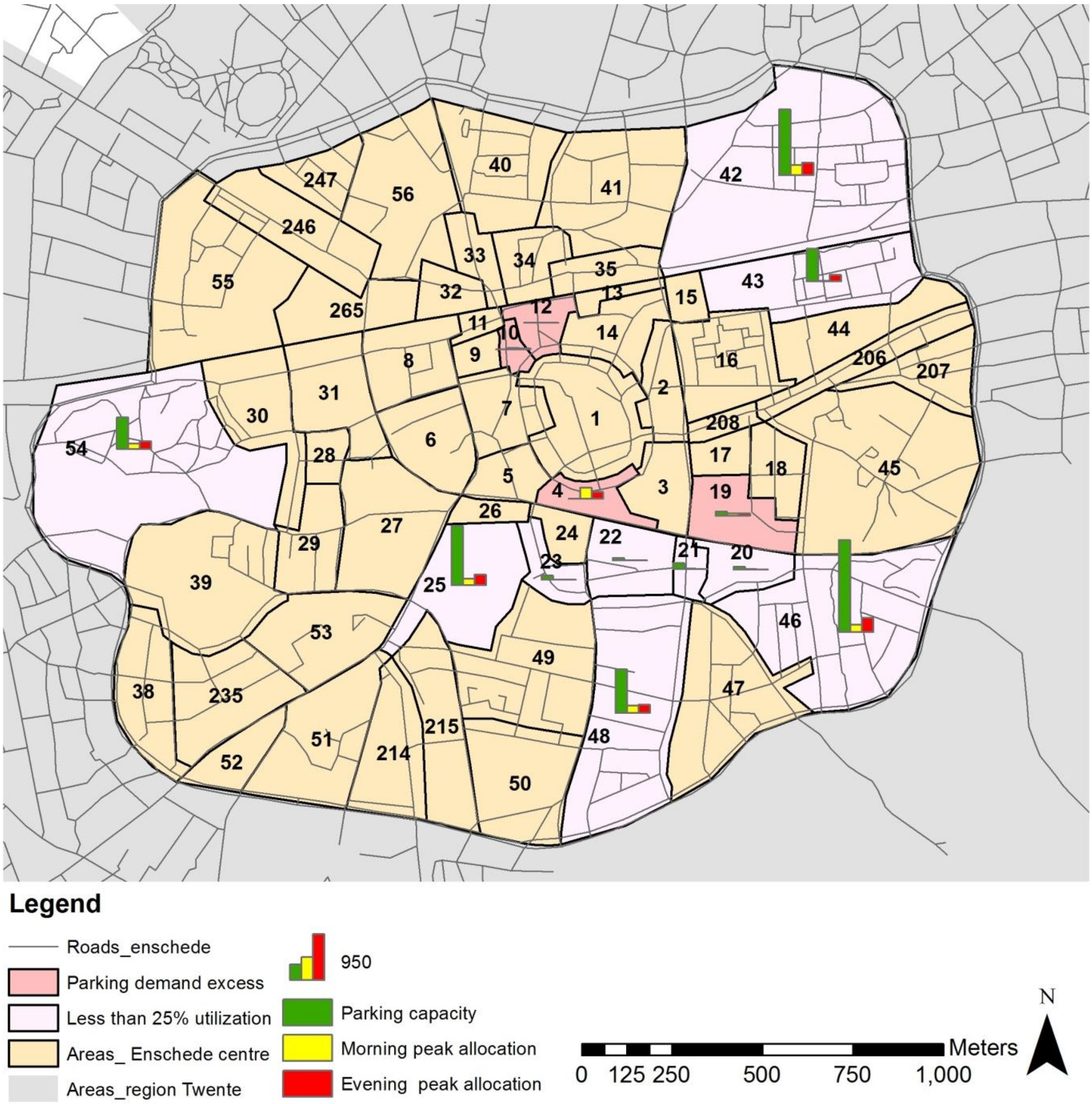

Figure 5.2: Base Scenario- Problem areas in both morning and evening peak

5.1.1. Calculating error of prediction

Table 5.2: Error of predicted values as compared to actual utilization data

	Mean Absolute error (MAE)	Root mean square error (RMSE)
Morning peak	20	40
Evening peak	19	32

The RMSE for morning peak suggests that each predicted value is likely to be deviated by 40 from the observed values, this suggests that the model is not able to predict the phenomenon very accurately. The difference between MAE and RMSE is almost 20, which suggests this amount of variance in individual errors in the sample. The RMSE for evening peak suggests that each predicted value is 32 values deviated from the mean of observed values. The difference between MAE and RMSE is 13, which suggests that variance in individual errors in the sample is 13. The RMSE of evening peak is less than the RMSE of morning peak which indicates that the evening peak allocation is better predicted by the model than the morning peak allocation.

The difference of the actual utilization and the predicted value by the model can be explained through various explanations:

- The model allocates the trips in the morning an evening peak hour durations i.e. 9:30 to 10:30AM and 4:30 to 5:30PM respectively and this has been compared to parking volume data of 9:00Am and 3:00PM respectively which was collected from a different source. It is possible that this difference of time has been the cause of this difference.
- Secondly, the model does not accounts for any illegal parking that might be the case in reality and the parking volume data does accounts of any such cases.
- Thirdly, it is also possible that the trips made just outside the study area also park within the area. The model allocates only the trips within the ring area thus not considering any trips outside the study area. But no such differentiation is made while collecting the actual data in field surveys.
- Also utilization for 4 garage parking areas and 15 other areas is not provided which constitute almost 15% of the total capacity of parking and these lots are of high suitability score. So the deviation of the allocation in these lots is very high when compared to actual utilization which is considered 0 in these cases. The root mean squared error is very sensitive to the occasional large error and due to the squaring process it gives disproportionate weight to very large errors. This might explain to some extent the high value of RMSE.
- Lastly it is also possible that the factors that are used to explain parking choice decision are not enough or are not good predictors of the phenomenon. Thus the difference between the actual utilization and model allocation is observed.

5.2. Scenario- Testing policy to decongest the centre

This scenario is tested by using two different policy interventions; increasing the parking tariff by 20% and decreasing the capacity by 20%. The results in both alternatives are compared to the base scenario to check the difference within the centre and outside the centre in percentages of utilization of lots and visualizing the changes in problem areas.

5.2.1. Increase the parking tariff in the centre by 20%

The spatial efficiency parking zone wise in the scenario (see annexure VII) for morning peak shows that still all the zones have excess of parking lots to accommodate for the incoming trips. The same two zones as in the base scenario in the north of the study area (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots. A further detailed zone wise analysis shows that 7 areas experience excess of parking demand and parking lots in 16 areas are less than 25% utilized.

The spatial efficiency parking zone wise for evening peak also shows that almost all the zones have excess of parking lots to accommodate for the incoming trips. The centre zone still has problem of demand spilling and the same 2 zones (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots available. The zone wise analysis shows that 7 areas experience excess of parking demand and parking lots in 12 areas are less than 25% utilized.

Thus it is to be noted that zones 4 and 7 (neighbourhoods of Boddenkamp and De Laares) have an excess of parking lots in morning as well as evening peak hours (refer to figure 5.5) also there are 2 specific areas which have demand spilling and 12 areas which are less than 25% utilized in both morning and evening peak hours (refer to figure 5.6).

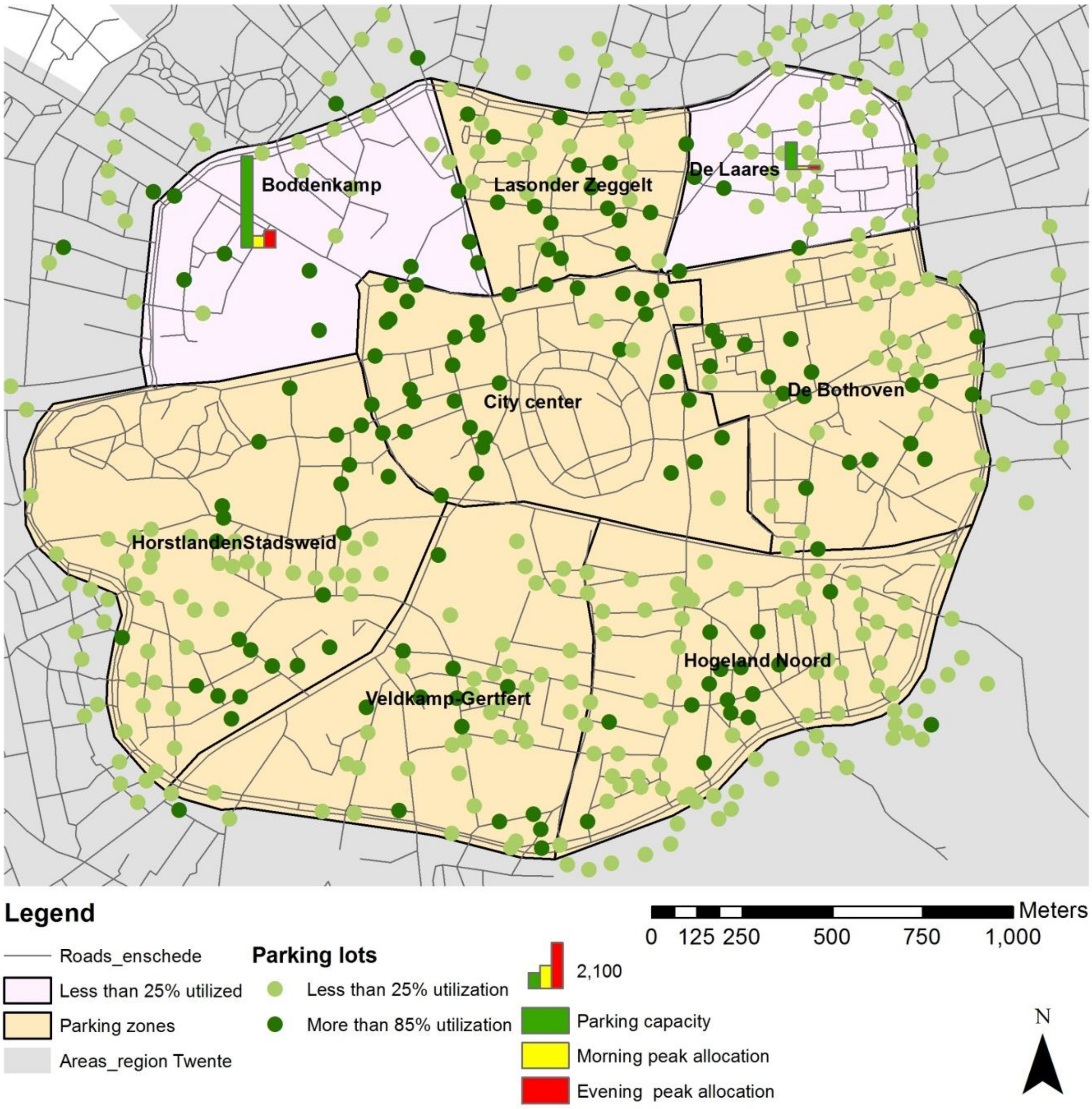

Figure 5.3: Scenario (Tariff differentiation) - Problem zones and parking lots utilization in both morning and evening peak

Table 5.3: Scenario (Tariff differentiation) - Number of parking lots over utilized or underutilized

	No of lots	**Capacity**	**Utilization-Morning**	**Utilization-Evening**
Overutilization	112	3205	3579	3729
Underutilization	306	9400	297	388

Table 5.3 shows that out of 610 parking lots almost 50% are underutilized and almost 18% over utilized in both morning and evening peak hours. As compared to the base scenario the condition of very few lots is improved the overutilization is minimised but the underutilization has increased.

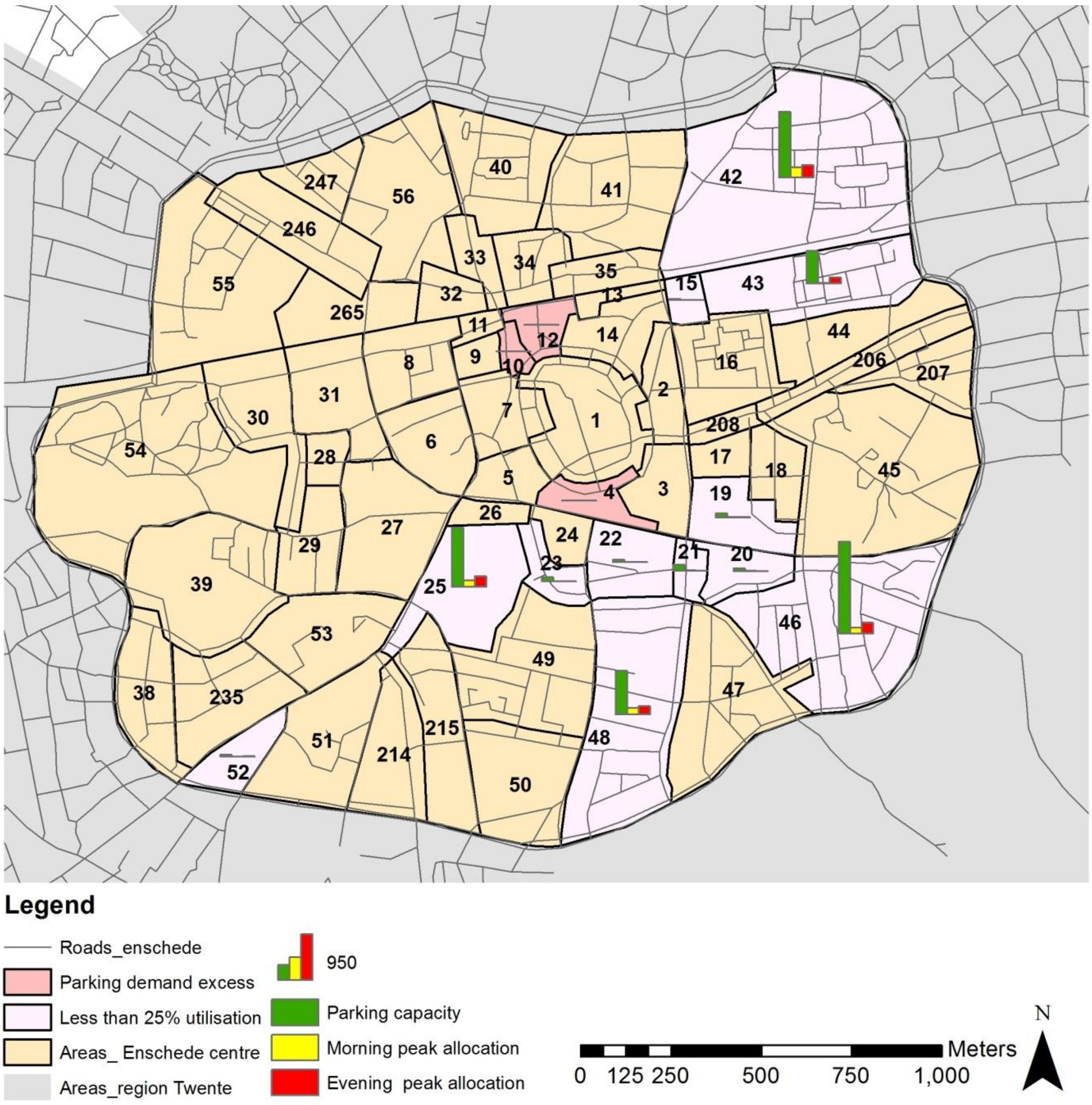

Figure 5.4: Scenario (Tariff differentiation) - Problem areas in both morning and evening peak

Table 5.4: Comparison of the percentage utilization of parking lots in the base scenario and after the implementation of the policy to increase the tariff in the city centre

	Morning			Evening		
	Base scenario	**Scenario-Tariff differentiation**	**% change**	**Base scenario**	**Scenario-Tariff differentiation**	**% change**
Within the center	2116	2086	-1.42	1411	1377	-2.41
Outside the center	6727	6757	0.45	6970	7026	0.80

From table 5.4 it can be noticed that increasing the tariffs in the city centre do not have much significance on the utilization of the lots. There is a decrease of only 1.4% and 2.4% in morning and evening peak utilization rates respectively. Also outside the centre a decrease in the utilization of the lots is merely 0.5% and 0.8% in morning and evening peak hour respectively. Although from this result it cannot be concluded that the sensitivity of the parking choice decision to parking charges is low as it is possible that the model is not able to predicts the user behaviour accurately the but it definitely shows that this particular model does shows a weak relation between parking charges and parking choice decision.

5.2.2. Decrease the capacity in the centre by 20%

The scenario uses the parking demand as of the base scenario i.e. the arrivals in the morning and evening peak hours of 2010. This scenario assumes that the parking supply in the centre has been decreased by 20% as a parking policy measure and tries to assess the changes in the parking system due to this policy intervention. The suitability of the parking lots is recalculated (see annexure VIII) as any change in the supply affects the parking choice decision. Based on the new suitability scores the parking allocation is done and the efficiency of the system is calculated.

The spatial efficiency parking zone wise in the scenario (see annexure IX) for morning peak shows that still even after this policy measure all the zones have excess of parking lots to accommodate for the incoming trips. The same two zones as in the base scenario and in the scenario where parking tariffs were altered, in the north of the study area (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of total parking lots. A further detailed zone wise analysis in the scenario shows that now 12 areas experience excess of parking demand as now the overall capacity is decreased it was expected that some parking lots with higher suitability will be much more utilized. Also parking lots in 16 areas are less than 25% utilized. Although the number of areas have increased from the base scenario but still the utilization in these areas are more than that in the base scenario.

The spatial efficiency parking zone wise for evening peak also shows that all the zones have excess of parking lots to accommodate for the incoming trips. There is no case of demand spilling although the same 2 zones (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots available. The zone wise analysis shows that 7 areas experience excess of parking demand and parking lots in 12 areas are less than 25% utilized in the evening peak hour as well.

Thus in conclusion, the same two zones, zones 4 and 7 (neighbourhoods of Boddenkamp and De Laares) have an excess of parking lots in morning as well as evening peak hours (refer to figure 5.7) and there are 3 specific areas which have the case of demand spilling and 11 areas which are less than 25% utilized in both morning and evening peak hours (refer to figure 5.8). The results from this scenario are then compared to the base scenario and the scenario of parking tariff differentiation to measure the scale of the impact of this parking policy intervention on the parking system.

Table 5.5 shows that out of 610 parking lots almost 50% are underutilized and almost 18% over utilized in both morning and evening peak hours. As compared to the base scenario the condition of very few lots is improved. When compared to the scenario- tariff differentiation the condition has worsened in terms of the lots over utilized, as now the same lots are much more utilized, whereas the condition of the underutilised lots has improved as now there are less underutilized lots and also they are more utilised.

Table 5.5: Scenario (Capacity differentiation) - Number of parking lots over utilized or underutilized

	No of lots	Capacity	Utilization-Morning	Utilization-Evening
Overutilization	112	3205	3764	3788
Underutilization	300	9132	310	410

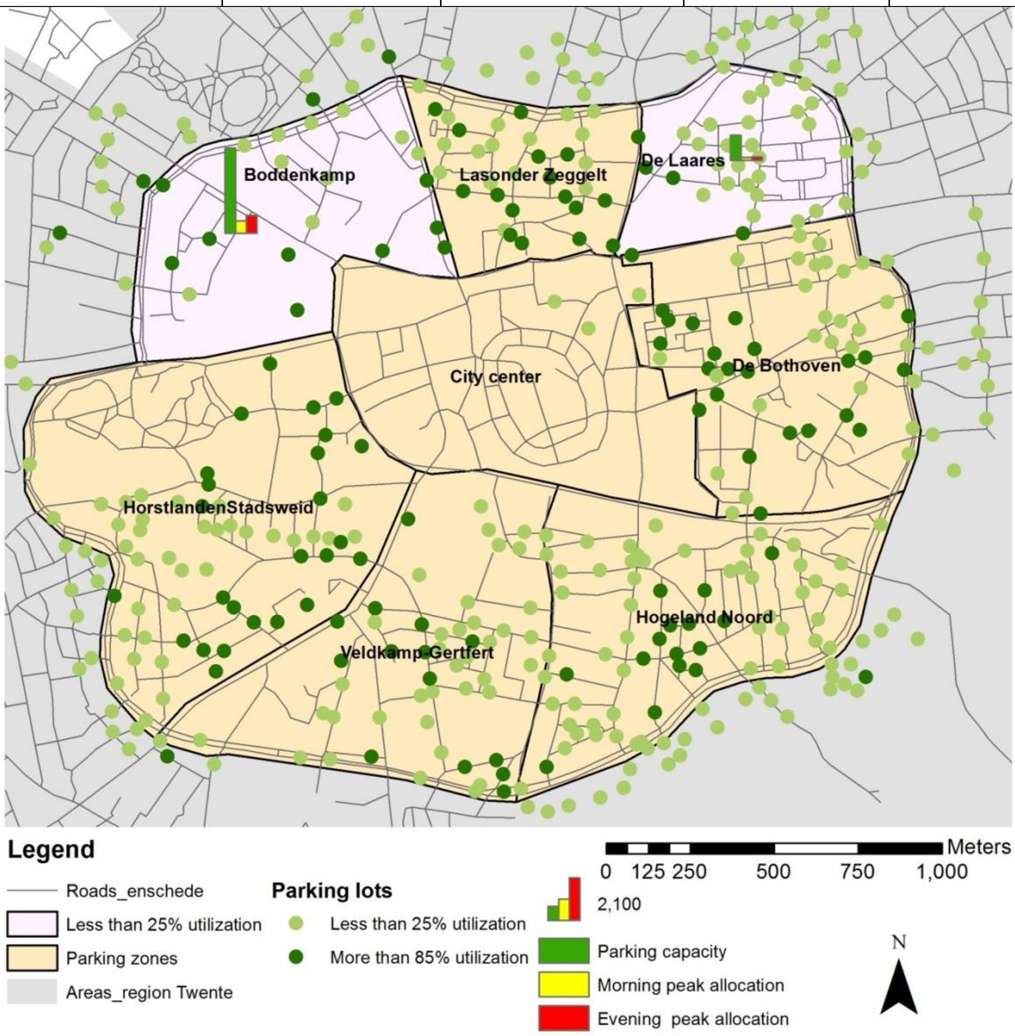

Figure 5.5: Scenario (Capacity differentiation) - Problem zones and parking lots underutilized and over utilized in both morning and evening peak

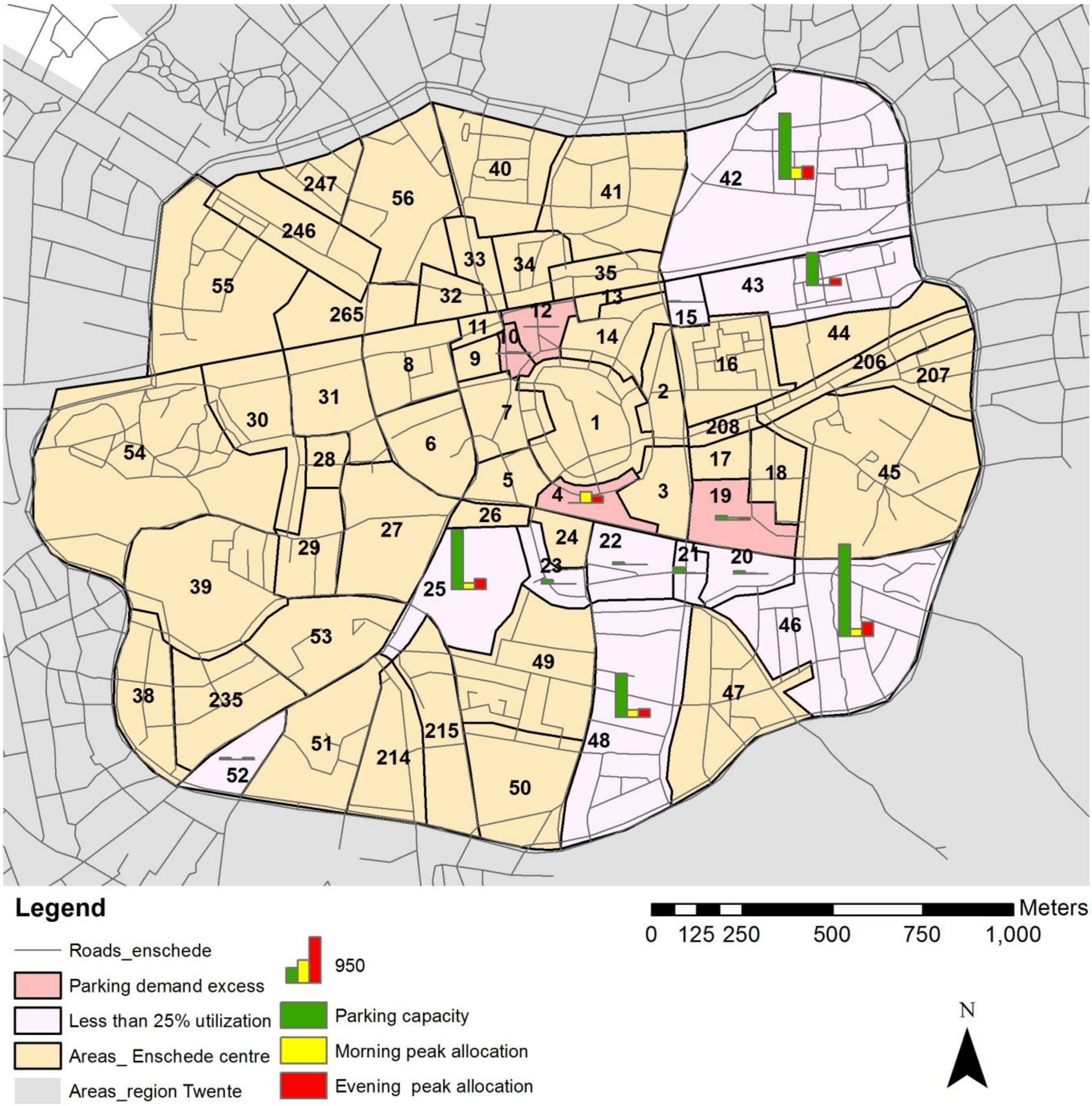

Figure 5.6: Scenario (Capacity differentiation) - Problem areas in both morning and evening peak

Table 5.6: Comparison of the percentage utilization of parking lots in the base scenario and after the capacity differentiation

	Morning			Evening		
	Base scenario	Scenario-Capacity differentiation	% change	Base scenario	Scenario-Capacity differentiation	% change
Within the center	2116	1788	-15.50	1411	1288	-8.72
Outside the center	6727	6822	1.41	6970	7089	1.71

From table 5.6 it can be observed that decreasing the capacity of the parking lots in the city centre do has some significant implications on the utilization of the lots. There is a decrease of 15.5% and 8.7% in morning and evening peak utilization rates respectively in the city centre. Outside the centre an increase in the utilization of the lots is observed approximately 1.4% and 1.7% in morning and evening peak hour respectively. Although from this result it cannot be concluded that the sensitivity of the parking choice decision to parking noticeability factor is high as it is possible that the model is not able to predicts the user behaviour accurately but it definitely shows that this particular model does shows a strong relation between parking capacity and parking choice decision as also when compared to the model behaviour in previous scenario of parking tariff differentiation where a weak relation was observed.

5.3. Scenario- Future travel demand 2020

This scenario is using the O/D data for 2020 for calculating parking demand. Parking supply is assumed to be equal to the base scenario i.e. assuming that no more parking lots are provided. The scenario attempts to estimate the bottleneck areas which need to be focussed on in the future parking policy plan. It is also assumed that the suitability of the parking lots remain the same as in the base scenario (see annexure IV) as there have been no change in the supply of parking and the factors considered in the CommunityViz model are only location characteristics.

The spatial efficiency parking zone wise in this scenario (see annexure X) for morning peak shows that still all the zones have excess of parking lots to accommodate for the incoming trips. Although there is one case of demand spilling in the city centre where all trips were not allocated and the same two zones as in the base scenario in the north of the study area (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots. A further detailed zone wise analysis shows that now 8 areas experience excess of parking demand and parking lots in 14 areas are less than 25% utilized.

The spatial efficiency parking zone wise for evening peak also shows that almost all the zones have excess of parking lots to accommodate for the incoming trips. There is no case of demand spilling and the same 2 zones (neighbourhoods of Boddenkamp and De Laares) have less than 25% utilization of parking lots available. The zone wise analysis shows that 7 areas experience excess of parking demand and parking lots in 11 areas are less than 25% utilized in the evening peak hour as well.

Thus even in 2020 the same two zones, zones 4 and 7 (neighbourhoods of Boddenkamp and De Laares) have an excess of parking lots in morning as well as evening peak hours (refer to figure 5.7) and remain underutilized. At the post code 5 level there are 3 specific areas which have demand spilling and 11 areas which are less than 25% utilized in both morning and evening peak hours (refer to figure 5.8).

The results show that that there is not much of a change in 2020 as compared to the base scenario of 2010. The same zones are highlighted as problem areas as in the base scenario. Although the parking lots in area centroid 54 in the neighbourhood of Horstlanden Stadsweide are now not underutilized. Also some more parking lots are more than 85% utilized now. As the parking demand increased but the parking supply was assumed constant and under these conditions it was expected that the parking lots with high suitability score will be more utilized than the 2010 scenario.

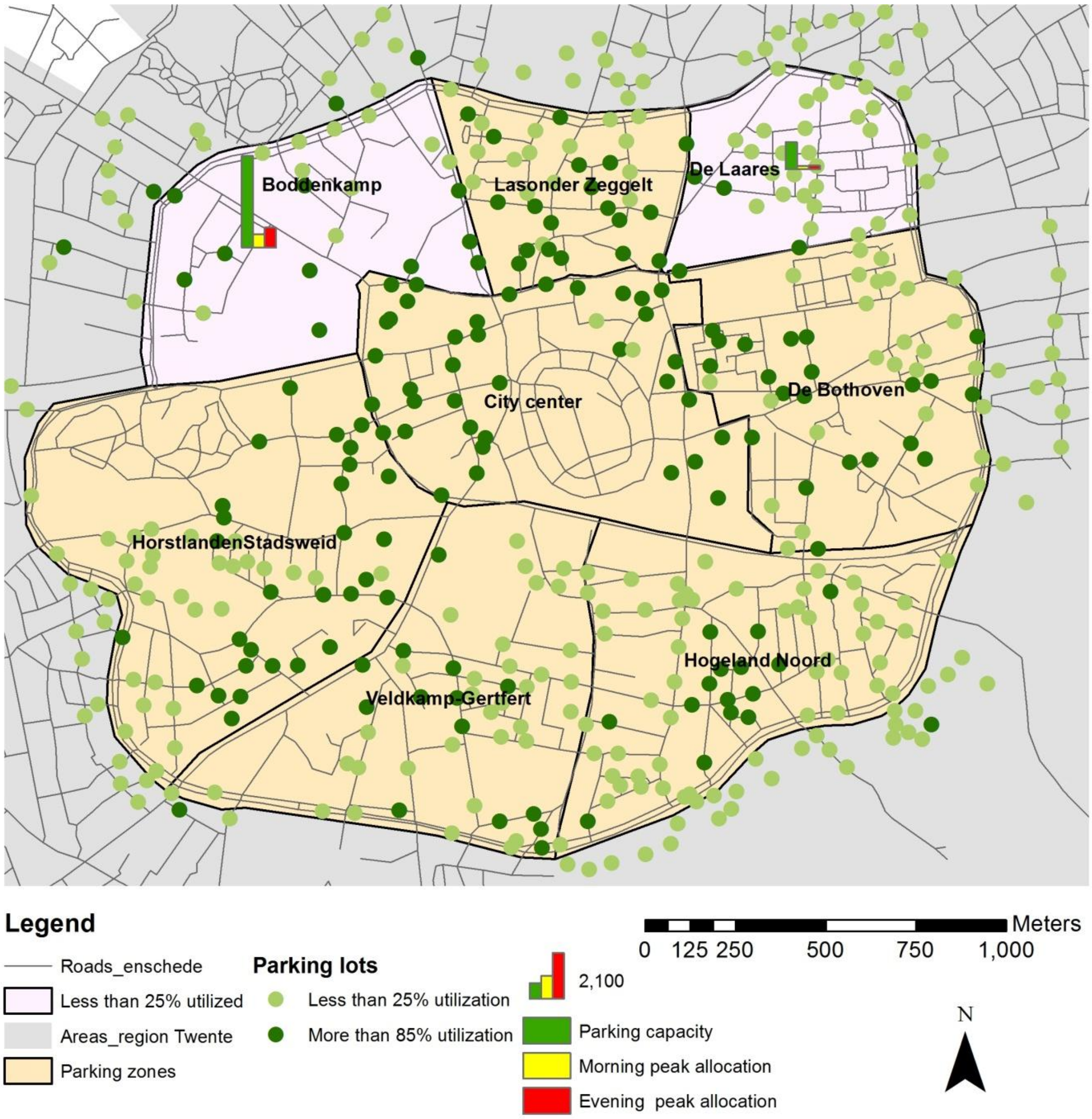

Figure 5.7: Scenario (Future travel demand) - Problem zones and parking lots underutilized and over utilized in both morning and evening peak

Table 5.7: Scenario (Future demand) - Problem zones and parking lots utilization

	No of lots	Maximum Capacity	Utilization-Morning	Utilization-Evening
Overutilization	155	4290	5069	5056
Underutilization	288	8938	287	367

Table 5.7 shows that out of 610 parking lots almost 48% are underutilized and almost 25% over utilized in both morning and evening peak hours. As compared to the base scenario the condition of very few lots is improved. But surely there are fewer parking lots which are underutilized and more parking lots over utilized when compared to the base scenario.

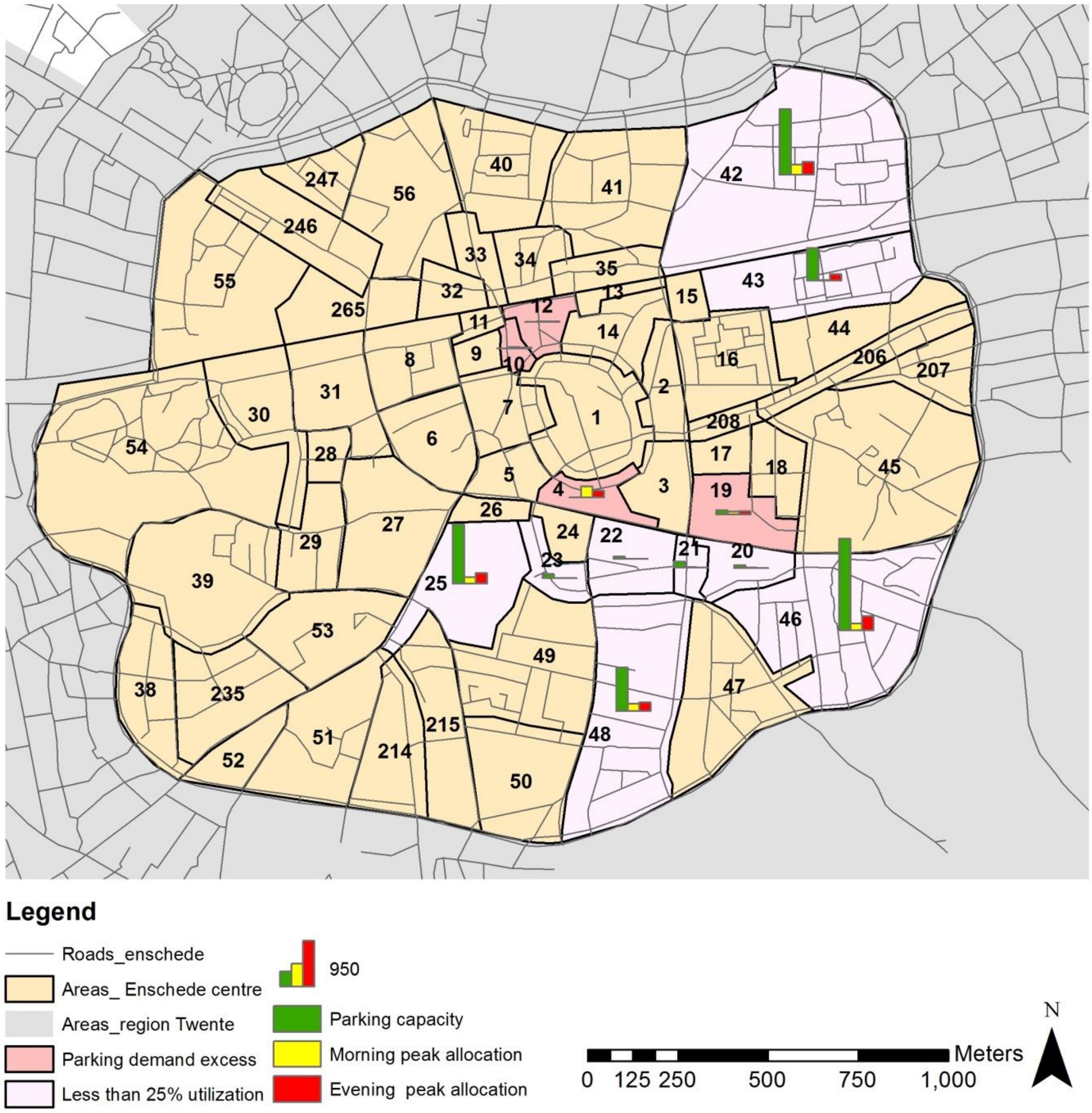

Figure 5.8: Scenario (Future demand 2020) - Problem areas

Table 5.8: Comparison of the percentage utilization of parking lots in the base scenario-2010 and in future-2020

Morning			**Evening**		
Base scenario	**Scenario-Future demand**	**% change**	**Base scenario**	**Scenario-Future demand**	**% change**
8843	9109	3.01	8381	9040	7.86

From table 5.8 it can be observed that the spatial efficiency in 2020 has improved. The utilization of the parking lots has increased 3% and approximately 8% in morning and evening peak hours. But there still are some areas which remain underutilized and need some planning and management measures for improvement.

6. CONCLUSIONS

The objective of this chapter is to conclude the study and give recommendations. It is composed in two main sections; firstly conclusive remarks from the scope of the study are presented as the achievements and limitations of the work. Finally some recommendations for improvements within the scope of the study and further research ideas have been discussed.

6.1. Research Achievements and Limitations

In drawing conclusion to the study, the research achievements and limitations have been emphasized based on the defined scope of the study.

6.1.1. Research Achievements

6.1.1.1. Addressing the research problem

The main problem of the research was to develop a methodology to assess parking policy interventions geospatially, while also ascertaining the assessment criteria. The research has been successful in addressing this problem. The assessment criteria have been established as the 3 efficiency measures, namely; spatial balance, user group balance and economic efficiency. Also a clear and easy to implement methodology in any case, finally being able to assess the efficiency of the parking system has been developed. Consideration of the dynamics of parking location choice decisions (based on the parking location characteristics and trip based characteristics) and consideration of the competition between parking locations (by allocating trips not only in the zone but within a feasible area from the final destination of the trip using a network analysis) are other achievements of the research.

The research has been successful in addressing the challenges involved with the study of parking policy interventions by making a justifiable choice of parking demand variable (using the trip ends), ascertaining the assessment criteria (as the efficiency measures) as well as trying to calculate the scale of the impact of parking policy measures (by statistical measures).

6.1.1.2. Realizing the research objectives

The first objective of the research was to set up a GIS model incorporating parking supply (tariffs, location, capacity) and parking demand (peak hour, off peak hour and holidays) factors to test the efficiency of parking system and test the functioning of parking policy interventions. A tool was thus developed incorporating the parking supply and parking demand factors to model location choice and allocate the demand to the parking stock available.

The second objective was to study efficiency (spatial balance, demographic and economic) of existing parking lots (in peak hours). This objective was achieved although not entirely due to the lack of data. A detailed analysis of the spatial efficiency at three scales was presented while answering the research question of where (in the study area) are bottlenecks present in terms of parking excess or demand spilling.

The third objective of constructing scenarios of how changes in parking tariffs/ supply (increase/decrease) will affect the efficiency of the system was also realized by testing the model on these changes made on the parking supply side. The scenarios changed the suitability of each parking lot based on which the allocation was done and efficiency calculated. Finally making a comparison of these scenarios with the base scenario provided a measure of the extent of change in the spatial efficiency of the system by different policy instruments.

The last objective of studying the impacts of future land use developments on parking areas while studying the changes in utilization rates and identification of major bottleneck areas in terms of parking excess or demand spilling was achieved by making changes on the demand side of the model. Considering the parking demand of the year 2020 the efficiency of the system was calculated. The results presented the areas which will be affected in future, thus highlighting the areas to be considered while developing a parking policy for the case study area.

6.1.2. Research Limitations

6.1.2.1. Calibration of the model

The calibration of the model was required to adjust the factors such that the allocation was as close to the actual on ground collected parking volume. But due to time limitations and lack of some data it was difficult and was thus not accomplished. Although a mean absolute error and root mean square error from this actual utilization to the allocated volume was calculated.

The data limitations for not calibrating the model were that the parking volume data for different hours (6:00AM, 9:00AM, 11:00AM, 3:00PM and 8:00PM) on an average weekday was available from the I&O research (data collected through primary surveys in September/October, 2010) , but the parking demand data as provided by Goudappel Coffeng was only for the peak hours (Morning 9:30 to 10:30 AM and Evening 4:30 to 5:30 PM). This difference of time resulted in some mismatch of the total utilization (actual data) and total allocation (model prediction). Also the model could not account for any illegal parking whereas the data of parking volume collected through field surveys does consider that. It is also possible that the trips just around the ring area may be parking inside the ring, thus explaining the large difference between the actual utilization and the trips arrival in the study area, the model does not account for these trips as well.

For calibrating the model, firstly some changes in the model itself are required such as consideration of some percentage of trips just outside the ring area which would probably park inside the ring. Secondly consideration of more factors in the parking choice model is required, specially the user characteristics and trip characteristics which could explain the user behaviour more accurately. Next is the consideration of the parking turnover rates, as data for average parking duration of the parking lots was not available it was assumed that all the trips that enter in the peak hour park at least for an hour, although it should be considered that it gives a crudely a wrong idea of the actual utilization. Finally the data for the utilization during the peak hour interval of parking lots is required, which would also consider the parking turnover rates.

6.1.2.2. Other data Limitations

Plenty of assumptions have been made in the model due to lack of data. Few of these assumptions could be avoided if data was available. Also all parameters of efficiency could have been assessed if data was available for the same.

Table 6.1: Assumptions made and data required for avoiding them

	Assumptions made	**Data required**
Demand for parking	Trip purpose- O/D data trip purpose wise for a day of Twente region is used	O/D trip purpose wise data for peak hour required
	Only shopping and work purpose was finally used in the allocation model	Detailed land utilization data required
CommunityViz model	The five location factors and two trip characteristics	More factors could have been added
	Safety and winter provision- Assumed to be relative to parking type	Parking location surveys required to check for these factors
	Condition of parking surface- Assumed to be relative to parking type	
	Weightages of the factors 1. Parking charges- 3.5 2. Noticeability- 2.5 3. Ease of searching- 2 4. Safety and winter provision- 1.5 5. Condition of parking surface- 0.5	Stated preference survey required
Allocation model	Vehicles park at least for an hour	Parking turnover rates for each parking lot required
	5 minutes of walking distance is assumed to be feasible	Stated or revealed preference survey of users required

Also only spatial efficiency of the parking system was finally calculated. Demographic/ user group balance required user group wise availability of parking lots and user group wise trips distribution data. Also for calculating economic efficiency all the data that was collected was required not only for peak hour but each hour of the day for a week. After allocating trips for each hour in a week, assuming the same behaviour for the month a monthly economic efficiency can be calculated by considering the monthly maintenance costs and parking charges.

6.2. Recommendations

6.2.1. Improvements within the scope of the study

The model in the research has been developed using CommunityViz for parking choice modelling, ArcGIS model builder for allocation modelling and the efficiency measure was calculated manually. Before every run of the model few changes in the model were as such required. Also for each scenario it was first required to run the CommunityViz model and then the ArcGIS model, thus a lot of time was spent on running the models separately and doing efficiency calculations manually. Due to the limitation of time these three tasks could not be aggregated to provide just one single interactive tool to consider parking choice decision, perform parking allocation and calculate efficiency of the system automatically. Thus a need for research in planning support systems is felt, using the principles defined in the research one can develop an interactive tool for decision makers.

As also discussed in limitations very few factors have been considered in the parking choice model due to data limitations and the results show that the model could not predict very accurately the parking utilization rates. Thus need for adding more criteria of user characteristics and trip characteristics is required in the parking choice model, which requires plenty of field surveys as discussed in table 6.1. While also calibrating the model to find out which factors are good predictors of the location choice.

6.2.2. Further research ideas

This research reflects an initial step in the development of methodological framework to assess parking policy interventions. However further research in the subject is required.

First and foremost a need is felt to model behaviour of users towards parking policy measures. The parking choice decision considered in the research was simulated using very few location factors and trip characteristics. Although this choice should be modelled using stated or revealed preference surveys through logit models or multi criteria models. Also the model in this research only considers the choice of feasible parking location whereas it is possible that parking policy intervention result in mode shift, change of time of the trip, change of destination or cancellation of the trip.

Secondly, mode choice in itself is a very complex decision and modal shift patterns specifically due to parking policy interventions, excluding the other transport policies which may affect the choice is difficult to assess. Thus further research in modal shift patterns due to parking policy interventions is required.

Lastly, assessment of parking policies effects on the whole transportation system needs further research as this would reflect on the significance of parking policies.

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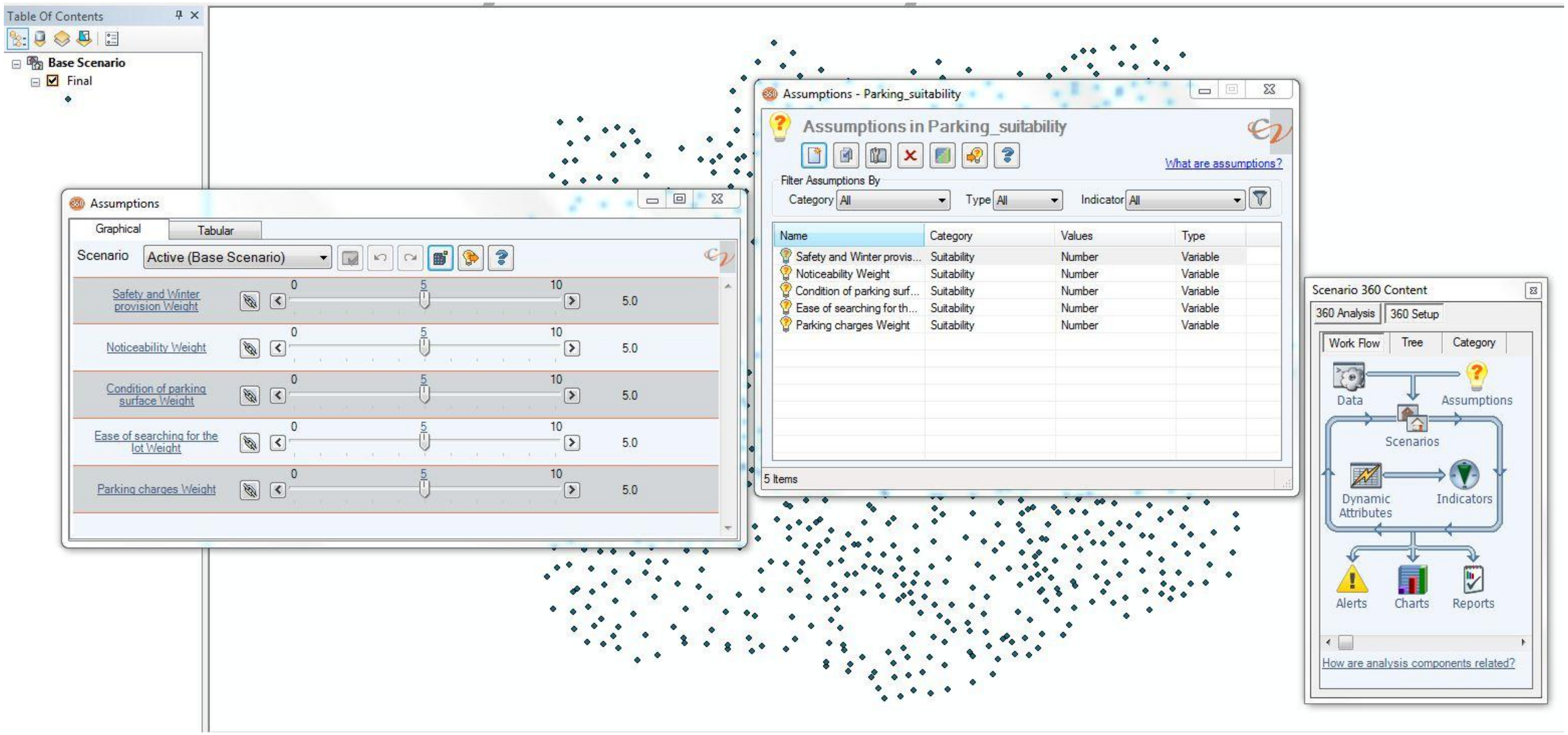
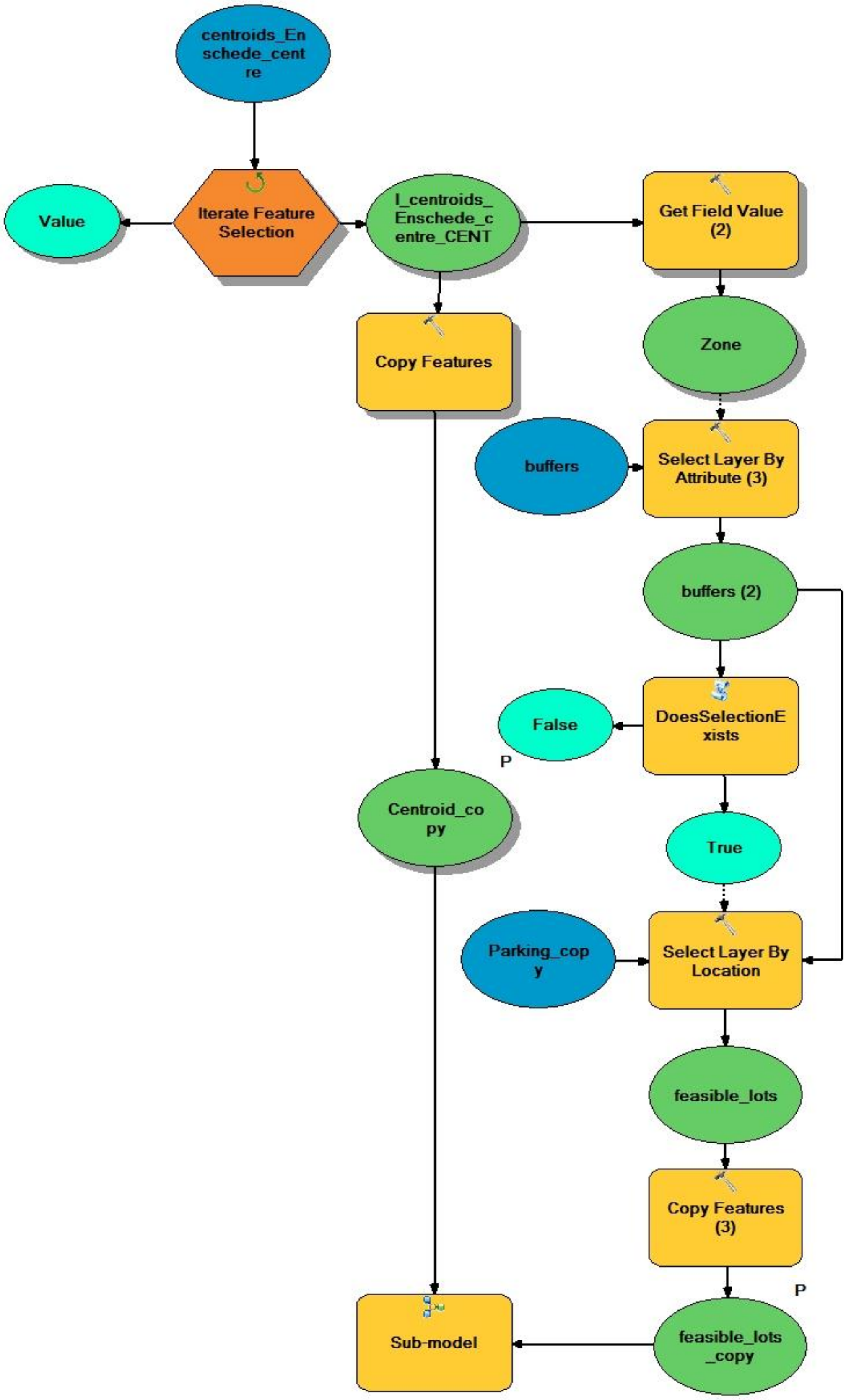
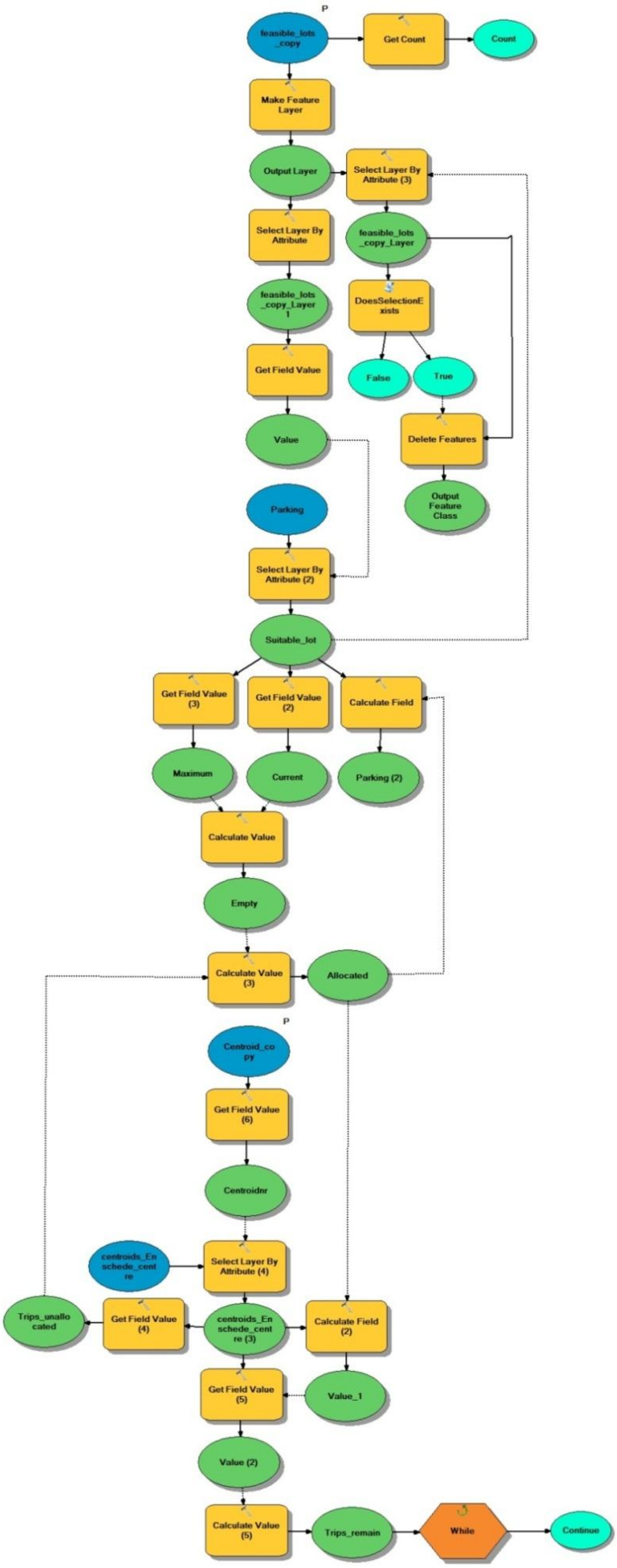
ANNEXURE 1: COMMUNITYVIZ MODEL SETUP



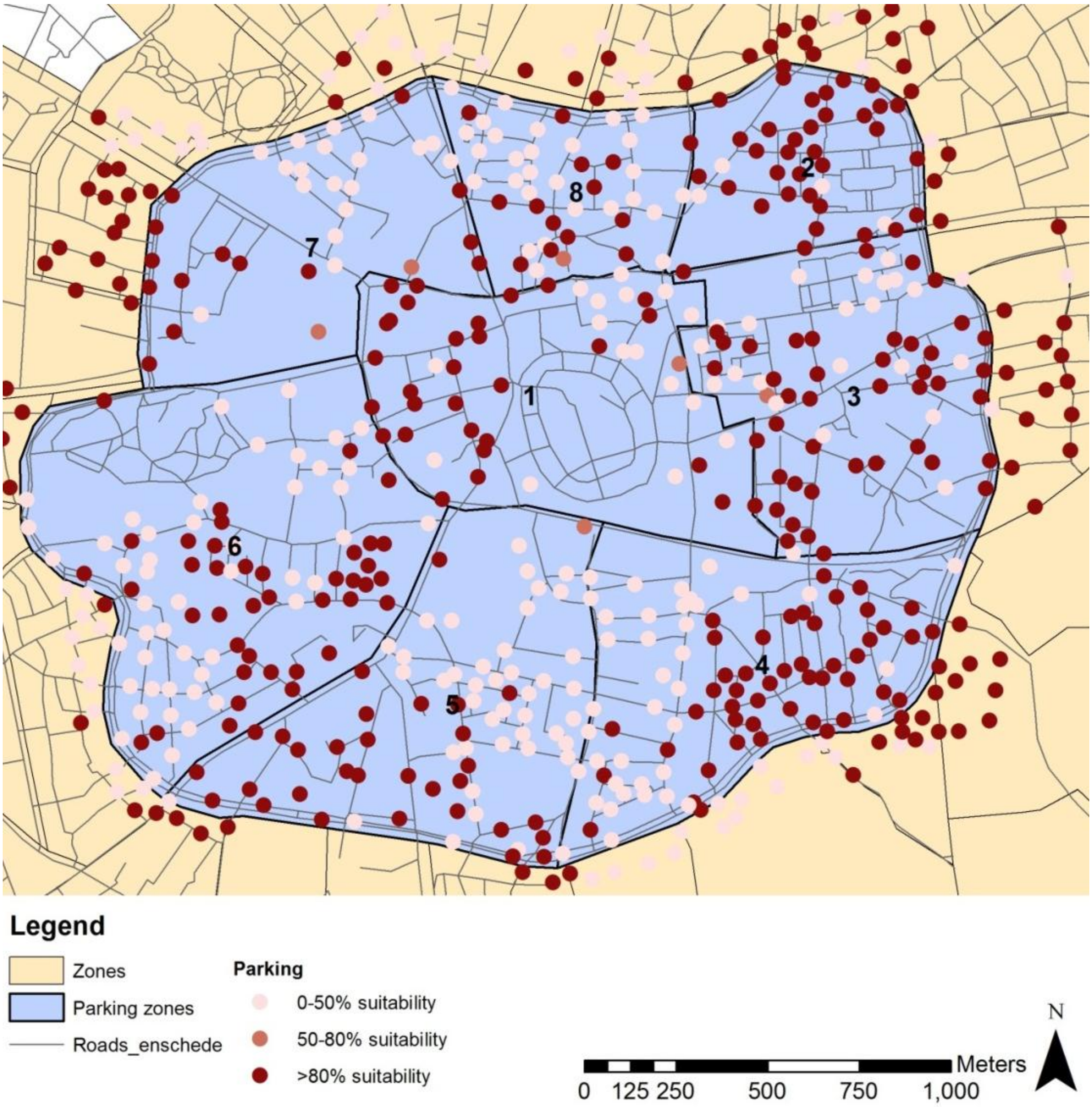
ANNEXURE II: ARCGIS MODEL SETUP- MAIN MODEL



ANNEXURE III: ARCGIS MODEL SETUP- SUB MODEL

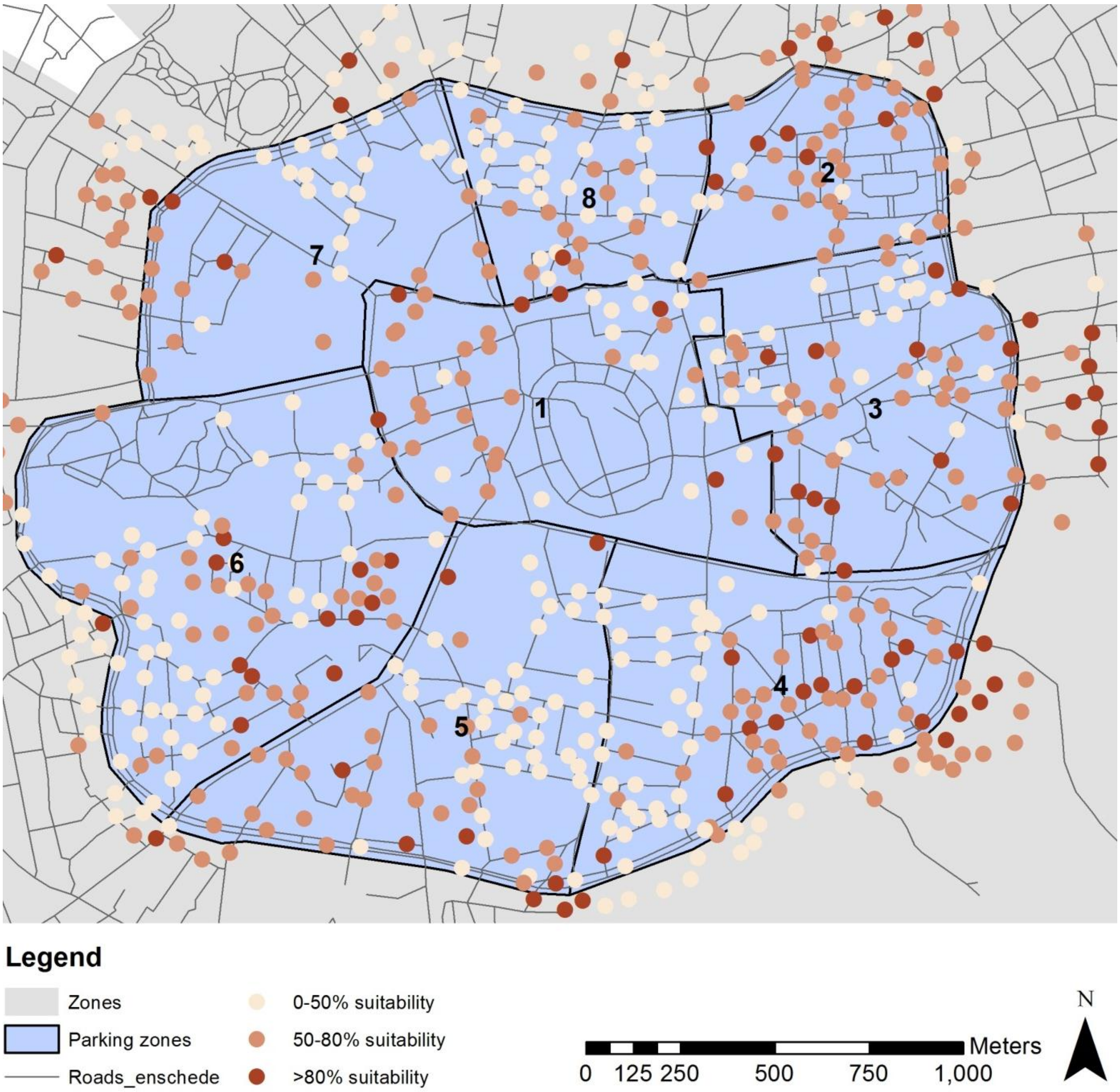


ANNEXURE IV: BASE SCENARIO SUITABILITY



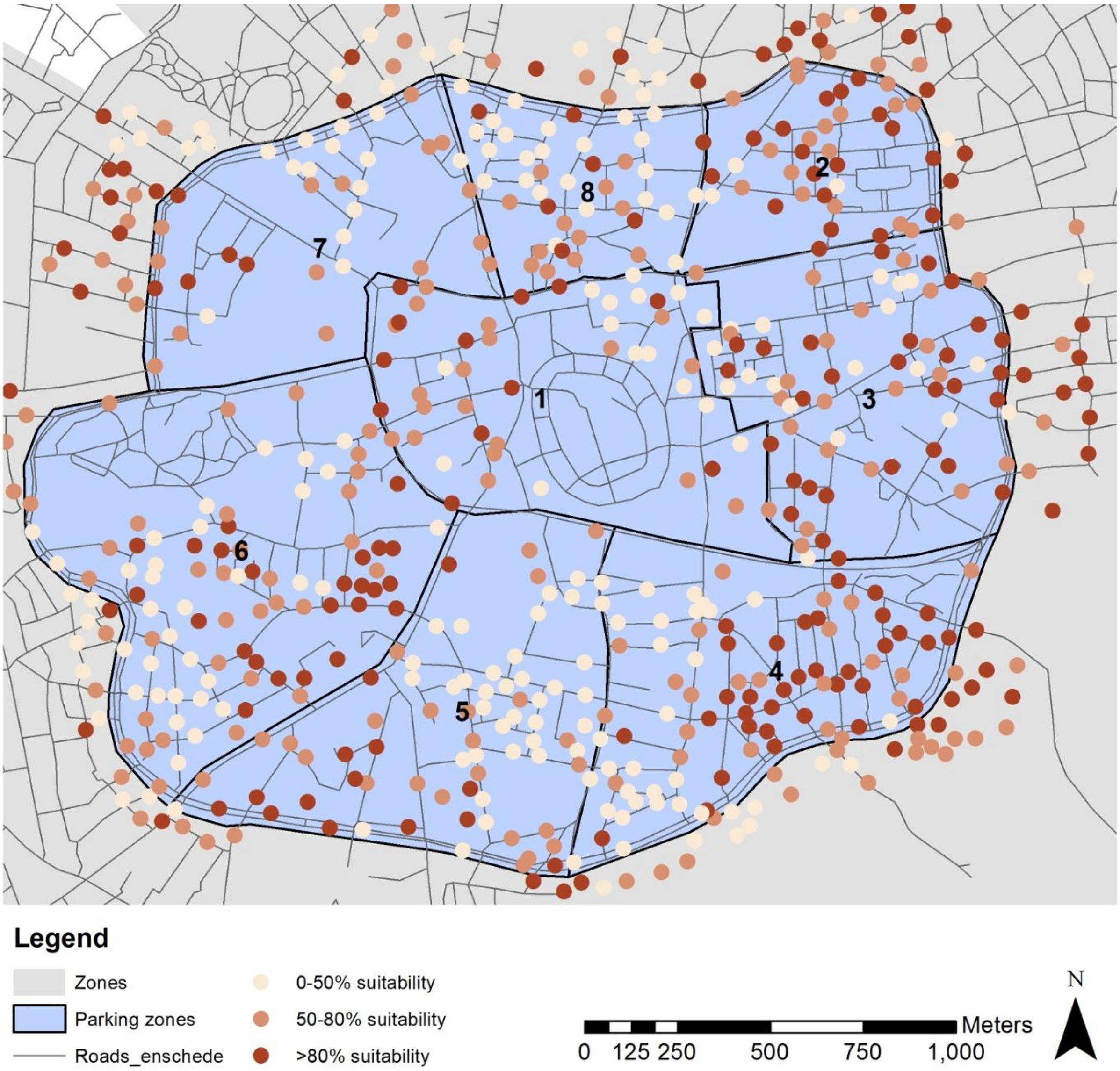
ANNEXURE V: BASE SCENARIO SPATIAL BALANCE

ANNEXURE VI: SCENARIO- PARKING TARIFFS IN THE CITY CENTRE INCREASED BY 20% SUITABILITY



ANNEXURE VII: SCENARIO- PARKING TARIFFS IN THE CITY CENTRE INCREASED BY 20% SPATIAL BALANCE

ANNEXURE VIII: SCENARIO- PARKING CAPACITY IN THE CITY CENTRE DECREASED BY 20% SUITABILITY



ANNEXURE IX: SCENARIO- PARKING CAPACITY IN THE CENTRE DECREASED BY 20% SPATIAL BALANCE

ANNEXURE X: SCENARIO- FUTURE PARKING DEMAND 2020