Determining the Relationship between Urban Form Dynamics and Transport

Ahmed Gishe

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by

Ahmed Gishe

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Thesis Assessment Board

Chairman:	Prof.Dr.Ir. M.F.A.M. van Maarseveen
External examiner :	Ir. J. Van Vliet (RIKS)
First superviser :	Dr. Ir. M.H.P. Zuidgeest
Second supervisor:	Dr. J. Flacke

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Abstract

In modern cities the issue of using resources on a sustainable basis, and limiting environmental pollution, is one of the main concerns of planners, engineers and policy makers. The transport system, being an integral part of the urban environment, plays a large role in both energy consumption and in emission of pollution in the form of noxious gasses. These negative impacts have galvanized researchers, authorities, and planners into looking for a way of providing efficient transport while minimizing negative impacts. One of the key reduction mechanisms currently featured is to reduce car dependency and enhance both mass transit and non motorized means of transport. An understanding of the factors that affect transport in the first place is paramount to effective creative of such positive change. Urban form of a city is considered to be one of the main factors in this study, and one where the relationship with transport is poorly understood.

The objective of this research is to model urban form and determine its effect on transport, and particularly mode choice, in Ahmadabad, India. There are numerous indicators of urban form available. However, the impact of development density on transport mode choice is rarely investigated in developing nations, and hence is utilized for this research. The concept that the density of a city is not uniform across the entire area and instead decreases with distance from the city centres was adopted and modelled on the AB-Metronamica modelling platform. Using empirical data, the correlation between the density of activities (residential, commercial, institutional and industrial), distance from the city centre, income and transport mode choice have been analysed. The correlation factors and densities of activities simulated in AB-Metronamica were then used to compute the probability of particular of mode choices. Home based trip generation was calculated considering all the activities and then multiplied with the mode choice probability to compute the likely number of trips made by each mode. Further, the number of cars and buses was calculated based on the average number of passengers they carry. Finally, using emission factors the total amount of emissions was calculated and analysed to identify which urban form is more susceptible to transport induced pollution.

AB-Metronamica is a promising modelling platform for urban form modelling using activity simulation. It can produce a result which is much closer to reality than other approaches, with some improvement from incorporation of a multilayer cellular automata model and development of an algorithm that enables the model to allocate activities according to the potentials of cells at the start of the model rather than a uniform distribution. One of the model's very important aspects is its ability to model multi-nucleated cities such as Ahmedabad by introducing CBDs and access points.

The impact of change in urban form is observed to affect transport, although other factors, such as socio-economic factors, also need to be considered. Beside increment in trip generation, high density areas tend to favour public transport more than car dependency, although this has to be substantiated by further studies using all relevant data which are as precise and detailed as possible since autocorrelation of urban variables may lead to wrong conclusions.

Key words: Urban form, urban dynamics, Density gradient, Transport system, urban form effect on transport system, Modelling, AB-Metronamica, Activity distribution

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1. Introduction

In urban environments, transportation is the backbone of the system that eases spatial interaction. Provision of an efficient and effective transport system and reduction of energy consumption and environmental impact have become the main concerns of planners and policy makers. Spatial interaction is affected by many factors, one of which is the layout of the city itself which is called urban form. This study pursues a better understanding of the dynamics of urban form and its effect on transport, with particular reference to distribution of activities (both population and jobs) and their concentration at different places in the city. Density of population and jobs are used as the indicators of urban form and their distribution and concentration over space and time are modelled using activity based modelling software (AB-Metronamica) (Vliet and Delden 2008).

1.1. Background

In recent years the study of the relationship between the built environment and transportation has increasingly attracted attention due to its consequences on the environment, energy use and ease of access. In particular, the emerging philosophies of urban design such as new urbanism, transit-oriented development and traditional town planning, have become popular as ways of analyzing travel demand (Cervero and Kockelman 1997). The main objective of such studies and philosophies is to reduce motorized trips, shorten trip length, reduce travel time and frequency, lessen car dependency, boost public transportation systems, reduce environmental impact and energy consumption and abate class and social segregation (Scott and Horner 2004). However, the relationship between the land use pattern and transport, particularly travel demand, is complicated by the variation of socio-economic characteristics and travel preference factors associated with different land uses (Stead 2001). This increases the difficulty of establishing a precise relationship between urban form characteristics and travel patterns, and adds complexity to the comparison of travel patterns in different areas.

Generally, urban environments are complex and dynamic where interactions between the economics, societal pressure and politics cause change and growth of cities (Godoy 2008). Godoy (2008) pointed out that urban change and growth are driven by demographic and economic growth and public policies, which are stimulated by commercial, industrial and service activities. These are the sectors that determine the dynamism of cities. These activities are distributed and have different concentrations over space. The concentration and pattern of their distributions results in a particular urban form. Urban form refers to the physical layout and design of the city. Urban design takes into consideration density, street layout, transportation, employment areas and urban design issues. In most developing countries with fast economic growth, the rate of urban growth is very fast and this results in both a planned and an organic (unplanned) urban pattern. This is complicating the issue of urban planning in these cities.

Urban form is, generally, described as the arrangement or distribution pattern of different urban components in relation to each other. For instance, it is about the arrangement of different land uses and the distance between different urban components, such as working places, shopping centres and other important urban centres and residential areas. Besides the relative arrangement of these components, the concentration or density of different activities is also an important factor explaining urban form. Although at different rates, urban environments are in a dynamic process, continuously changing from one form into another. This implies that arrangement of urban environment is not forever static, as is assumed in many planning studies. The rate of dynamism varies from country to country, city to city and region to region. It is highly related to the economic activities, the initial planning when the city was being built and other factors. For instance change in urban form is much faster in developing countries, particularly in the emerging economies such as India. This is very visible in relation to Ahmadabad, India, where fast economic growth and social transformation are leading to changes in the spatial spread of the urban environment (Geetam Tiwari 2001).

Understanding urban form of a city and its dynamism means understanding the effect that a particular urban form and its level of change have on the overall quality of life for urban dwellers, environmental impacts and energy consumption. An urban environment is a place where a large number of people reside in a clustered manner. Providing sufficient services, such as transport, is one of the challenges to be addressed by policy makers. Urban form has an effect on travel behaviour, such as trip length, travel frequency, mode choice and travel time (Newman and Kenworthy 1991), as it has an effect on many other urban services, such as job makers, drinking water, etc. Transport is however fundamental to most urban services, and is therefore of great concern. The main concern nowadays is how to provide a sufficient transportation system where energy consumption for transport is reduced (Shim, Rhee et al. 2006), and environmental impacts are minimized (Marquez and Smith 1999). In other words, it is a matter of how to meet current provision without compromising future resource needs. This means that the use of limited resources on transport should happen on a sustainable basis. For doing so, understanding the pattern of a city is important. However, there seems no consensus about which urban form is preferable when it is seen from different points of view. The whole process of trying to capture the complex urban system, the influence of its' components on each other and the consequent impact on urban life, environment, energy consumption and environment is often done through modelling. Thereby all these processes are artificially created in a computer environment, while scenarios are developed to visualize the future outcome of current practice. Hence, it is required to model the city and simulate the changing structure that takes into account the complex behaviour in the simplest way possible. This would thus allow decision makers to understand and predict the impacts of development plans, current development pattern, and future development choices to be able to make appropriate decisions. This study also deals with modelling changing urban form and analysis of its impact on transport systems.

The study area is Ahmadabad city, India. Ahmadabad is the seventh largest city in India with a population of 3.5 million. The city is the economic backbone of the region. It is characterised by high density in the eastern part where relatively low income population dwells. In this high density area public transport utilisation is very high. On the other hand, the western part is occupied by a high income population where they occupy larger areas and car ownership is high. The city is characterised by fast economic growth that lead to development of new areas in the city. These will add to the dynamism of urban form and transport. So, it is feasible to assess in this city how urban form dynamics affects transportation systems.

1.2. Research Problem

Urban form is the physical layout and distribution pattern of different land uses in a city. The challenge is to make town planners and policy makers understand the nature of urban form and its consequential effect on transport, energy use, pollution, the economy and social aspects (Scott and Horner 2004). Indicators of urban form, such as compactness, centrality, density, etc, have been used to study the nature of cities. Studying these over time gives insight into how cities change. Activities are distributed over the space and travel is a variable derived from the movement of people to participate in these activities. The aim of this work is to model the distribution and concentration of these activities and investigate how this affects the transport system.

This research is the continuation of Deepty Jain's MSc in which she already modelled urban form using activities. Considering some of the stated shortcomings, such as the even distribution of activities over space, it is meant to further develop the dynamic urban form model based on a distribution of activities (activities as a proxy of urban form) using an activity based modelling (ABM) concept. The model hence produced will give the concentration and distribution of activities over time as an indicator of urban form dynamics. Population and job density are the main indicators of urban form. Since concentration and distribution of activities best explain travel behaviour, the second phase of this research will deal with finding a relationship between urban form and choice of mode and quantifying this relationship in Ahmadabad city.

1.3. Research Main Objective

Transport systems connect components of the urban environment. The pattern and distributions of these components, which is described as urban form, affect the transport system in one way or another. This study is meant to determine how the change in urban form affects the transport system. Therefore, the main objective of this research is to determine the induced dynamics of transport due to changing urban form in Ahmadabad, India.

1.3.1. Sub Objective

1. To model changing urban form using activity based modelling. Ahmadabad has been in transition and growing fast due to its economic importance in the region. To understand and model the pattern of the development of the city, the following questions can serve as guidelines.
   a. What is urban form and how it is described?

   b. What are the indicators to define urban form and how can we measure them

   c. Urban environments are in a dynamic state that leads to changing in urban form. So how this change can be understood and perceived?

   d. There are several methods of modelling changing urban form and one of them is activity based modelling (ABM). But what is ABM and how can ABM serve as a proxy to model changing urban form in Metronamica software?

e. How was this done in the previous study of Jain (2009) and what can be improved?

2. To study the effects of changing urban form on mobility in particular mode choice. Urban form can be described through concentration and pattern of distribution of activities over the space and these activities are connected by transport systems. To understand the effect of changing urban form on transport, the following questions are to be answered.

a. Does urban form affect mobility elements such as travel time, trip length, mode choice, etc?

b. The development of Ahmadabad is characterised by variations in urban form and, due to its population and economic growth, the city is in dynamic state. This implies that there is high spatial interaction and people use different types of modes to participate in activities. So, how the variation and changing in urban form, such as density, affects mode choice? Can a relationship be developed between urban form and mode choice in the city?

c. In transport model, modal split is carried out depending on the utility or disutility of a particular mode choice. But if mode choice is affected by urban form, would it be possible to incorporate the effect of urban form as well? And how can this be operationalised?

1.4. Conceptual Framework

The entry point of this research was understanding and describing urban form from past works and concepts of urban form. This part mostly deals with literature review. After conceptualizing urban form and selecting one of the indicators of urban form, the next step was to choose a modelling method and platform that captures the very essence and dynamism (change) of the indicator selected.

The second phase of the research was investigation of the correlation between the urban form and transport, which was selected in the first phase. In this phase, although there has been positive correlation between the indicator and transportation, particularly the mode choice, this correlation should be seen from a different perspective. It is imperative that the impact from socio-economic perspective is taken into consideration as this plays a great role in affecting transport mode.

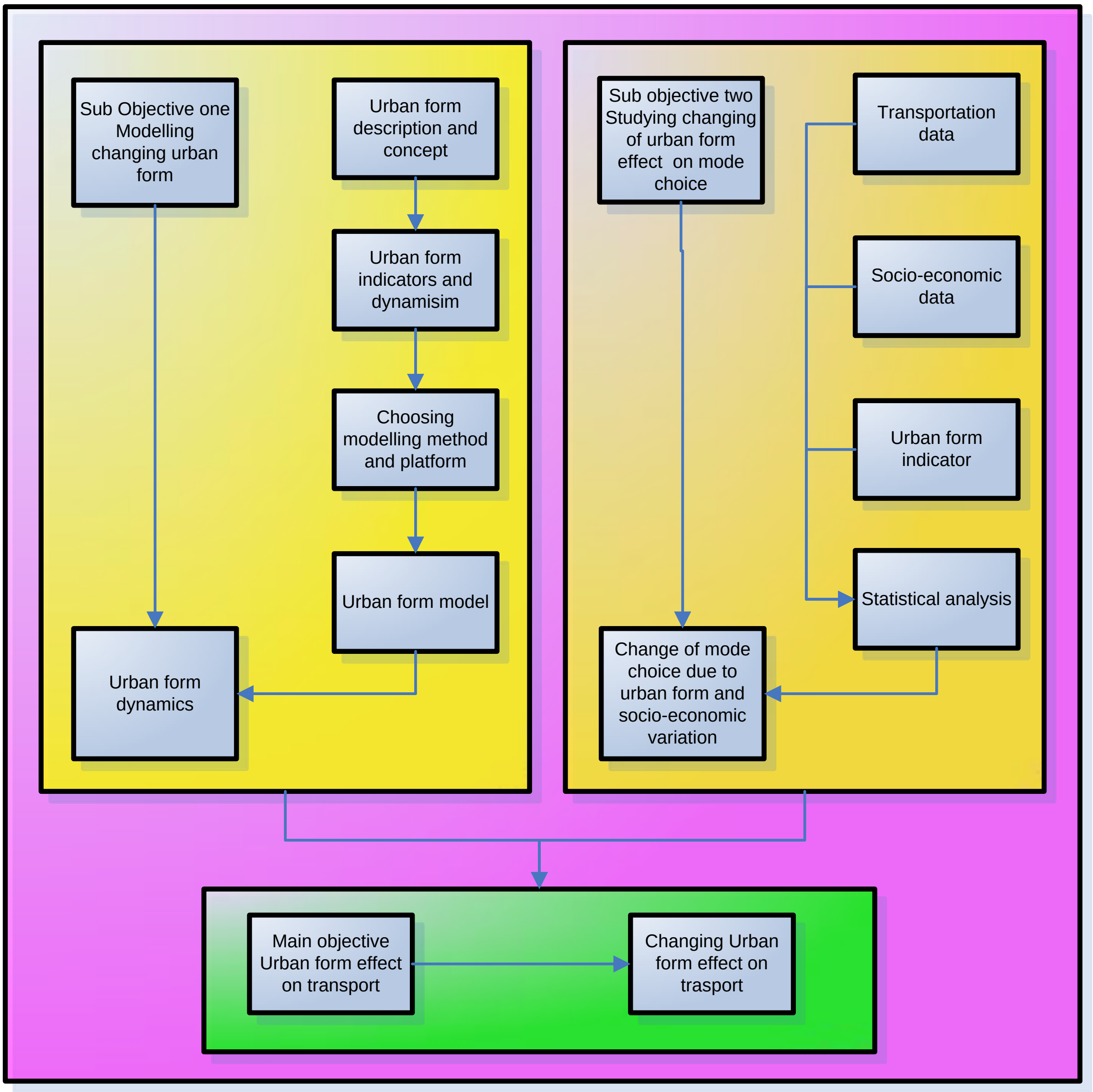


Figure 1: Conceptual Diagram

1.5. Research Methodology

This research was designed in two phases. The first phase dealt with modelling urban form based on activities using Metronamica software. The input data are raster based and the demand for each activity is computed exogenously and fed into the model. The computation of the demand has been determined according to the population and activities available for the base year. Then the rate of growth of demand has been set based on current trends and future expectations. To run the model, first the potential of each cell to be assigned an activity is determined. The potential of a cell is determined by land use of the cell, accessibility, neighbourhood effect, suitability, externalities, and others. Jain (Jain 2009) modelled urban form in terms of land use, percentage of job-activity and building density indicators. In this research, population and job density gradients have been considered as indicators of urban form. Using ABM, the number of activities in each cell has been determined and this result was used as a proxy to model urban form, as indicated by density. Density in this case is the number of activities per unit area.

The second phase analysed the relationship between urban form and transport. Using empirical data, the correlation between activity (residential, commercial, institutional and industrial) density, distance from city centre, income and transport mode choice was then analysed. The correlation factors and densities of activities simulated in AB-Metronamica were used in computing the probability of choosing a particular type of mode. Home based trip generation was calculated considering all the activities and it was multiplied with the mode choice probability to compute the number of trips made by each mode. Further, the number of cars and buses were calculated based on the average number of passengers they carry.

In this study the following steps have been taken:

- Urban form and transport literature review: this is to find out from literatures how urban form is described and the indicators used. It has been also mentioned that there are changes in urban form so what are the driving forces and how transport is affected by this change?

- The previous work on modelling changing urban form has been reviewed. This step assessed the way urban form is conceptualised, data used, modelling process and the assumptions made will be carried out.

- Identifying and assessing quality of data that are relevant for the research. This considers the way the data were collected, the year they were collected and updated, coverage of the study area, reliability and completeness of the data.

- Comparing and choosing methods to model urban form. Out of several models that model changing urban form, the one that would best accommodate the input variables such as population and jobs as activity; and considers other important factors has been chosen.

- Transition rules of cells have been determined. This has taken into consideration how activities are influencing each other and the rate of change from one land use to other depending on the strength of the interactions as a function of the distance separating the different functions and features within the neighbourhood of a cell. The rules that determine the interactions between different functions are inertia (the resistance of a cell to change), the push and pull forces whereby some functions are attracted to and some repel each other. These rules are basically determined based on knowledge or data of the area. Since there is no enough data some rules have been adopted from previous work of Jain.

- Analysis of the relationship between urban form through its indicator, which is density in this case, and mode choice from the actual data using correlation test has been carried out.

- The analysis of the result has been carried out if the modelled urban form reveals the reality on the ground and what an effect its changing has on transport.

- Limitations have been identified and further research suggested on the overall process of modelling urban form and its dynamic effect on transport.

- Conclusion has been drawn that AB-Metronaimca is the robust way of modelling urban form with some improvement.

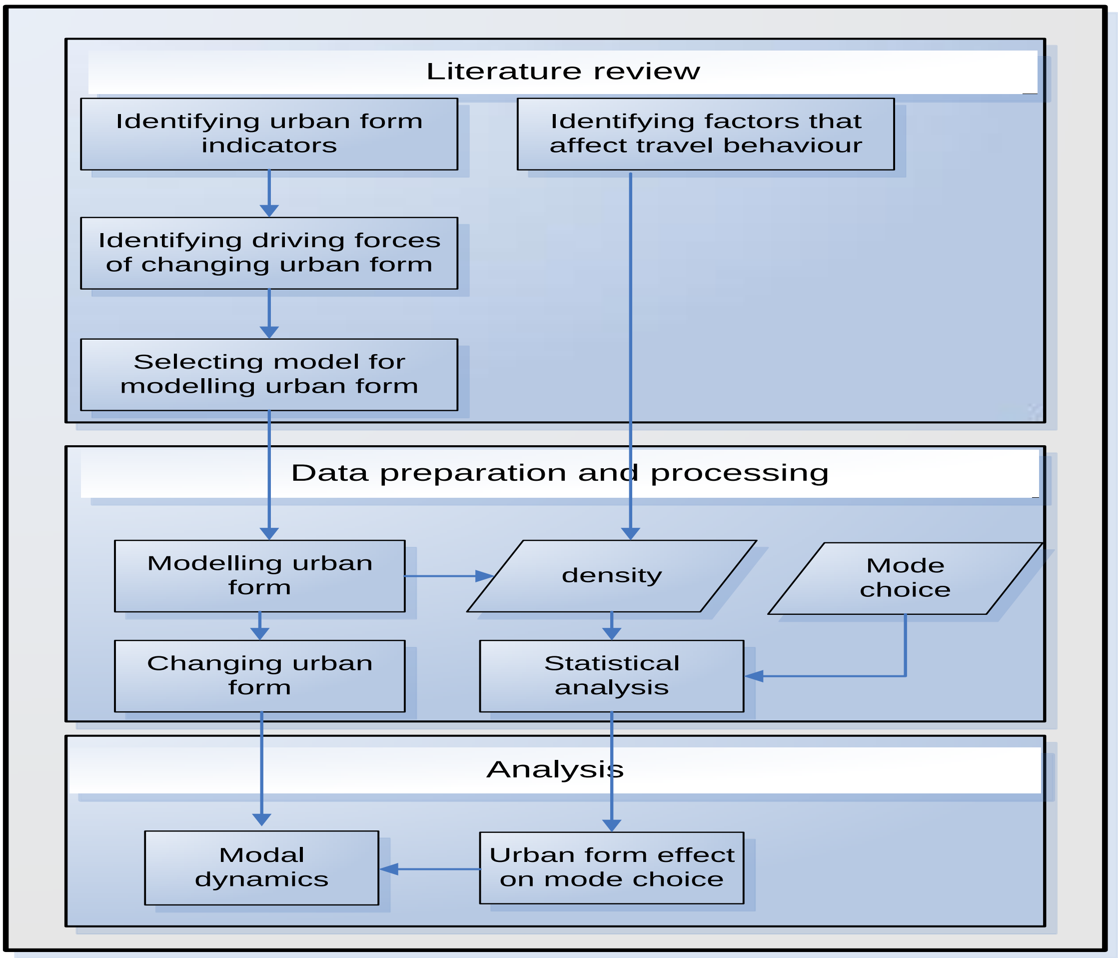


Figure 2: Research Methodology

1.6. Thesis Structure

This thesis has seven chapters:

Chapter one: Introduction
It includes general introduction, research background, research problem, research objectives, conceptual framework and research methodology.

Chapter two:
Literature review
It contains urban form and transport relationship, preceding work of urban form modelling, urban form description and driving forces of changing urban form and how urban form is conceived in this work.

Chapter three:
Contains models and modelling frameworks
It contains how some modelling frameworks, including Metronamica, operate, the definition and application of cellular automata and its components, and finally how to model changing urban form using AB-Metronamica.

Chapter four:
Analysis of the urban form of the study area
It contains: study area background, land use, jobs and employment distribution.

Chapter five:
Modelling urban form of Ahmadabad in AB-Metronamica:
It contains activity simulation description and defining and driving factors on which the simulation is based, such as accessibility parameters, neighbourhood and suitability. Finally, determining potentials of cells, macro model and finally running the simulation and discussing the output.

Chapter Six:
Analysis of transport effect on travel mode and emission
It contains: computation of trip generation, modal split, and trips made by car and by bus and finally the number of cars and buses which is later on multiplied by emission factors to calculate amount of emission.

Chapter Seven:
Conclusion of the research and recommendations for further research

2. Literature Review

2.1. Impact of Urban Form on Transport System

Urban environments are where spatial interaction occurs due to the movement of people to participate in activities situated at different parts of a city. The existing land use arrangements in part determine where people live, where they work and how and when they travel there, where they shop, where they play. Such behaviour in turn contributes to shape future land use patterns. It was the recognition of this mutual interrelationship between land uses and travel behaviour that underpinned the science of land use/transportation planning in the early years (Rhind and Hudson 1980).

Urban form can be seen from two perspectives: the external structure of cities which describes the shape and size of settlement and the internal structure which is mainly about how the urban land is used (whether it is mix or distinct land use) and about the intensity of certain activities such as population and employment density. Based on these distinctions of urban form, studies have been conducted to establish the relationship between urban form and transport.

Researchers in transport, urban planning and other fields have put much effort to understand the relationship between urban form and travel behaviour (Frank 1994; Chatman 2003; Lee and Washington 2009). Many cities around the globe are struggling to devise strategies to decrease congestion, automobile dependency and reduce energy consumption and air pollution(Crane and Crepeau 1998; Boarnet and Crane 2001).

Urban form that is considered to affect travel pattern is represented by two dimensions (Mindali, Raveh et al. 2004): the land-use intensity and the land-use distribution or centrality. The intensity dimension was operationalised through the population and employment density and land use centrality is represented by the percentage of the total number of inhabitants or jobs that is located in the inner area or CBD.

Cervero and Kockelman used three principal dimensions – density, diversity and design to test the how urban form affects trip rate and mode choice (Cervero and Kockelman 1997). They found that density, land use diversity, and pedestrian oriented designs generally reduce trip rates and encourage non-motorized travel significantly. Compact neighbourhood can decrease car trips and encourage non-motorized trips. This is due to shorter distance between origin and destination, less parking, better quality transit services, wider mixes of land uses, and larger share of low income households in compact areas. In this work accessibility is used as an indicator of commercial intensity. According to this work, accessibility measures relative proximity of neighbourhoods to activities and thus reflects compactness.

The built up environment variables used by Cervero and Kockelman are defined as follows:

1. Density:

- Population density: Population per developed area
- Employment density: Employment per developed area

2. Accessibility to jobs: expressed in gravity model form; the accessibility index serves as a proxy of relative proximity and compactness of land uses.
3. Diversity:

- Dissimilarity index: Proportion of dissimilar land uses among hectare grid cells within a tract.
- Entropy: mean entropy of the land-use categories among hectare grid cells within a half mile radius of each hectare grid cell with in the tract
- Vertical mixture: proportion of commercial/retail parcels with more than one land use categories on the site
- Per developed acre intensities of land uses classified as: residential, commercial, office, industrial, institutional, park and recreational.
- Activity centre mixture:
  - entropy of commercial land use categories computed across all activity centers within a zone
  - proportion of activity centers with more than one categories of commercial retail uses
  - proportion of activity centers with stores classified as: convenience, auto-oriented, entertainment/recreational, offices, supermarkets, service-oriented
- Commercial intensities, measured as per developed acres rates of: convenience stores, retail services, super markets, eateries, entertainment and recreational uses; auto-oriented services, mixed parcels
- Proximities to commercial-retail uses:
  - proportion of developed acres within ¼ mile of: convenience store; retail services use;
  - proportion of residential acres within ¼ mile of: convenience store, retail service use

4. Design:

- Streets:
  - predominant patter (e.g. regular grid, curvilinear grid);
  - proportion of intersections that are: four-way (proxy to grid pattern)
  - per developed acre rates of freeway miles with or abutting tract, number of freeway under or over passes, number of blocks (proxy for the grain of road net) and number of dead ends or cul-de-sacs
  - average of arterial speed limits and street widths
- Pedestrian and cycling provision:
  - proportion of blocks with sidewalks, planting strips, street trees, overhead
  - street lights, bicycle lanes and mid block crossing
  - proportion of intersections with signalized controls
  - Averages of block length, side walk width, distance between overhead street lights, slope, pedestrian green lights at signalized junctions
  - Bicycles lanes per developed acres
- Site design: proportion of commercial-retail and service parcels with: off street parking; off street parking between store and the curbs; on street front or side parking; on site drive-ins or drive through

Cera (*nd*.) implicated four reasons why to link travel pattern and population density (Cera ND). High urban density increases opportunities for the development of local activities and personal contact without extensive use of motorized travel, longer travel trips are reduced as higher population density extends the range of services that can be supported in the local area, travel distance is reduced as higher density tend to reduce the distance between homes, services, employment and other opportunities and high density might be more favourable to public transport operation and use but less favourable for car ownership and use.

A study in London shows that with increased density the percentage of travel by car decreased while that of public transport increased (ECOTEC 1993). The effect of urban form on transport is studied through energy consumption of different urban forms. The study shows that high density is characterized by low energy consumption as compared to low density (Shim, Rhee et al. 2006). This is attributed to densely developed city decreases the need for travel and enhances transit use and decreases automobile dependence.

Population density is particularly a strong factor when compared to other predictors of mode choice. Davis and Seskin's 1997 study, based on data from the American Housing Survey, found that housing density had an effect ten times greater than land use mix. Likewise, when forty land use and demographic variables were considered, housing and employment density were the most significant in determining public transit demand (Davis and Seskin 1997).

In a study on travel behaviour in the U.S., based on the 1995 Nationwide Personal Transportation Survey, Chatman found that an additional 1.5 housing units per gross acre is associated with a 0.2 mile reduction in personal VMT on a given day (Chatman 2003). A 1996 study also found that residents of denser areas travel fewer miles in automobiles than residents of spread-out areas (Dunphy and Fisher 1996). A 2002 study of the effects of several dimensions of sprawling development found that a group of factors including population density has a significant effect on VMT and transit use (Ewing, Pendall et al. 2002).

Employment density, or the number of jobs within a certain area, is also considered a good predictor of travel behaviour. Many studies show an even stronger correlation between employment density and VMT than between population density and VMT. Frank and Pivo found a significant positive correlation between employment density at the trip origin and/or destination and public transportation use (Frank and Pivo 1994). Likewise, Chatman found an average half-mile reduction in personal commercial VMT for each additional 10,000 employees per square mile at the workplace, as well as a 3% decreased probability of using an available car to commute to work for every increase of 1.5 employees per gross acre at the workplace (Chatman 2003).

Recca and Ratledge (Racca and Ratledge 2004) pointed out how land use and urban design can affect mode choice. The elements of urban design and land use they pointed out as factors affecting and/or even altering travel mode are the following:

- Sidewalks
- Population density
- Employment density
- Parking fees / parking availability
- Availability of parking
- Average commute time
- Housing density
- Retail, commercial, service, industrial, employment density
- Average parcel size

- Pedestrian environment factors

Most of the above studies are done in developed countries and it may not exactly reflect the reality in developing nations like India. Dissanayake and Morikawa said that many developing countries lack coordination between transport and land use creates complications in urban form(Dissanayake and Morikawa 2008). As a result of this mismatch between land use and transport, the number of vehicles ownership arises and this causes serious congestion on the road network. Most developing countries' cities are characterized by suburban sprawl and unplanned growth that causes an increment of trip length and makes it difficult to provide public transport.

Generally as Stead pointed out that the relation between urban form and travel behaviour is complicated by other factors such as socio-economic factors (Stead 2001). To deal with this complexity and understand the impact of different factors that contribute to the effect on transport Bodoe and Miller demonstrated how the impact of one factor affects and how consequently transport is affected (Badoe and Miller 2000). The factors and the impact on transport analysis they conducted in their paper demonstrated that the impact on travel pattern is not purely affected by urban form or any effect on transport cannot absolutely be attributed to only urban form. Some of the factors employed here are auto ownership, demographic factors, economic status, employment density, proximity to network, transit availability and service quality etc. the diagram below shows how the impact of one affects the other and ultimately the overall effect on transportation.

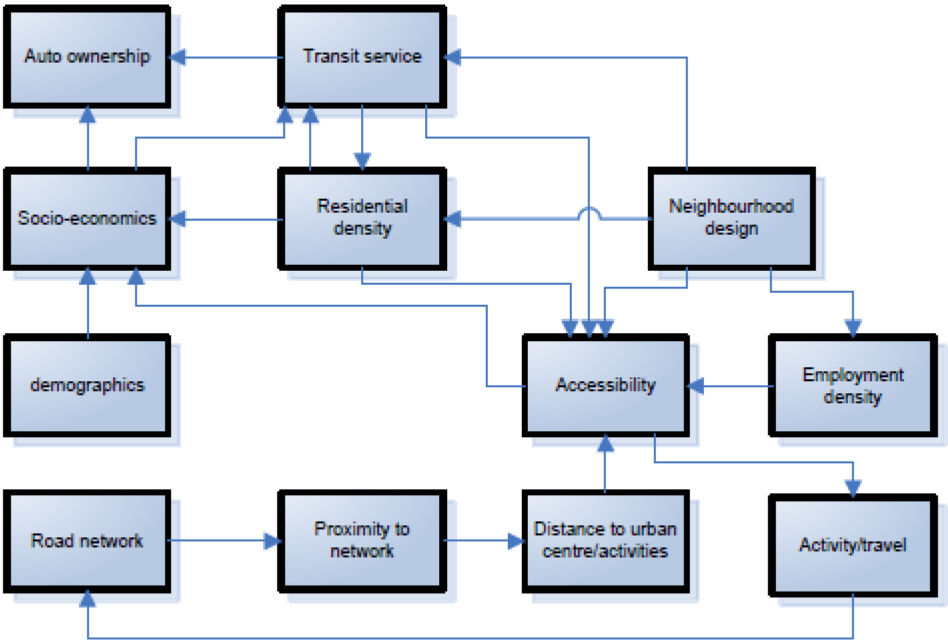


Figure 3:urban form impact on activity and travel pattern (adapted from Badoe and Miller 2000)

2.2. Preceeding Work by Deepty Jain

In her MSc thesis Deepty Jain (Jain 2009) modelled changing urban form over time using cellular automata (CA) as a modelling tool on the Metronamica platform. Urban form was defined and three indicators of urban form were used, i.e. land use, percentage of job activity and building density. The selection of the indicators was based on their contribution in having impact on travel behaviour. Land use is termed as a function that a land serves or to the activity that is allocated over a land. It is an important indicator used to control the trip lengths, trip rates and also the mode choice. Percentage of job activity in an area describes the percent of job available in different land uses. This is from the concept of mix land use. Mix land use is a name given to those areas that support different activities within it. An area termed as mix land use thus supports both residential and job-activity at same level of study that can vary from land parcel to different cell sizes. Since mix land use provides residential and job in the same area it reduces travel demand. Building density is the indicator of how intensely land is used. If the density of the building is less that means more land resource is used where by buildings are sparsely built which increase trip length. To model urban form Ms. Jain used activity based modelling (ABM). The ABM-Metronamica models magnitude of each activity defined as number of population and job in every cell. The simulation of activities is done by calculating the area for every land use activity using ABM from the starting year of 2001. To do so first the existing distribution of activities were explored to study the behaviour of the activities location. Activity constrained land uses are the ones that have activities associated with them. The demand in the model for activity constrained land uses is area which is required to meet the space needed for growing city. But the simulated land use change did not reflect much the reality on the ground since activities are evenly distributed which is not the case in reality. This is because of the nature of the growth of the city that did not happen uniformly. So the nature of the growth of the city is to be analyzed and modeled differently. This part of Deepty's work is to be reviewed critically and requires amendments to be made to reflect the reality of the city better. It includes the demand and allocation of different land uses and activities, accessibility, randomness factor etc in the modelling process.

2.3. Urban Form Description

Urban form is often described based on the purpose of the study it is wanted for. For instance the city planners might have seen the urban form from the point of view of the arrangement of different land uses relative to each other as this will guide them to analyze how different arrangements of land uses affect the overall liveability of urban environment. Service providers such as transport and health can see urban form as the number of people within a unit area so as to direct their resources to the areas where high number of people are living and to understand how different level of density affects the service provision. Urban density can also be taken into consideration with those who are concerned about how high or low density can affect quality of life. Urban designers see urban from the perspective of outlook and function of elements of cities. Their concern will be the pattern and design of buildings and the street lay out. On the other hand urban form can be defined differently in accordance with the principle it is defined by. For instance, in economics urban form can be seen in terms of land value; sociology can describe urban form in relation to the society living in a particular part of a city such as ethnic group, sex, age, low income people, middle income high income and others.

Urban form is predominantly described as the physical layout and design of the city. the physical layout and its structure takes into consideration the composition of urban elements such as the pattern and distribution of buildings the intensity of built up areas, the layout of streets, the composition of population age, sex, and ethnic background and generally urban form emerges as a consequence of local actions and interactions between these actions that results in a particular pattern in arrangement and distribution of urban components that are a result of activities. Many indicators have been employed to quantify or are used to describe urban form. Urban design takes into consideration density, street layout, transportation and employment areas and urban design issues.

Anderson and his colleagues (Anderson, Kanaroglou et al. 1996) depicted urban form as the spatial configuration of fixed urban features within metropolitan region. In this context urban form refers to the relative location of residences, work places, shopping malls, and recreation areas. It is also interpreted in terms of their densities, and the location of transport infrastructure. Finally, the urban spatial structure refers to a set of organising principles that define the relationship between the urban form and the urban interaction. (Urban interaction, also called spatial interaction, refers to the flows of goods, people and information among different location in a city.)

The above-sketched development of the urban form concept could, according to Anderson and his colleagues, be described in three simple archetypal forms: the concentric city, the radial city and the multinuclear city, see also Figure 1. The characteristics of the concentric city are a central business district (CBD) that is constituted by maximum employment density, maximum rents and maximum trip ends as well as segregated land use located in concentric zones around the CBD. In the radial city intense land uses are extended out from the CBD along major transportation routes. The multinucleated city is constituted by a number of focal points with local maxima according to population and employment density, rents and trip ends.

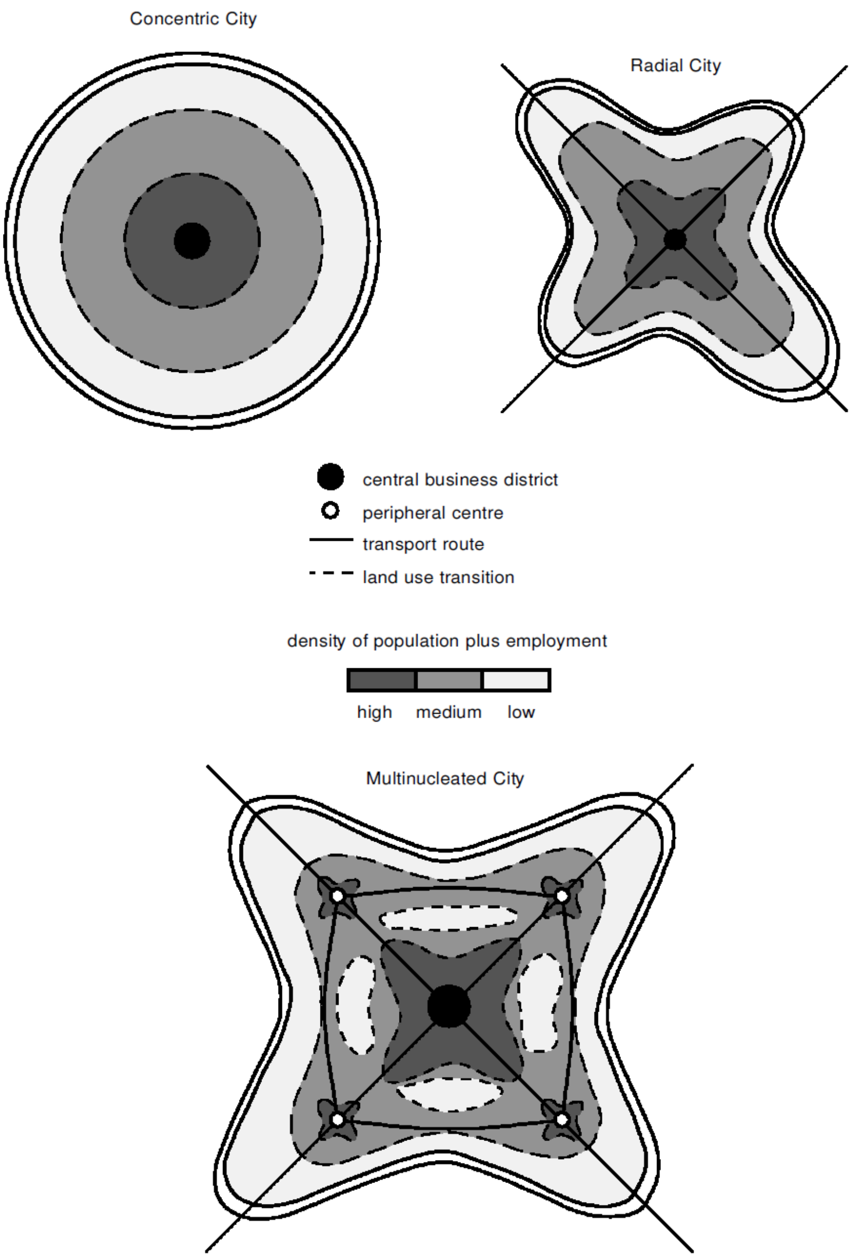


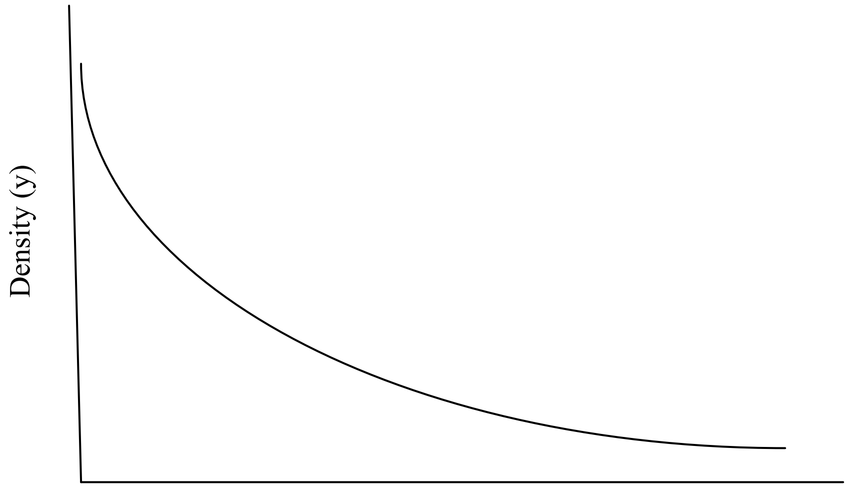
Figure 4: Archetypical urban forms (adapted from Anderson, Kanaroglou et al 1996)

The description of urban form using density-gradient was proposed by Clark (Clark 1951) that density varies over space from the CBD. The theory of density-gradient explains that density falls with distance from the centre on the city and with time density falls in the central city and rises in the outer suburbs as the city spreads out. But this pattern of density, though virtually universal applicability, varies between western and non-western culture (Berry, Simmons et al. 1963). The density pattern is expressed by the exponential formula given below

$$y = Ae^{-bx} \qquad \text{Equation 1}$$

Where: y is the population density at any given point
A population density in the centre
b the rate at which the density declines
x the distance from the city centre

The quantities x and y are variable, e is a constant and *A* and b are parameters for different cities at any given time. A high value of b indicates a compact city while a low value of b indicates urban sprawling.



Though the density gradient theory of Clerk shades light on the spatial variation of urban density this might not represent cities with several centres where a single value of b in the above equation cannot represent the whole city. basically cities with more than one centre will have a density pattern falling as one goes away from the centre and rises again as approaching the other centre. There are also uncertainties in the cities that make fluctuation in the pattern it decreases in the real world. To capture this fluctuations and uncertainties Yeh and Li (Yeh and Li 2002) introduced stochastic disturbance variables R. this will make the density decay closer to reality.

$$R = 1 + \left(\frac{\gamma - 0.5}{0.5}\right)\alpha \qquad \text{Equation 2}$$

Where γ γ is a random variable within the range [0, 1], and α is used to control the size of stochastic perturbation. For example, a value of 0.1 means that 10% of maximum fluctuation can be produced by the density-decay function

Cao and his colleagues (Cao, Strauss et al. 1998) used homogeneity, directionality, connectivity, density pattern, density gradient, concentricity and sectorality to measure the urban form. Homogeneity measures diversity of land uses or social areas. Density pattern reflects the shape and intensity of population per unit area. Connectivity is used to demonstrate the roadway network. Density gradient measures change in population density from the CBD of a city to outer part. Concentricity is defined as the degree to which uses and activities are organized zonally around the centre. Sectorality is defined as the degree to which uses and activities are organized sectorally around the city centre. Zhang and Guindon (Zhang and Guindon 2006) defined compactness as the degree to which urban area is concentrated around a centre. It is the measure of the inverse of dispersed pattern of cities.

In this research urban form is described as a distribution of activities (both population and jobs) and their concentration over space which is density.

2.4. Driving Forces of Changing Urban Form

Changes in urban form can be conceptualized depending on how urban form itself is described. If we mean by urban form the structure of how a particular city is arranged, then the change in urban form means the change in its structure such as street layout and the overall design of the city. Indeed this type of description and change is concerned with outer look of a city. When the internal structure is put into consideration such as population, employment, and job density, the change in urban form means the change in these elements either increasing or decreasing. Generally each component of the urban environment is constantly evolving due to changes in technology, policy, economics, demographics and even culture and/or values, etc. The urban structure is a result of human actions and it is shaped and reshaped primarily by human action and activity that is either driven politically or economically. The political systems on different levels put attention to the urban structure and its relationship to the ecological, sociological and economical systems (Ham, Hooimeijer et al. 2000). The economic growth can result in huge construction of buildings, residential areas, expansion or building of new business district, like the case in Dubai, highways and other physical structure of urban environment which finally alters urban form. In Ahmadabad, India, where the economic growth is significantly observed, there are new development projects such as river side and a city expansion Especial Economic Zone called GIFT city whereby hundreds of thousands of jobs would be created that attracts a lot of employ to the area and that shapes the distribution of jobs and population density. Beside other influential factors that drive the change in urban forms, job distribution which is associated with economic growth and economic policy of a particular city plays a greater role. Ham and his colleagues stated that deconcentration of employment is the driving force behind the rise of the complex urban forms of the polycentric city and the polynucleate metropolis (Ham, Hooimeijer et al. 2000). They explained that the deconcentration process improves job access for average and highly skilled workers, allowing them to move to peripheral residential locations and triggering a new round of urban sprawl. They also hypothesised that access to suitable job opportunities is withheld from low-skilled workers living in inner-city neighbourhoods as a result of the deconcentration of low-skilled employment beyond their commuting tolerance. These processes would lead to the movement of people to the area where they can easily reach their destination and finally these would result in reshaping urban form such as density over time. Generally, the term urbanization is linked to the demography and economy of a city (Taubenböck, Wegmann et al. 2009). To analyse the spatiotemporal process of urbanization by urban form and its change over time at city level, Taubenböck *et. al* (2009) adopted absolute areal growth or built up density (sealed areal per spatial entity) and spatial metrics (measurement of spatial heterogeneity at specific scale and resolution) parameters.

In summary this section has dealt with urban form description, urban form indicators, the definition of urban form indicators, the dynamics of urban form and their causes, and also the effect of changing urban form on transport. The next section deals with finding the tools to model the dynamics of urban form using the density gradient concept which deals with sealed areal per spatial entity pattern.

3. Modelling changing Urban Form and The Modelling Techniques

3.1. Modelling Changing Urban Form

Urban and city environments are where the biggest share of the population of the world dwells. The capacity of the city to offer the better quality of living depends on the organization of the city's founding elements such as transportation facilities, service providing centres, utility infrastructures, and the pattern of residential areas and the intensity at which the land is used in terms of putting these elements at particular distance from each other and their overall arrangements.

The main challenge for policy and decision makers is to understand the urban environment and its interaction so that to come up with a policy and decision that will lead to sustainable urban environment and ultimately to provide for the urban dwellers a possible quality life. Sustainability being at the core of current concern and providing better life for today's generation is also paramount. To utilize resource in a sustainable manner knowing which form of urban consumes more resource and which form of urban makes life easy and accessible.

Since their inception urban environment have been expanding dramatically and the number of people living in urban environments are growing at alarming rate around the globe. These expansions of urban areas are at the expense of agricultural land, forest, environmentally sensitive areas. The consumption of land by urban environment depends on how the built environment is arranged and how the different land uses are arranged relative to each other. In the contemporary world the biggest challenge is how cities are growing and the urban sprawl that of course consumes a lot of land. Beside the inefficient use of land the big concern is how to make accessible one part of the city to the other part and make the spatial interaction easier. To deal with all this challenges there must be a mechanism of understanding how cities have developed and resulted with current urban form and how this is going to evolve in the future and the impact of the past on present and developing different scenarios based on the past and present to forecast what is going to happen. For this scientists have come up with idea of modelling through which they can evaluate the past assess the present and speculate the future based on empirical information and assumptions.

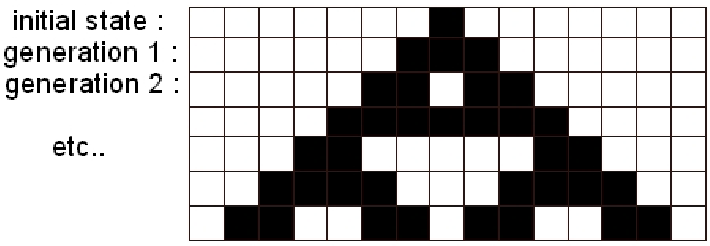
3.2. Models Used To Model Changing Urban Form

Models are techniques that we employ to represent the real world in a computer environment and explore it. "A model is an abstraction of an object, system or process that permits knowledge to be gained about reality by conducting experiments on the model" (Clarke 2004). Urban environment is very complex where the dynamic interactions between its elements are so complex and cannot be inferred easily. So models help in simulating this complex urban system and simplify the process of understanding it. One of the characteristics of urban environment is its urban form and its dynamics. Several models have been employed to simulate the spatial temporal change of urban environment. Now a days, simulating urban dynamics using cellular automata, which is based on self organizing theory, is becoming prevalent. The CA models that are used to model urban form dynamics, beside neighbourhood influence, has to consider many other factors with respect to urban development since urban system is highly complex system (Long, Shen et al. 2008).

3.2.1. Cellular Automata

Cellular automata is a collection of cells grid of specified shape that evolves through a number of discrete time steps according to a set of rules based on the states of neighbourhood cells. The cellular automaton's rules determine how the states change. When the time comes for the cells to change state, each cell looks around and gathers information on its neighbours' states. Exactly which cells are considered "neighbours" is also something that depends on the particular CA neighbourhood type and size (Batty 2005a; Saskia 2008). Based on its own state, its neighbours' states, and the rules of the CA, the cell decides what its new state should be. The transition of all the cells from one state to another happens at the same time resulting in new generation of the CA (Saskia 2008). The row of cells can be considered as a miniature world that runs through a sequence of years or generations. At the end of each time step, all the cells simultaneously decide on their state for the next. The rules are then applied iteratively for as many steps as desired. According to Conway's Game of Life (Gardner 1970), a cell can either be alive or dead and its state is determined by its neighbours. If the minimum and maximum number of neighbouring cells needed for a cell to develop is set to two and three respectively, then when the number of neighbouring cells is less than 2, a cell which is already developed 'dies' through isolation. When the number is greater than 3 the cell 'dies' through overcrowding. When between 2 and 3, an already developed cell remains developed but an empty cell is also developed, giving rise to a 'birth'. These simple rules lead to structures which are self-perpetuating as is 'life itself' (Greene 1988). As the name indicates CA is an automatic simulation over space divided in the form of cells.

There are several types of cellular automata and the one described by Saskia is simplest type. "The simplest type of cellular automaton is the one-dimensional CA. Here the cells are arranged on a single line, and each cell looks to its left and right neighbours to decide its next state. How far left and right it looks, is determined by the radius. By graphically placing the one dimensional cell arrays of consecutive generations underneath each other, complex patterns can be observed"(Saskia 2008).



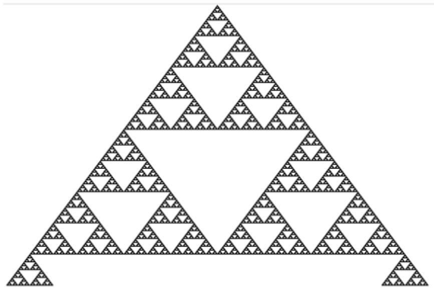


Fig (a) First 7 generations

(b) First 300 generations

Figure 5: Graphical representation of a one-dimensional CA (adapted from Saskia 2008)

3.2.1.1. Cells and Cells' State of CA

The cells used in cellular automata are predominantly rectilinear grid tessellation as it has advantage both in terms of compatibility with raster based data and computational efficiency though these sometimes introduce artifacts into the spatial structure generated by CA (White and Engelen 2000). The size of the cells depends on the level of disaggregation and details needed.

Cell state is mostly the land use and land cover or any variables that are spatially distributed for the purpose of modelling. For instance cell states may be used to represent population density levels (Wu 1998). In this approach the transition rules add population to cells so that each cell is characterized by population counts that change with each iteration. Since cell sizes are uniform, the cell values in fact represent population density.

3.2.1.2. Neighbourhood

Neighbourhood in CA, neighbourhood is considered as the cells that are surrounding a cell under investigation. The size and shape of neighbourhoods depend on the cell size and number used. For simplicity purpose most application of CA adopts either the Von Neumann

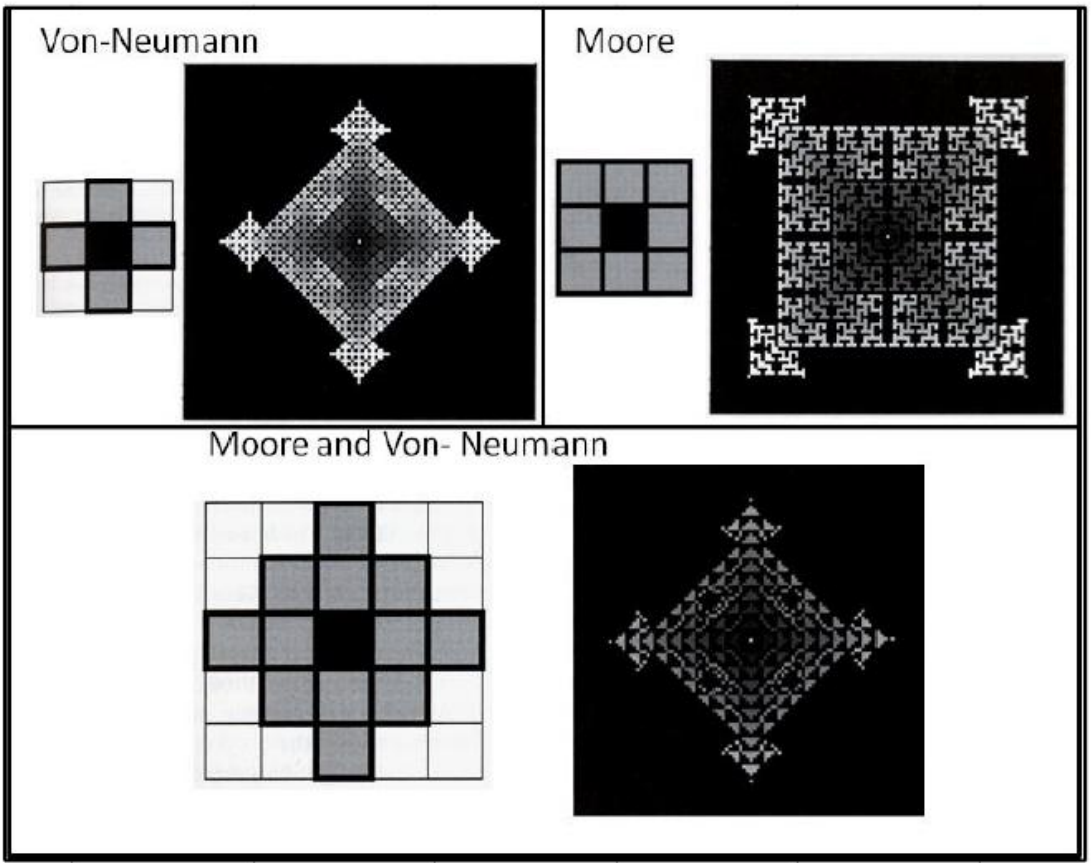


Figure 6: Types of neighbourhood and emerging patterns; source (Batty 2005)

neighbourhood (consisting of the four cells adjacent to the sides of the Cell) or the Moore neighbourhood (the eight adjacent cells) (White and Engelen 2000). Aside from choosing a neighbourhood type, one must also decide on a radius, which is a parameter that determines how far the neighbourhood extends.

3.2.1.3. Transition Rules

Transition rules are the local rules that determine the transition of a cell state from one to another. “The key reason why locality is so important in CA revolves around the idea that local action leads, in many circumstances, to global order, to emergent structure. Often local rules which are applied routinely lead to structures in the large that look highly ordered but cannot be predicted from any top-down command-like process or model” (Batty 2005b). The transition rules are the heart of a CA as they represent the logic and spatial dynamics of the whole process being modelled. They differ according to the process they represent. They might be as simple as game of life or spatial voting models whereby a cell takes the state of the majority state in its neighbourhood. The complex rules may consist of an entire sub models and they are developed to neighbourhoods with a large cell radius which will represent local spatial process that includes a distance-decay effect. For instance, a rule relating the future land use of a cell to the actual land uses within an eight-cell radius will represent the attraction and repulsion effects of the various land uses in the neighbourhood, but with a shrinking of the effect of the more distant cells (White and Engelen 2000).
There are several frameworks of modelling urban changes that use cellular automata as a modelling tool. Some of these are: CLUE, SLEUTH, Metronaimca, LEAM, etc

3.2.2. CLUE (Conversion of Land Use and its Effect)

CLUE is used to make a spatially explicit, multi-scale, quantitative description and analysis of land use changes through the determination and quantification of the most important bio-geophysical and human drivers. The CLUE methodology is based on the analysis of land use systems as complex, multi-level systems. This complexity is captured by a combination of dynamic modelling and empirical quantification of the relations between land use and its driving factors (Verburg 2008). The concepts implemented in the CLUE methodology are:
Connectivity: locations that are spatially distant influencing each other as a consequence of direct processes (e.g. erosion/sedimentation), neighbourhood effects or feedback over higher scale levels.
Hierarchical organization: Higher level processes can steer and constrain lower level processes while, at the same time, higher level features might emerge from lower level dynamics
Stability and resilience: land use systems are able to absorb disturbances before the structure of the system is changed, e.g., farmers will not change land use directly upon fluctuations in market prices of agricultural products Driving factors: a large set of socio-economic and biophysical factors can be seen as the 'drivers' of land use change, steering the rate and/or location of change.

3.2.3. Metronamica

Metronamica is modelling framework developed by research institute of knowledge and Systems (RIKS) to model urban complexities based on cellular automata system. Its’ primary goal is to explore the effects of alternative policy options on the qualitative of the socio-economic and physical environment(RIKS 2005). It operates at three levels (figure 5): local regional and national. At the Global level the model integrates figures taken from economic, demographic and environmental growth scenarios. The growth figures for the global population, the activity per economic sector, and expansion of land uses are derived and fed into the model as a global trend lines. The main economic activities are categorised into 3 to 10 aggregated sectors such as industrial, commercial, services, farming etc. At the regional level the model consists dynamic spatial interaction based or dynamic gravity based model where by the administrative regions computes for activities based on their attractiveness in terms of geographical location of a region relative others, employment level, population size, type and quantity of existing activity and proximity to transport systems . So the national growth over the modelling area will not occur evenly but the regional inequality will influence the location and relocation of new residents and new economic activities. At the local level the detailed allocation of economic activities and people is modelled by means of cellular automata based land use model (White and Engelen 1993).

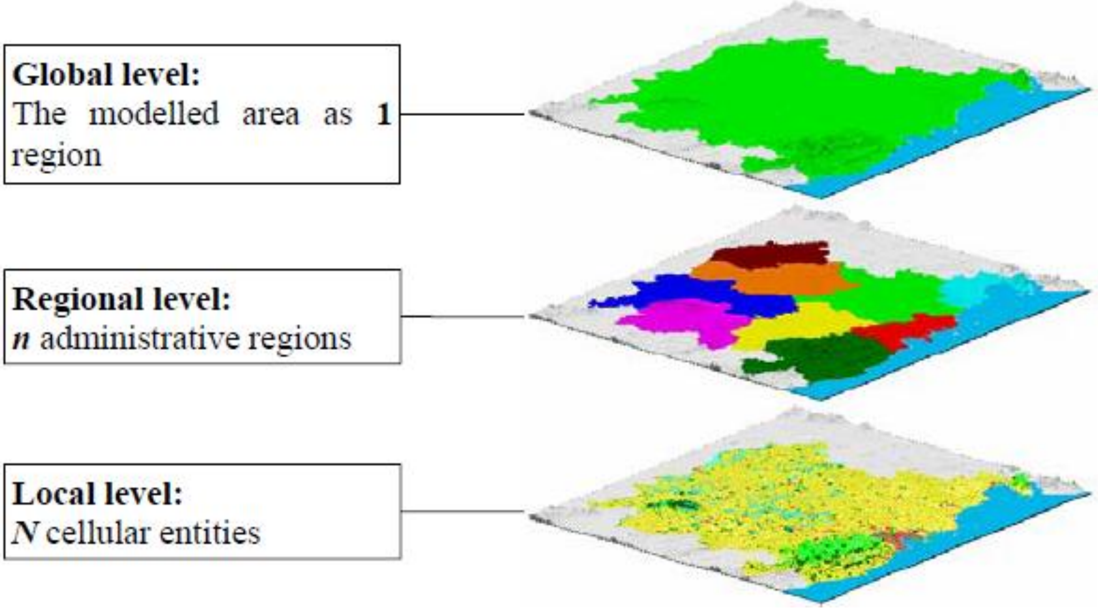


Figure 7: Metronamica represents process at three spatial levels: Global, Regional and Local (source: RIKS 2005)

The model has macro-model determining demand of land use at each time step at regional and national level and micro-model that simulates land use change at local level. The land use change of any cell is determined by the transition potential that is based on four factors: neighbourhood, accessibility, suitability and zoning along with randomness perturbation as demonstrated in figure 6 (RIKS 2005).

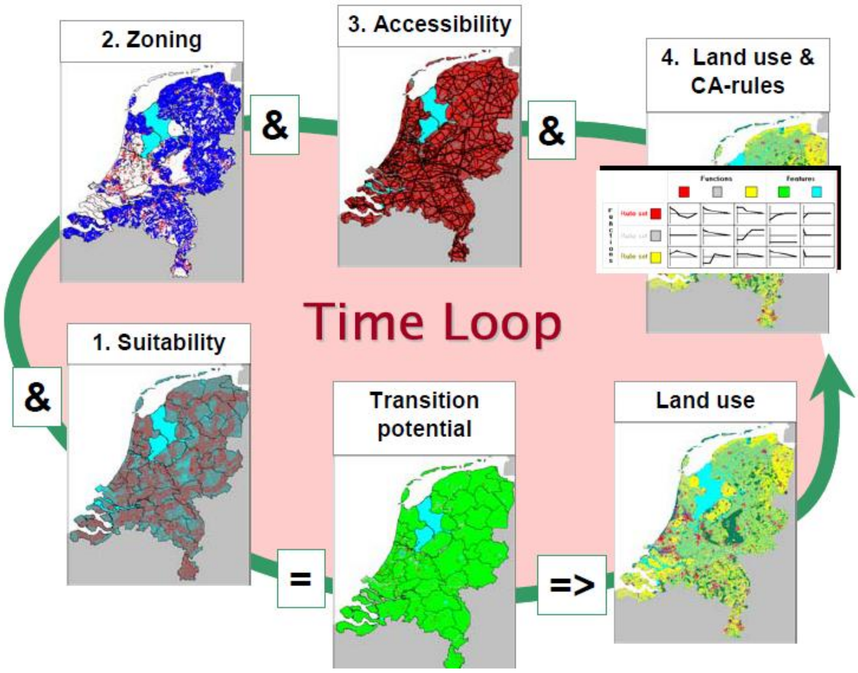


Figure 8: Four elements determining the dynamics at the local level (source: RIKS 2005)

Based on the four elements the model calculates at each simulation step the potential for each cell and function. The allocation of cells will be carried out until the regional demand is satisfied and cells will change to the land use function for which they have the highest transition potential.

3.2.3.1. Activity Based Modelling Metronamica (AB-Metronamica)

Is another version of Metronamica developed by RIKS used to model land use dynamics based on activities (population and number of jobs). Vliet and Delden (Vliet and Delden 2008) explain that AB-Metronamica is cellular automata model constrained by activities. At every time step the model distributes activities over cells based on transition rules. The land use is computed based on the amount of activity distributed which indicates that land use and activities are mutually dependant. The value of the simulated resulting cells will have land use and number of activities.

3.2.4. SLEUTH

SLUETH is land use change model developed by Dr. Keith C. Clarke at UC-Santa Barbara and the name SLEUTH was derived from the simple image input requirements of the models: Slope, Land cover, Exclusion, Urbanization, Transportation, and Hill shade. SLEUTH is a cellular automaton model of urban growth and land use change. The model uses two tightly coupled cellular automata models, one for urban growth and the second for land use change. It includes self-modification of control parameters, and has a self-calibrating capacity built into the computer code for the model (Silva and Clarke 2005). The disadvantage of SLEUTH is that it currently only defines built-up land and does not model intra-urban categories that help to model urban form.

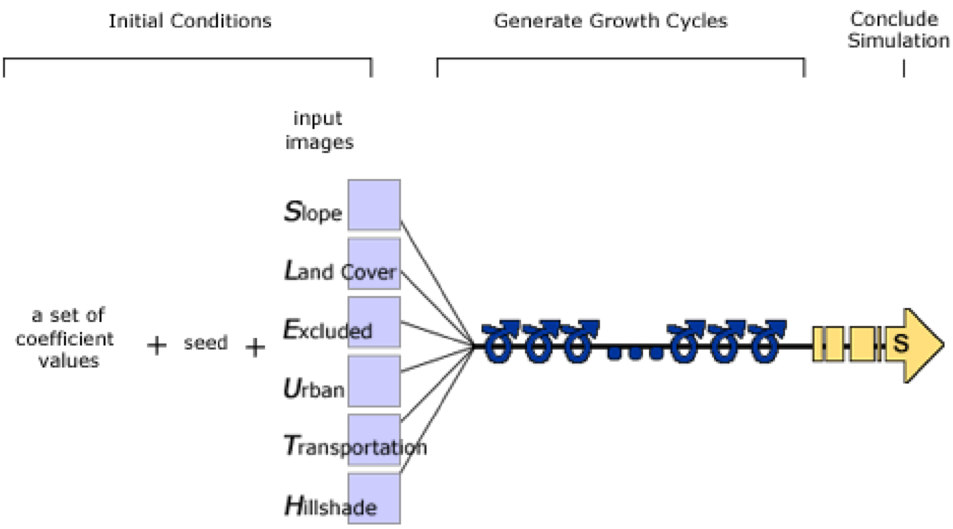


Figure 9: SLUETH modelling framework (Source: sited in Jain 2009)

3.2.5. LEAM

LEAM is extended CA concept model of land use change that has been developed as a comprehensive urban planning support system on a regional scale that simulates land use change across space and time. The cell will evolve in a constrained surface defined by biophysical factors such as hydrology, soil, geology, land form etc and social-economic factors such as administrative boundary, census district. The model incorporates ecological, economical, social, geographic and environmental theories into a single hierarchical framework. LEAM helps to examine and comprehend the complex relationships between what causes growth, where growth is likely to occur under different scenarios, and the likely impacts be it positive or negative.

3.3. Conclusion

The modelling platforms, which are discussed above, are all good to model changing land use and urban growth. But AB-Metronamica offer an opportunity to explicitly model changing land use and additionally the number of activities (population and jobs) and their distribution and concentration over space and time. Besides, the algorithm on which the transition rules are based flexibly set in the model that allows the user to define their own algorithm or use the predefined ones. This makes Metronamica much more user friendly and adoptable to a situation being modelled. Moreover, the platform suits the main purpose of this study which is meant to analyse the effect of changing urban form on transport as it models the changing urban form and its' output can be used directly to analyse the effect of changing urban form on transport. So in this study AB-Metronamica is chosen to model changing urban form and it is discussed in detail in the following section.

3.4. Activity Based Modelling and Its' Use to Serve as Proxy to Model Urban Form

The inception and development of cities are the results of human activities where interaction between people results in a sort of building up environment. Days back when urbanization in the planet was not rampant and built environments are not situated at close proximity people used to come together at some particular intermediate place to interact and exchange both goods and information. When this particular place became customary they started building buildings in which this interaction was being carried out. As the size of the population attracted to the area grows the number and types of activities grows. This leads to creation of new activities, duplication and expansion of the existing ones. In the process some activities are attracted to each other that results in agglomeration of buildings and some repel each other that cause expansion and stretching out of the building pattern of the growing urban environment. This attraction and repulsion of different urban founding elements and their eventual distribution and concentration over the space result in some particular pattern and this is called urban form.

Basically urban form is the result of the interaction between the human and its environment on space. This relation can be described through the following points: where are this people situated, how intense they use the space, how close they are living relative to each other, and what is the arrangement or pattern of their settlement, what type of activities are being carried out at particular space and others are to determine how urban structure would look like and the pattern of its growth.

Modelling urban form should put into consideration all these human activities and their situation relative to each other. At some point the idea of simulating how cities are growing and how one activity is attracting the other or repelling is not the only issue. Human decisions quite often interferes this soundly spontaneous process of self adjusting or organizing system. These include some development policy that only encourages development in some areas and restricting at some other places, planning of new development at some point in the future or now. So in modelling urban form this sort of random decision should be taken into account. So this concept can lead us to a conclusion that urban form is the result of the distribution and concentration of activities and population. This implies that when activities and population distribution is known implicitly this tells what type of urban form is that using any of the indicators of urban form that are used by several researchers and choosing the one that serves the purpose at hand. In this paper density of population and jobs is used to later on assess the impact of density on transport.

Activity based modelling (ABM) is used to model land use dynamics based on activities which represents population and number of jobs. Vliet and Delden explain that ABM is cellular automata model constrained by activities. At every time step the model distributes activities over cells based on transition rules. The transition rules take into consideration the effects of activities in the neighbouring cells, the land use of the cell, externalities and stochastic perturbation terms. The land use is computed based on the amount of activity distributed which indicates that land use and activities are mutually dependant. The value of the simulated resulting cells will have land use and number of activities. To model land use based on constrained cellular automata (CA) the area demand for each land use is defined exogenously and the model executes the allocation based on transition rules. The number of activities per cell's area is density and it can be used as a proxy to model urban form since density is one of its indicators (Narayan Sarlashkar 2009).

3.4.1. Modelling Urban Form in AB-Metronamica Platform

Activity based Metronamica is a platform to model urban complexities based on cellular automata model. "Cellular automata are computable objects existing in time and space whose characteristics usually called states change discretely and uniformly as a function of the states of neighbouring objects, those that are in their immediate vicinity" (Batty 2005). Activity based modelling (ABM) is used to model land use dynamics based on activities which represents population and number of jobs. Vliet and Delden explain that ABM is cellular automata model constrained by activities. At every time step the model distributes activities over cells based on transition rules. The transition rules take into consideration the effects of activities in the neighbouring cells, the land use of the cell, externalities and stochastic perturbation terms. The land use is computed based on the amount of activity distributed which indicates that land use and activities are mutually dependant. The value of the simulated resulting cells will have land use and number of activities. To model land use based on constrained cellular automata (CA) the area demand for each land use is defined exogenously and the model executes the allocation based on transition rules.

3.4.2. The Cell State

Cell state can be defined depending on the purpose it is wanted for. Generally the cell state is the current state of the cell of the area being modelled. For example a cell state can be described as developed and not developed to express the extent to which a cell is occupied by a particular land use or activity relative to the capacity of a cell to accommodate these activities. Since there are some land uses that cannot be associated with activities there are three different land uses in this model. These are activity constrained land uses such as residential whereby population is associated, are constrained land uses and unconstrained land uses. Activity constrained land uses are assigned based on their corresponding activity distribution, area constrained are allocated next and all the remaining cells that are not occupied by two constrained land uses are allocated to unconstrained land use such as natural area. There are also other land uses which are not affected and maintain their location but affect the allocation of other land uses. These land uses are called feature land uses such as water body, mountains etc. as a result of this a cell will not only have a limited number of cell state indicating a predominant land use but also an amount of each activity that is explicitly simulated. In this process that simulates population dynamics and job as activity, the resulting cell will have predominant land use, a number of inhabitants and a number of jobs (RIKS 2008).

3.4.3. The Neighbourhood effect

The transition of a cell from one state to another is influenced by the state of the cells in the surrounding area of a cell under investigation. This neighbourhood is defined in the model description of Metronamica as the circular region around the cell out to a radius of eight cells. The neighbourhood thus contains 196 cells arranged in 30 discrete distance zones forming concentric circles. The influence of one cell over another in the neighbourhood varies according to the distance between them and this distance between two cells a and b is given by

$$D(a,b) = \sqrt{x^2 + y^2} \qquad \text{Equation 3}$$

Where: *x* and *y* represent the horizontal and vertical distance between the cells respectively

The principle of CA is that a state of a cell at a given time depends on the states of the cells within the neighbourhood. Therefore the neighbourhood effect for each land use needs to be calculated to determine which cell is being converted to what land use function. The effect of the neighbourhood can be either positive where some land use functions attract each other or negative where some land uses repel each other. The figure below shows the attraction and repulsion of land uses. It is also observable that as the distance between the cells increases the repulsion or attraction effect decreases though this is not the general pattern as some land uses attract each other to some distance and then they repel each other when certain threshold is reached or vice versa.

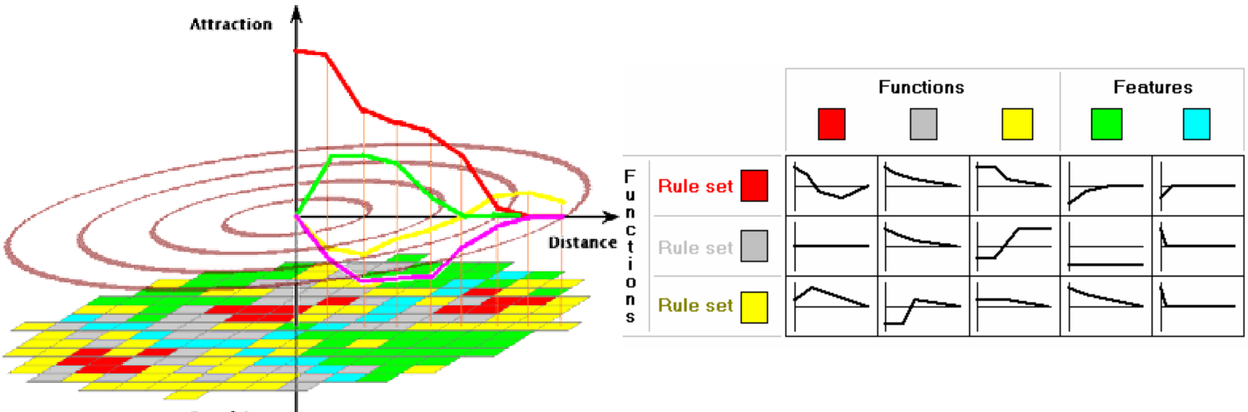


Figure 10: calculation of the neighbourhood effect (source: RIKS 2008)

For the calculation of the neighbourhood effect, a circular neighbourhood consisting of 196 cells is applied (left). For each land use function, the transition rule is a weighted sum of distance functions calculated relative to all other land use functions and features (right).

Generally cells in the neighbourhood that are situated at further distance will have less influence relative the ones which are closer to the cell being investigated. Each cell will have a weight depending on the distance and their state. And the effect is calculated as follows

$$N_{k,i} = \sum_{d} \sum_{j \in J_{d,i}} \sum_{i} w_{i,k}(d).X_{i,j} \qquad \text{Equation 4}$$

Where:

$N_{k,i}$ The neighbourhood effect for activity k in cell i

$J_{d,i}$ is the set of cells at a distance d from cell i

$w_{i,k}(d)$ is the weight function representing the attraction or repulsion from activity *l* on activity *k* at distance *d*

$X_{i,j}$ is the amount of activity l in cell j

The weight indicating the attraction or repulsion of one activity or land use to another is multiplied with the amount of activity in the neighbourhood cell. For feature land use and area constrained land uses their weight is added to the neighbourhood effect. Cells with a land use that is associated with activity will not contribute explicitly, but only through their activity itself. Otherwise, activities in cells with another predominant land use will contribute to the neighbourhood effect (RIKS 2008).

3.4.4. The Transition Rules

Transition rules are the mathematical based rules that determine the conversion of a cell state from one to another. The transition rules of cell takes into consideration the state of neighbourhood and the cell itself. So the transition rules determine the state of output cell state which will be based on the state of the input cells and other factors at every time step. In activity based modelling at every time step the activities are distributed over cell according transition rules and then based on the number of activities dominant land use is assigned to the cells.

The transition rule is meant to allocate cells state based on algorithms that assigns values for each cell according to their transition potential. The transition potential of each cell is calculated from the neighbourhood effect and other factors such as connection of the place to different transport networks, the physical suitability of the place to accommodate the new activity, and stochastic factor to take into consideration the possible effects of unpredictable occurrences (RIKS 2008).

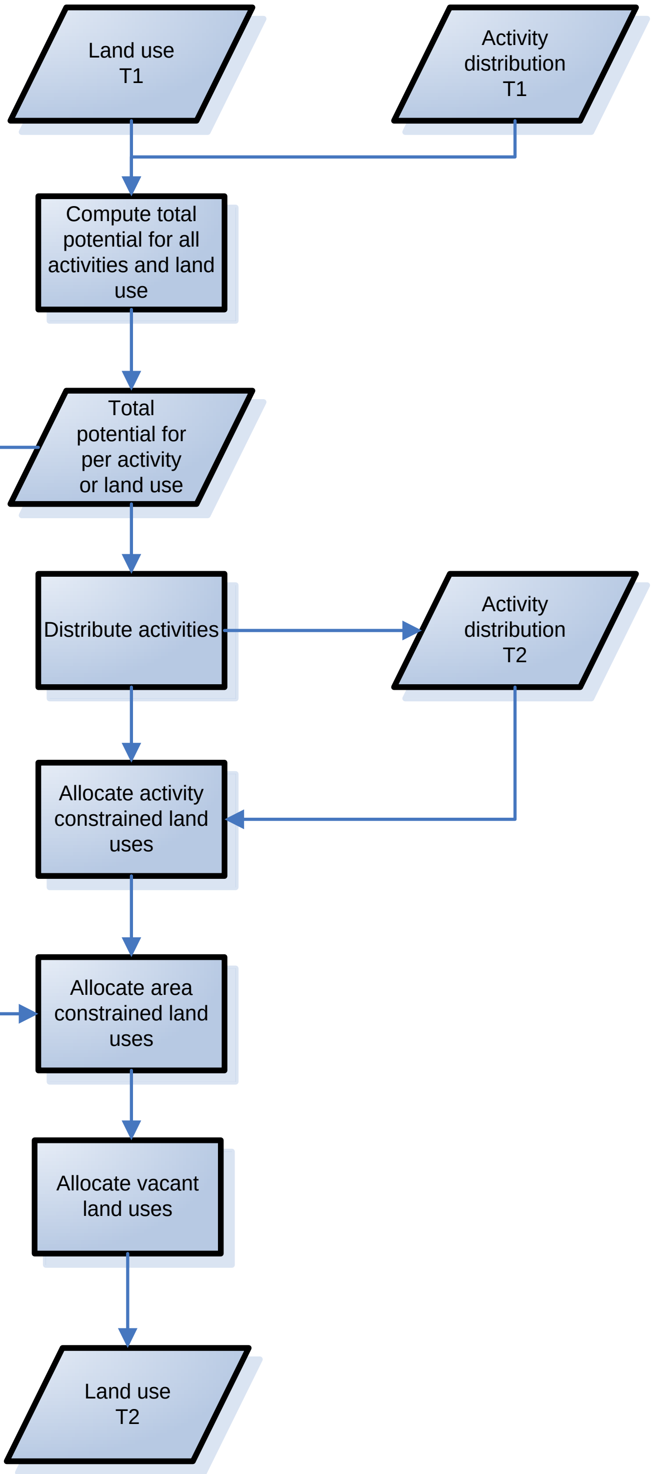


Figure 11: Transition rules for activity based cellular automaton model (RIKS 2008)

3.4.5. Activity Distribution

Land use change and the dynamics of urban environment is captured in the model by distributing activities over the modelling region to each cell on the bases of their potential to accommodate and flourish activities. First activities are distributed and associated land uses are assigned in accordance with the activity distribution and other factors at every time step (RIKS 2008).

The transition potential of each cell is calculated according to the following equation:

$$TP_{k,i} = C_{k,i}(g).f\left(N_{k,i} + E_{k,i} + \epsilon\right) \qquad \text{Equation 5}$$

Where: $TP_{k,i}$ is the potential for activity of k in cell i

$C_{k,i}(g)$ is the compatibility coefficient for activity *k* with land use g in cell *i*

$f(x)$ is the transformation function to avoid negative potentials:

$$f(x) = log_2(1 + 2^x)$$

$N_{k,i}$ is the neighbourhood effect for activity *k* in cell *i*

$E_{k,i}$ is the diseconomies of scale effect for activity k in cell I,

ϵ is a stochastic variable drawn from a Normal (0, α) distribution. This variable is drawn independently for each cell.

Once the potential of a cell is determined the next step is distributing activities according to their potential to accommodate activities that are to be distributed or redistributed at each time step. When there is more than one activity type the allocation is done separately and independently for each activity. So the effect of activities over each other is only at the previous time step distribution of activities through neighbourhood effect. The distribution of activities is executed according to the following expression:

$$X_{k,i} = \frac{TP_{k,i}}{\sum_j TP_{k,j}} \qquad \text{Equation 6}$$

Where: $X_{k,i}$ is the activity *k* in cell *i*,

$TP_{k,j}$ is the total potential for activity k in cell i

$\sum_j TP_{k,j}$ is the sum of activity potential for activity *k* in all cells j including *i.*

But there is a maximum limit of activities number a cell can accommodate. To halt more than maximum allocation the process is carried out till the allocated activity exceeds the maximum number of activity which is set by modeller. This is given as:

$$D_k * \frac{TP_{k,i}}{\sum_j TP_{k,i}} > M_K \qquad \text{Equation 7}$$

Where: D_k is the remaining demand for activity *k*,

M_K is the maximum level of activity in a cell for activity *k*

According to the above expressions and the constant maximum level each activity set to be allocated for each cell, the cells that are fully developed will result in having the same amount of activity which is the maximum and this will lead to uniformly distribution of activities and it implies that the development of a city is uniform . But in reality cities, particularly in developing countries, are far from the fact that the development will happen uniformly. So to capture this reality some amendments should be done to the above way of allocating activities specially the maximum amount of activities which is set fixed for the entire modelling region.

As it is well stated by Clark (Clark 1951), it is good idea to take in to consideration the density theory that cities are having more density in the centre and it declines with distance from the centre of a city.

$$D_x = Ae^{bd} \qquad \text{Equation 8}$$

$$M_x = aD_x = aAe^{bd} \qquad \text{Equation 9}$$

Where: D_x is a density of a cell x at distance d from the centre

A is the maximum density at the centre of the city

M_x is the maximum amount of activity in a cell x at distance d from the centre

a is the area of each cell

b is the rate at which density is decaying over distance

3.4.6. Zoning

Zoning or institutional suitability maps determine the availability of particular land for development at some point in time. It is a parameter that defines the authoritative decisions regarding the land use and activities. “It is a composite measure based on master plans and planning documents available from the national or regional planning authorities and containing among others ecologically valuable and protected natural areas, protected cultural landscapes, buffer areas, etc.” (RIKS 2008a). One zoning map is needed for each land use function and it contains three periods stating available for development which is free establishment is allowed, establishment is allowed after some specified time, and establishment is prohibited.

3.4.7. Suitability

Suitability is an assessment of the laws and nature like the physical suitability and other factors that are derived by human preference of location for a land use or an activity. The suitability is characterized by one map per land use function. Suitability map is a composite measure computed based on factor maps determining the physical, ecological, and environmental appropriateness of cells to support a land use function and the associated economic or residential activity. The physical factors are: elevation, slope, flood risk, soil quality, etc. The value of suitability ranges from 0 to 1. The higher the value for a land use the more suitable the cell is for that land use.

The zoning and suitability maps can be dynamically entered into the simulation according to the changing land use policies of the cities. Models thus allow an easy generation and assessment of future policies and development alternatives as well as pass spatial policies with the aim to support decisions of planners and policy-makers

3.4.8. Randomness Factor

The randomness factor and its influence can be defined explicitly in the model though it depends very much on the robustness of other defined factors. The more robust and crisp are the other influencing factors are the more randomness is required to be provided in the simulation and vice-versa. This therefore, introduces the degree of noise in deviating from the decisions that are normally taken like developing a new land far off from the city periphery. The vague factors themselves introduce the degree of noise in their definition and hence an introduction of randomness factor in the case may lead to an abnormal behaviour of city.

4. Study Area Background

4.1. General Overview of Ahmadabad

Ahmadabad is the largest city in Gujarat and the sixth largest city in India with a population of almost 5 million. It is the administrative centre of Ahmadabad district and former capital of Gujarat state. Ahmadabad is a one of the fastest developing cities in India with large roads and notable architecture. This city was originally built on the banks of the river Sabarmati but has expanded since as a result of its commercial and industrial activities. The city is the commercial capital of the state and its textile industry contributed a lot in enhancing the economy of the city and the state.

According to AMC and AUDA (AMC and AUDA 2006) the city is connected to several other parts of the country. The Ahmadabad-Mumbay corridor was the most important development axis. The city has seven major roads, one express way and five railway networks. A new corridor between Ahmadabad and Pune has recently emerged, connecting the city to four other metropolitan cities of Vadodara, Surat, Mumbai and Pune. All these factors have resulted in the axial growth of the region. The connection to other cities and the consequence increase in economic activity and the boom in already existing economy inside the city resulted in expansion of the city. On the other hand the expansion and growth in population of the city is not uniform all over. The population growth in the peripheral areas is more rapid than the areas within the city limits. This is partly due to the saturation of population within the city area and the consequent large-scale housing development in the peripheral areas. The contrasting spatial patterns observed in the eastern and western areas of AMC have extended into the peripheral areas in the same manner. The western part is experiencing more rapid growth than the eastern part.

Spatial unit	population				
	1981	1991	2001	2011	2035
Ahmadabad municipality corporation	2159127	2876710	3569008	4137488	4400510
Walled city	476138	398410	372633	318532	250263
East AMC	1122073	1902868	2521013	2953580	3209801
West AMC	463922	575433	675362	865376	940446

Table 1: Population growth of Ahmadabad Municipality Corporation

As it can be seen from the above table the population growth of the AMC is not uniform over the entire area. Rather, there is population growth in the east and west AMC while it is declining in the Walled city. This could be attributed to the growth of the economy where people who can afford are leaving the walled city where the density of population is very high. Another factor is the expansion of industry in the eastern where there is opportunity of employment which is attracting a great number of people from the other parts of the city.

4.2. Land Use Distribution

In the Ahmadabad municipality Corporation the biggest share of land is occupied by residential land use in all the three regions (walled city, east and west). The commercial land use is mostly concentrated inside the walled city and expanding to the other parts especially

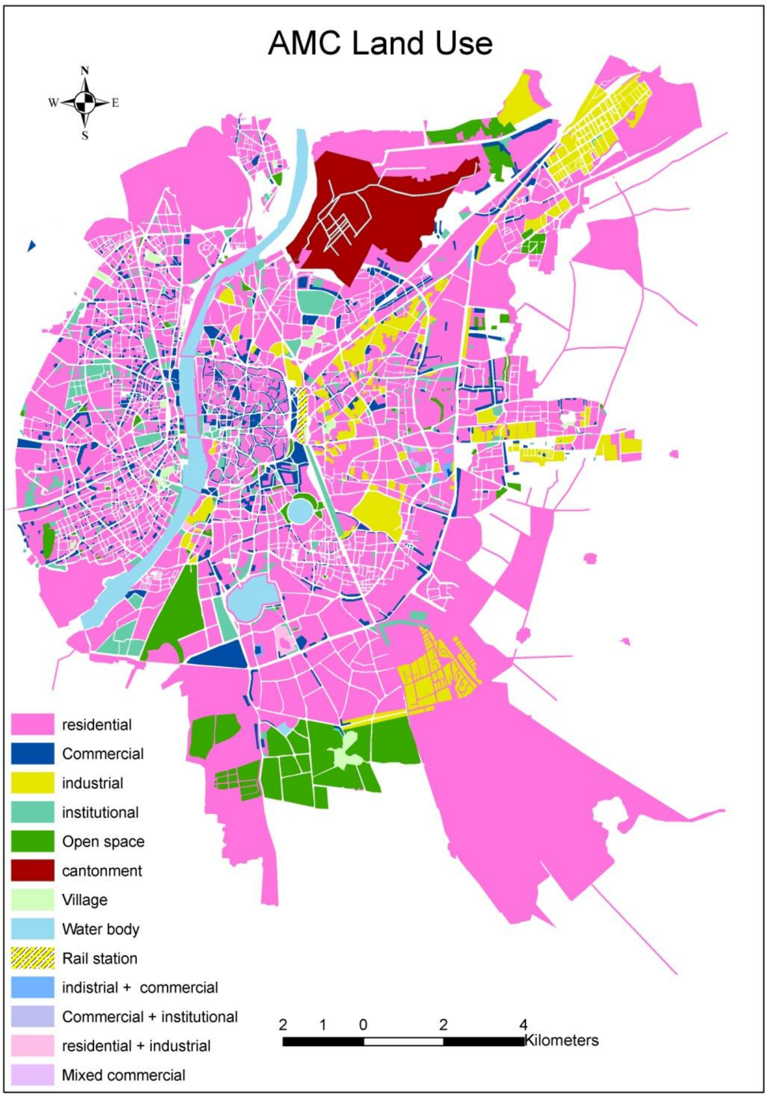


Figure 12: Ahmadabad land use distribution

in the AMC east along the major roads. In AMC East there are large shopping malls that increase well planned commercial area beside the industrial which characterizes the land use in East AMC. Industrial area is almost only concentrated in the east AMC. This part of the city is experiencing more growth of the population partly because of the employment opportunity as a result of the industrial expansion. Summarizing the area within Ahmadabad municipality is divided into three parts: the traditional city centre within the fort walls with relatively high-density development, large concentration of commercial activities and narrow streets, the eastern sector accommodating large and small industries and low income residential areas, and a well planned western sector with wide roads accommodating major institutions and high-income residential areas.

4.3. Job and Employment Distribution

Jobs are the types of activities available and employment is the number of people who are involved in performing these activities or employed. In correlation with land use distribution and the extent of the areal division of the city, employment and job distribution vary. The eastern AMC has the largest share of both job and employment distribution. This is attributed to the expansion of both industrial and commercial land uses. The walled city, in spite of its small areal extents relative to others, has very dense distribution of both job and employment

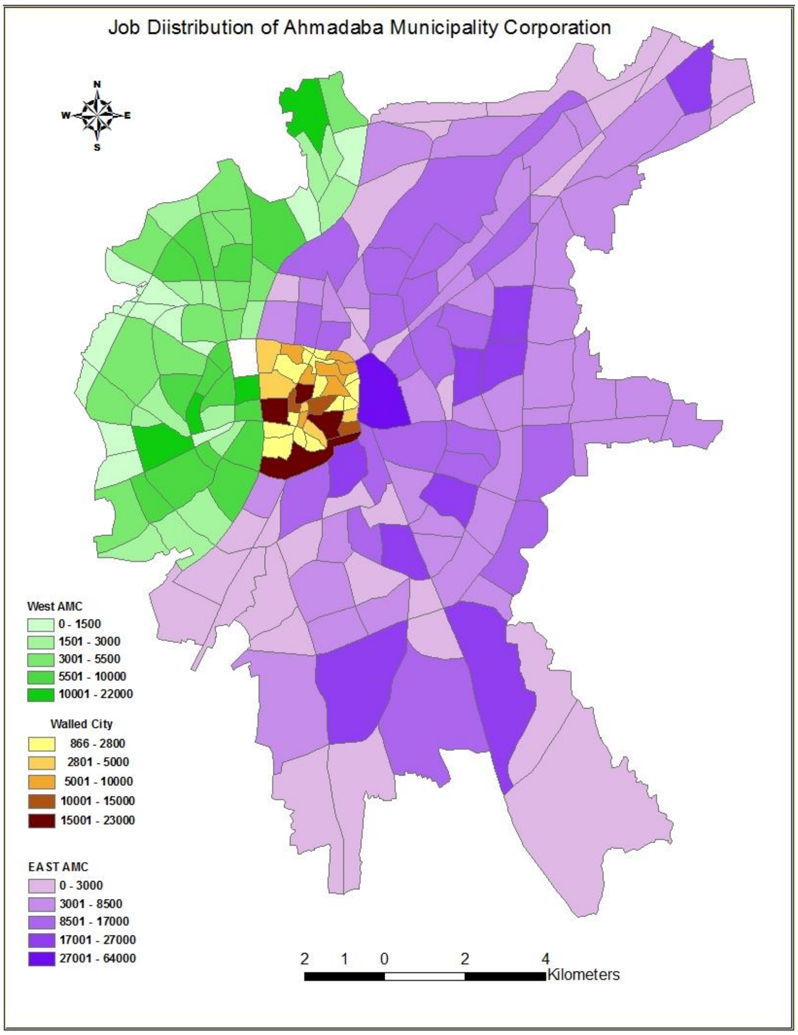


Figure 13: Job distribution over the three regions of AMC

The main activity in this part of the city is commercial and all the jobs and employment generation are mainly accounted to it. The western AMC is the newly developed area with well planned residential and commercial land uses. This part of the city generates the second largest share of employment and jobs. Besides commercial service related jobs and employment are also very significant.

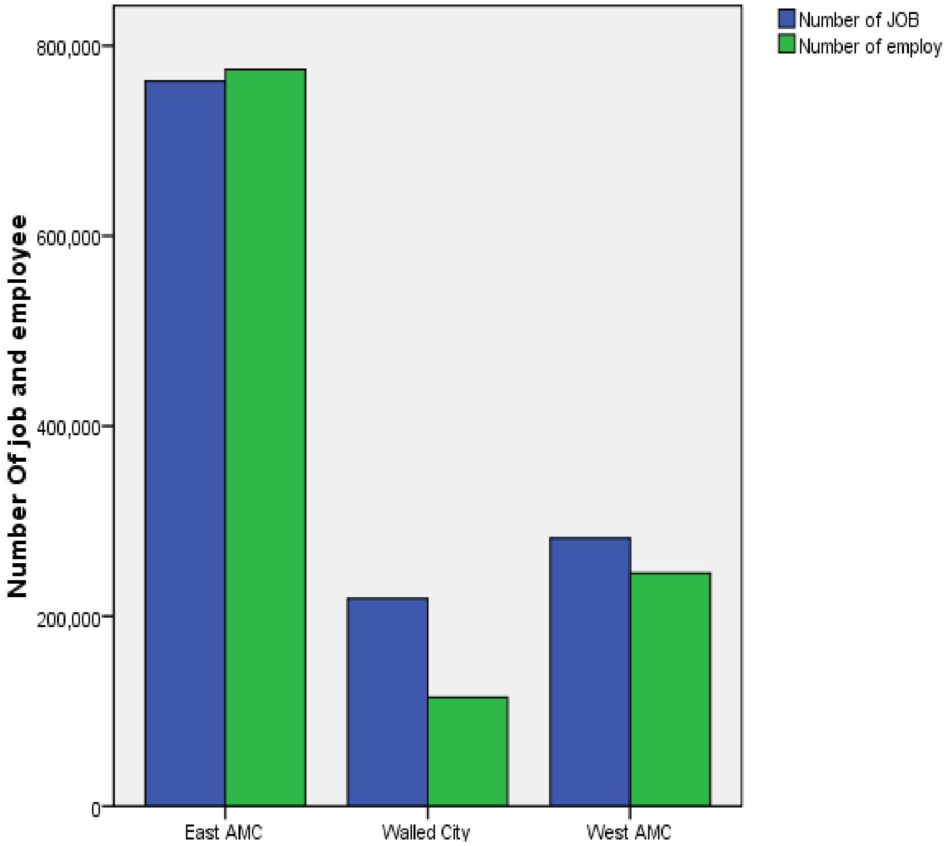


Figure 14: job and employment distribution of AMC

From the histogram above we observe that the number of employee in the east AMC is large than the number of jobs. It implies that some jobs, which are basically industrial based in this case, provide opportunity for more than one employee. In the other two areas the number of job is greater than the number of employee. This can be attributed to the type of job available in these areas. The type of jobs in walled city and west AMC are commercial and service oriented where one person can handle more than one job. This type of information helps in modeling the urban form based on activity. Since it provides crucial information that the number of job doesn't necessarily equate with the number of employee.

5. Modelling Changing Urban Form of Ahmadabad

5.1. Exploring Contemporary and Projected Activities' Density Pattern

In section 3 it has been discussed about the modelling process of changing urban form and several modelling platforms. Based on the purpose of this study and its' advantage of letting users define their own algorithm or use the preset one, AB-Metronamica is chosen to model changing urban form. Thus, this section deals with exploring the existing urban form of Ahmadabad and modelling its' change over time using the chosen modelling platform.

The nature of any city from it s inception is that first it grows around some particular centre and expands outward. As time goes on an archetypical development cycle of any city can be described in a rather simplified manner in the following way: the saturation level of activities and population in the centre increases that can lead to the shift of activities to the peripheries. Beside the saturation level the quality of life in the centre decreases due to ageing of infrastructure, increment in production of waste, over crowdedness and others. Partially beside the natural expansion of cities, people who are better off economically move to the outskirt of a city looking for better residential areas. This movement and growth of cities causes the movement and growth of activities outward following the shift of population. As a result of this a city can experience a condition whereby the city centre, which was once having dense population, can experience fall of density while it rises in the outskirts due to these dynamics.

The situation in Ahmadabad is not different but rather it reflects this description very well. To analyze the behaviour of the city, the population and job density of different years is compared over the three part of the city. The city centre is situated at the core of the city where it is traditionally called the walled city. This part marks high density of population and jobs which are falling over time. The other two parts west and east are experiencing the rising of population and jobs. Particularly the western part is characterized by better quality residential area with a type of job mainly associated with services and commercial. The eastern part is accommodating large industrial expansion with which a number of people and activities that are attracted to the area are rising.

The graph below (fig. 15) compares the density of the city over space and temporally. The comparison is done using the maximum density of a particular area in different years. The density in the walled city is the highest in all the three different analysis time but it is declining over time. In the contrary the maximum densities in the east and west are smaller than the centre but they are rising over time.

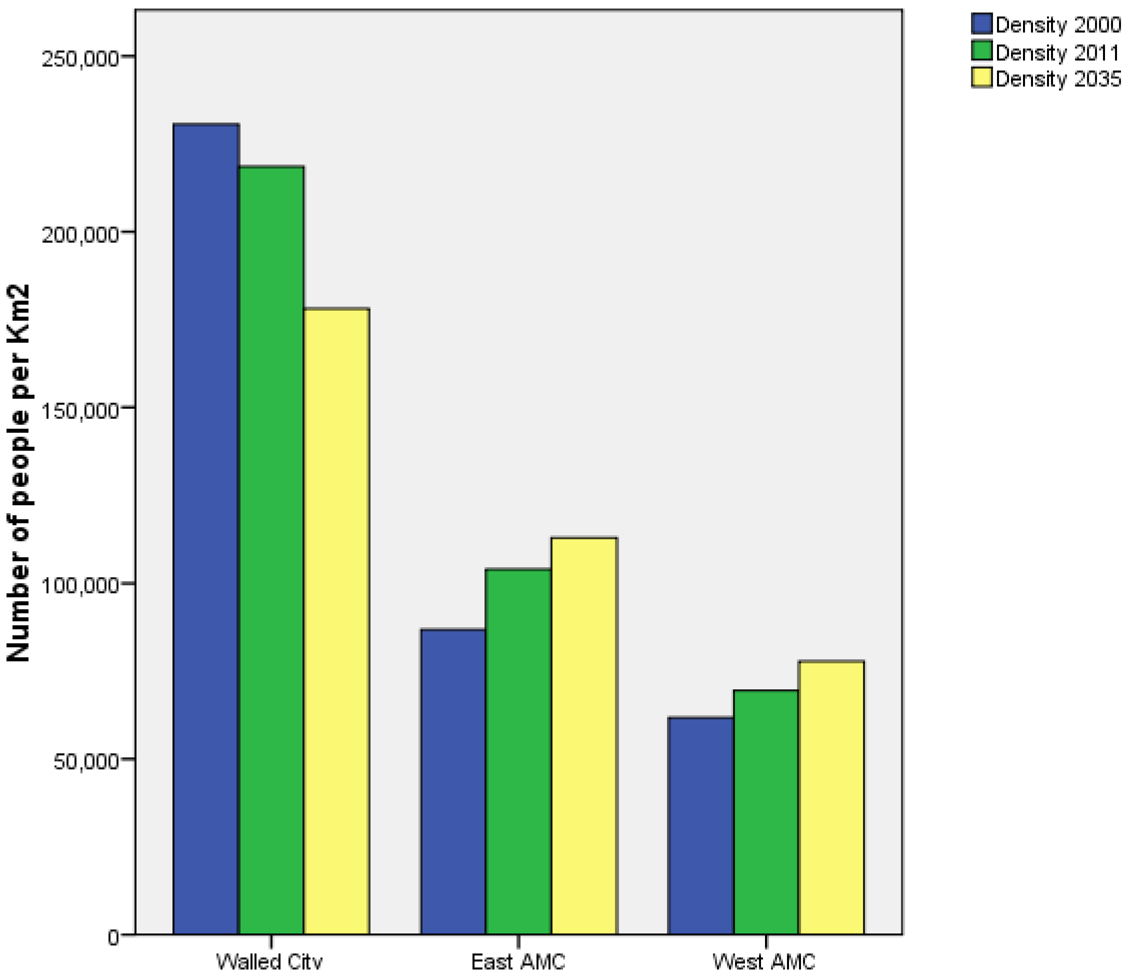


Figure 15: Change of maximum density spatially and temporally

Analysis of a single period density pattern of the city reveals that density is declining as one moves away from the centre to the outskirt (i.e. going from Walled City to the West and east AMC). As we can observe from the following diagrams (fig. 16), urban form of the city which is expressed in terms of density shows how density decays as we go out from the centre of the city. The density decay theory with stochastic perturbation seems to express approximately real density pattern of the city.

The urban form dynamics over time can also be captured by comparing density pattern of different years. Here the data used are population density of 2000 people per km^2, 2011 people per km^2 and 2035 people per km^2. As time goes on the density in the centre of the city falls while at the outskirt of the city it tends to rise. The rate at which density decays also decreases over time. If we look at the graphs below the maximum density at the centre is 23056, 218583 and 178097 for the three different years which shows the dynamics nature of urban over time. The decay factors which are constants of the exponential function used in curve fitting of density pattern as distance increased from the city centre in SPSS software and described in section 2.1.3, equation 1 as b. From the output graphs (fig. 16) the value of density decay rate obtained are [0.665], [0.645], and [0.535]. These decay factors show that at what rate density falls over distance from CBD in different years. These decay factors decline with time as the density in the centre decreases and in the outskirt increases the urban form shows tendency to have virtually uniform density in the long run unless there is interference from policy makers.

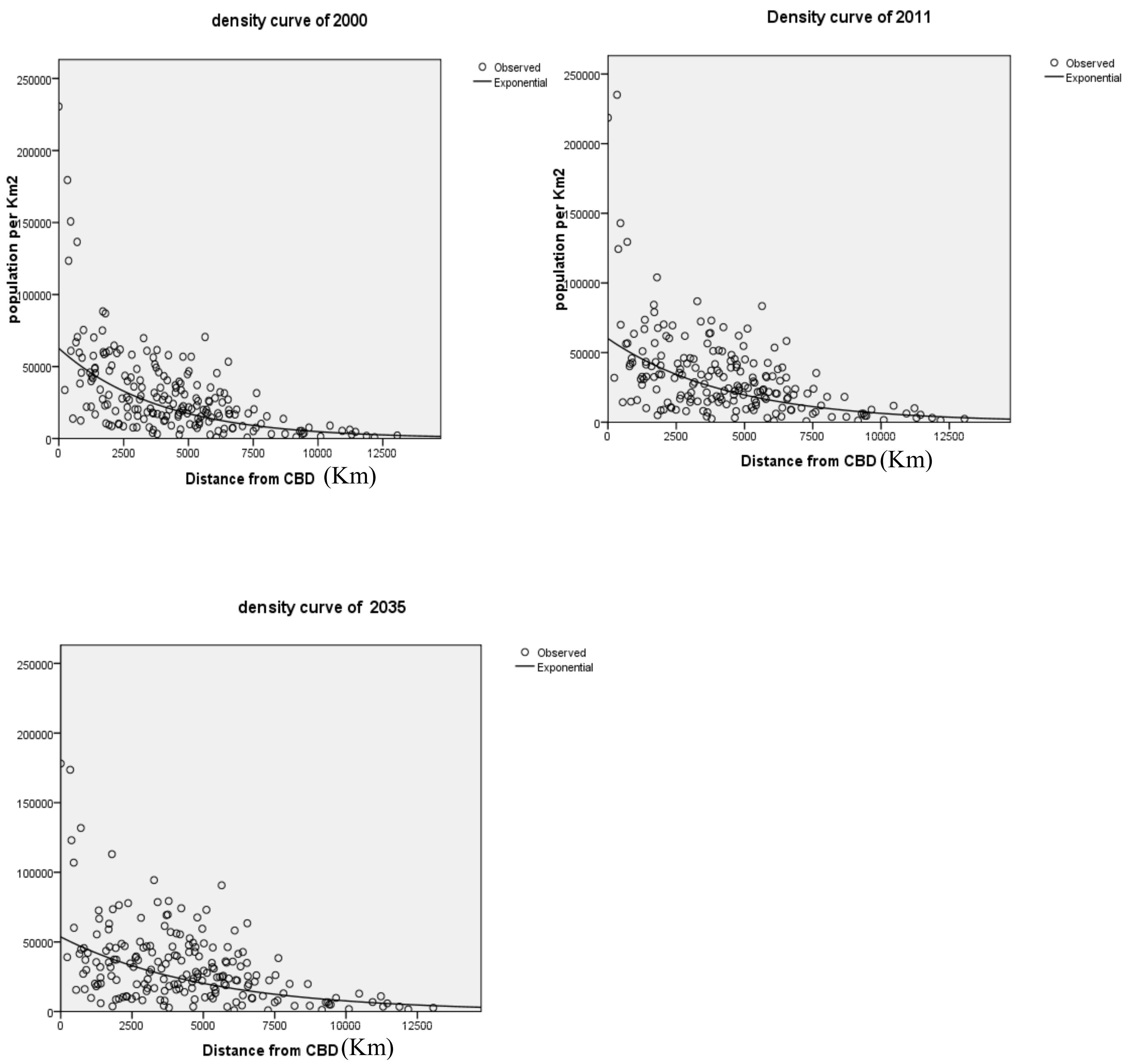


Figure 16: Density gradient and dynamics over time in Ahmadabad

From the empirical data analysis of Ahmadabad, it is observed that the density decay rate is different for different years. That means for a particular city there is no constant density decay rate but rather it is a function of time (year). Not only the density decay rate but also the maximum density at city centre is also changing over time. The analysis shows that the maximum density in the centre is falling over time while it increases with distance to the outer part of the city. So introducing time factor in both density decay rate and maximum density in the centre can bring the modelling process closer to reality.

So the density decay equation can be rewritten as:

$$D_{x,t} = A_t e^{b_t d}$$ Equation 10

$$M_{x,t} = aD_{x,t}$$

then $$M_{x,t} = aA_t e^{b_t d}$$ Equation 11

Where: $D_{x,t}$ is the density of a cell *x* at time *t*
A_t is the maximum density at the centre at time *t*
b_t is density decay rate at time *t*
d is distance from city centre
$M_{x,t}$ is maximum amount of activity in cell *x* at time *t*

Having in mind this analysis in the following section urban form will be modelled based on activity distribution in AB-Metronamica and the obtained result will be checked against this empirical finding.

5.2. Activity Simulation In AB-Metronamica

In section 3.2.3 the description of AB-Metronamica and its use to model urban form has been discussed. It has been discussed that AB-Metronamica is a cellular automata based software used to model amount of each activity expressed as a number of population and jobs that are found in cells of modelling area. The states of the cells are characterized by the dominant land use and the number of activities associated. The model allocates activities to the cells based on the potential of cells to accommodate activities. The potential of cells is calculated by taking into consideration accessibility, suitability and neighbourhood factors.
This section deals with determining these factors and simulating the city's four types of activities. They are residential, commercial, institutional and industrial.

5.2.1. Accessibility Parameters

As it is discussed in section 3, accessibility parameters determine the level of accessibility of a cell to a particular activity. During computation of cells potential accessibility parameters are taken into consideration and cells are assigned activities accordingly. In potential calculation each factors that is considered to contribute to accessibility is given weight in accordance with their importance to that particular activity. The derivation and assigning of weights and a distance decay function is carried out in Arc-GIS (fig 17) depending on the road network and the land use in which a particular activity is dominant. The concept used to derive these accessibility parameters is, the more a particular activity is closer to a particular type of road, CBD or access points, the more important is the factor to this activity and thus bigger weight is assigned to this factor relative to others. In other words, it tells where activities prefer to position themselves. To determine this, the following procedures are followed.
The road network is intersected with land uses and the length of different road types in respective land uses is calculated and the ratio of individual road length to the total length of

the roads intersecting the land use is computed. The weight to each type of roads is given in accordance with the individual ratio of the roads' length obtained. The distance decay is set by measuring distance where a particular land use ceases to exist. However, since distances measured vary from place to place, in the range of minimum and maximum the value that gives more realistic distribution of activity is taken.

As it is discussed in section 5.1 activity distribution is not uniform all over the city. Activities' density is higher in the CBD and some easily accessible parts. So to capture this fact, beside road network, CBD and some access points are introduced and given weights to increase the potential of cells in these areas that consequentially increases a number of activities allocated in these cells.

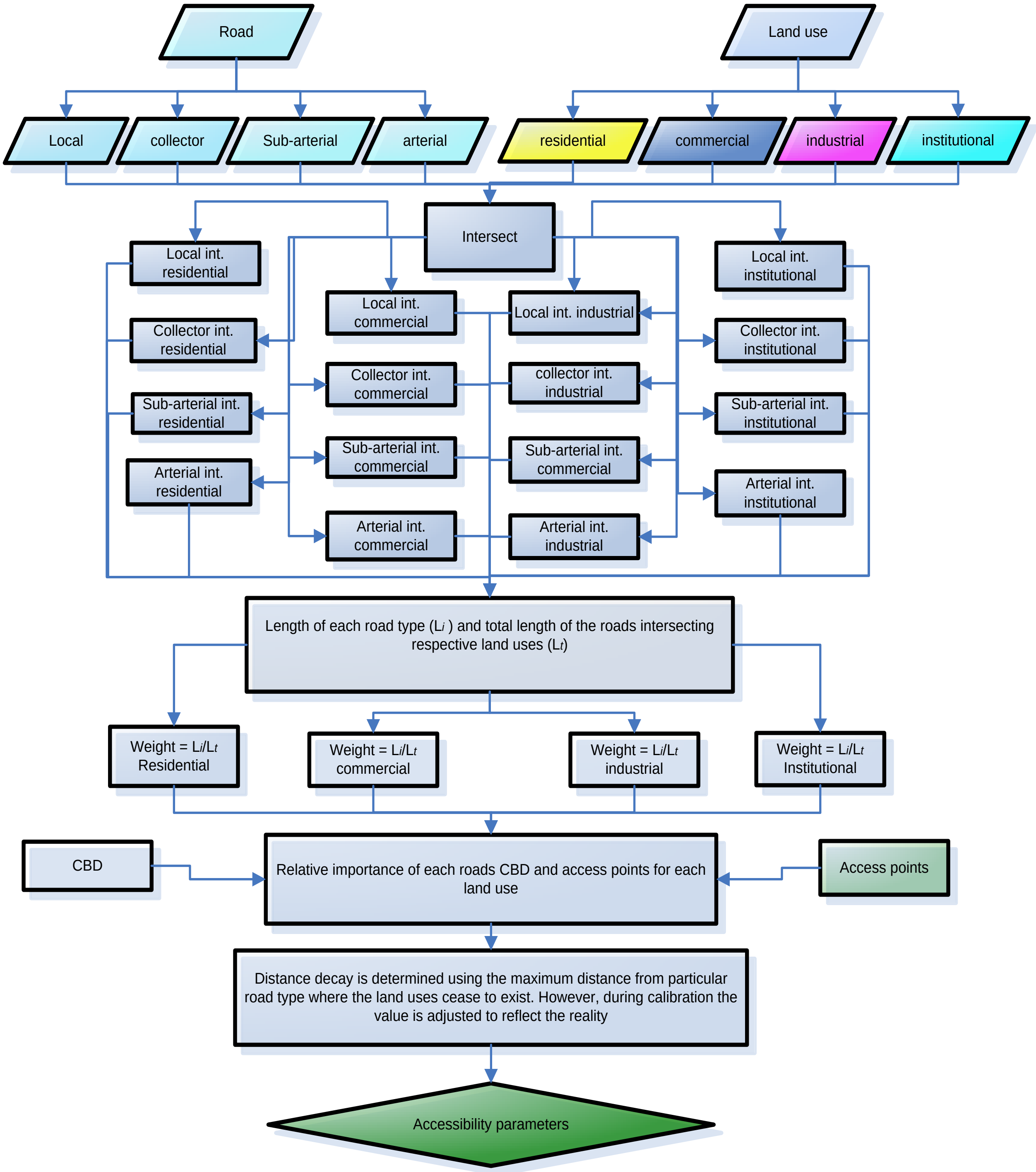


Figure 17: accessibility parameters derivation procedure and introduction of CBD and access points

After setting the parameters, for each activity their accessibility is computed and displayed in the following figure.

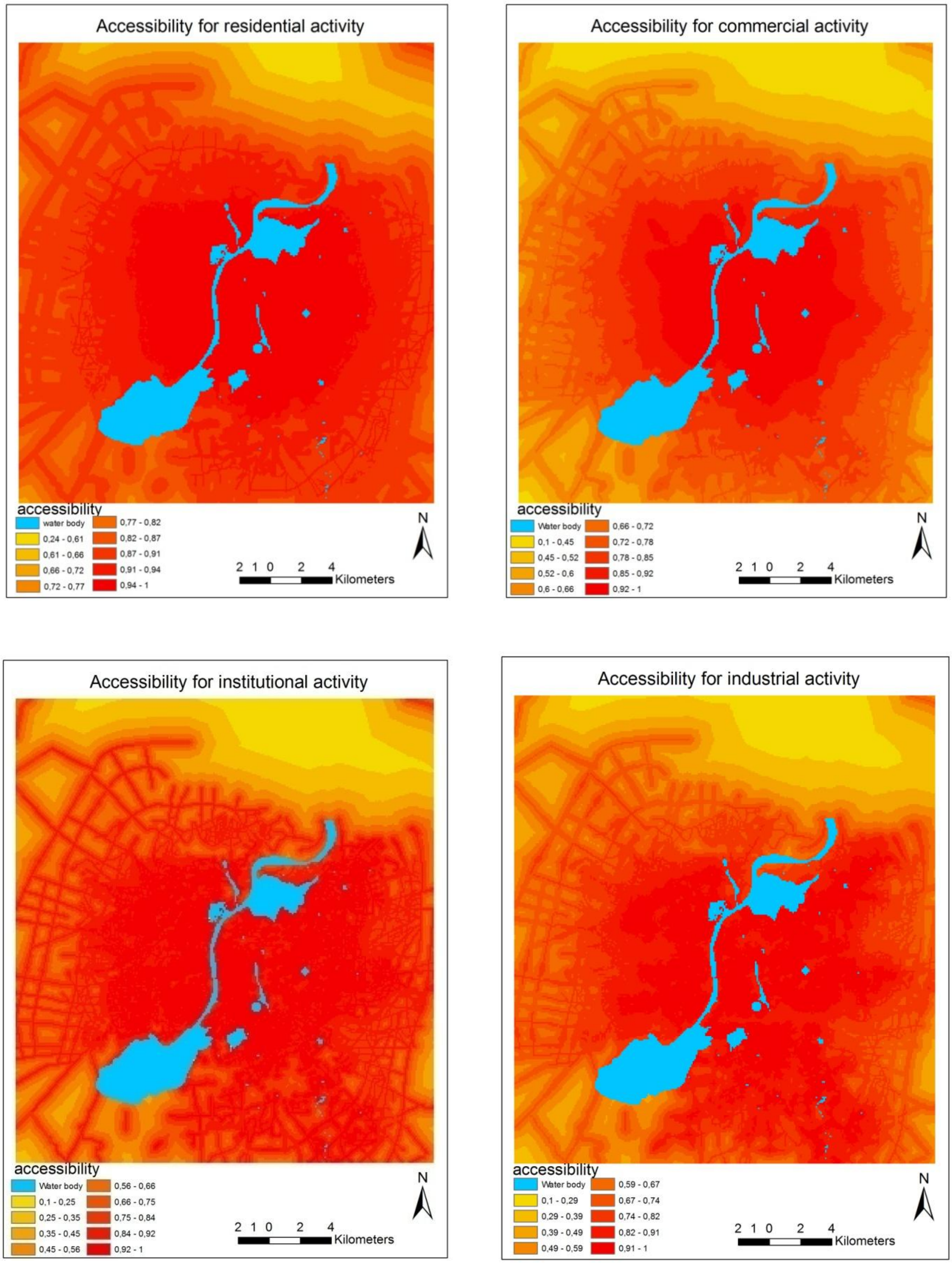


Figure 18: accessibility of activities

The above maps (fig. 18) show that the accessibility of each activity. It is clear that the computation of the accessibility depended on the roads CBDs and ace points. The accessibility of each activity is high at the areas where that particular activity exists since implicit accessibility the land belonging to that activity is also considered.

5.2.2. Neighbourhood Factors

Neighbourhood factors determine the influence of neighbouring cells on a cell under investigation. Their influence depends on the distance from the cell, the state of the neighbouring cells and a number of activities they accommodate. Based on this a cell might have either positive or negative influence whereby positive influence result in attraction and negative influence result in repulsion of activities. One of the methods of deriving the neighbourhood influence is using enrichment factors (Verburg, de Nijs et al. 2004). The enrichment factor F is defined by the occurrence of a land use type in the neighbourhood of a location relative to the occurrence of this land use type in the study area. It is calculated according to the following equation:

$$F_{i,k,d} = \frac{n_{k,d,i}/n_{d,i}}{N_k/N}$$ Equation 12

Where: $F_{i,k,d}$ is the enrichment of neighbourhood d of location i with land use type k

$n_{k,d,i}$ is the number of cells of land use type k in the neighbourhood d of cell i

$n_{d,i}$ is the total number of cells in the neighbourhood

N_k is the number of cells with land use type k in the whole raster and

N is all cells in the raster

But the above equation can be rewritten for the enrichment factor of activity as follows:

$$F_{a,k,j} = \frac{n_{a,b,i,j}/n_{i,j}}{(N_k/N)/n_{a,j}}$$ Equation 13

where: $F_{a,k,j}$ is the enrichment factor for an activity '*a*' by an activity 'k' in a neighbourhood of size *j*

$n_{a,b,i,j}$ is the total amount of activity *'b'* present in the neighbourhood of size *'j'* of cell *'i'* having activity *'a'*

$n_{i,j}$ is the total amount of activities in the neighbourhood of size *'j'*

N_k is the amount of activity *'k'* in the study area

N is the total amount of activities in area under investigation

$n_{a,j}$ is the amount of activities *'a'* in the cell *j*

Using this equation the influence of each activity can be derived from empirical data. In Ahmadabad, the existing distribution pattern of activities shows that residential activity is closer to institutional and industrial, commercial activities are closer to residential, industrial activity seeks existing industrial activity and institutional activity is determined by pre-existing institutional activity (Jain 2008). Fig 19 shows the influence of each activity on others.

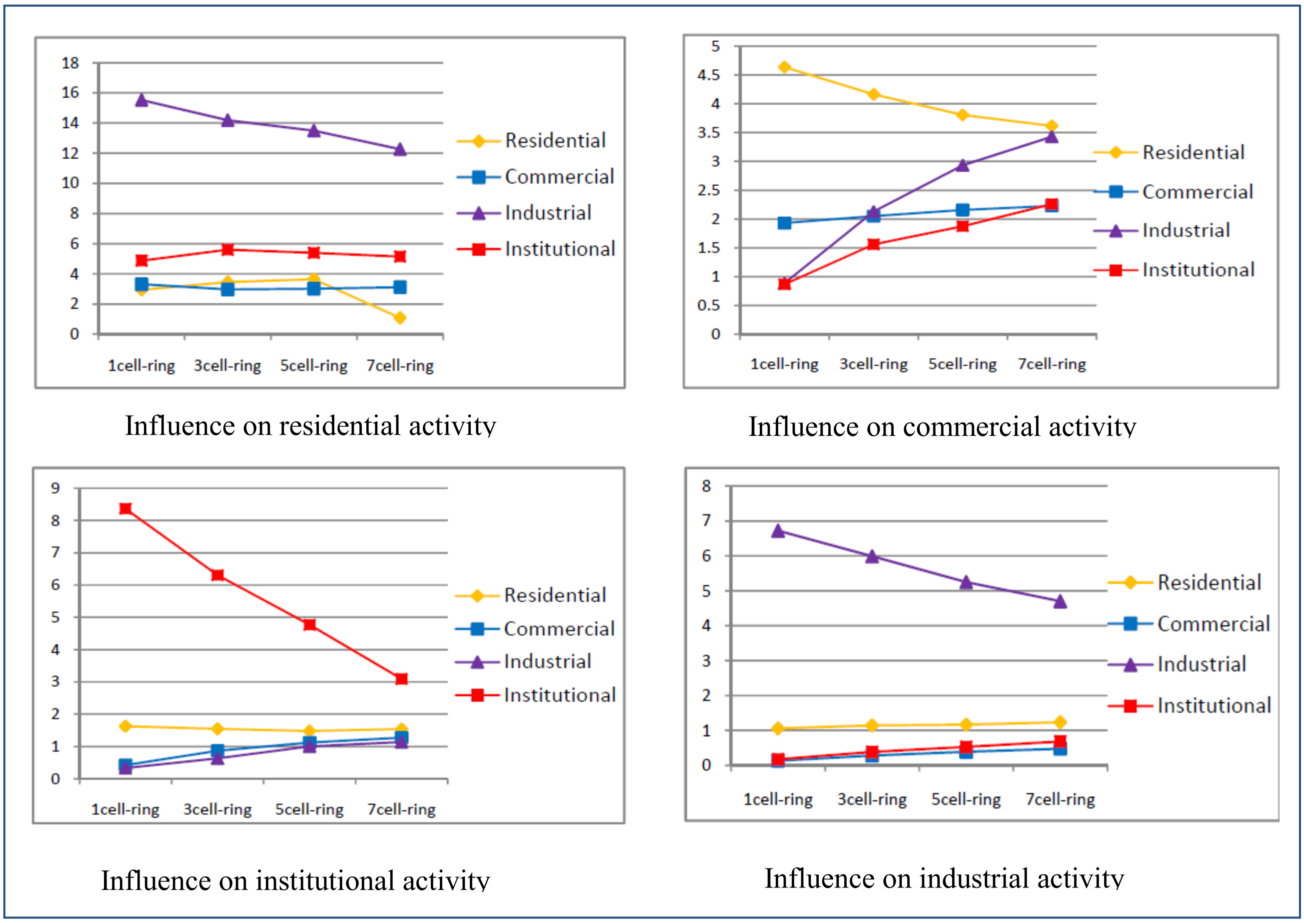


Figure 19: neighbourhood influence of activities (adopted from Jain 2008)

5.2.3. Suitability Factor

Suitability is an assessment of physical suitability and other factors that are derived by human preference of location for an activity. The suitability is characterized by one map per land use function. Suitability map is a composite measure computed based on factor maps determining the physical, ecological, and environmental appropriateness of cells to support a land use function and the associated economic or residential activity. The physical factors can for instance be: elevation, slope, flood risk, soil quality, etc. The value of suitability ranges from 0 to 1. The higher the value for an activity the more suitable the cell is for that activity. However, Ahmadabad is characterized by flat topography and does not have specific features like a coastline, marshy land, steep slope etc. that may deter the development of an activity (Jain 2009). This makes the city equally suitable for all activities.

5.2.4. Potential for Activities

The potential of a cell for an activity is determines the capacity of that cell to accommodate a particular activity or the transition of a cell from one state to another according to the potential for that activity. For instance if a cell initially classified as residential but later on its potential for commercial exceeds that of residential then the cell change its state from residential to commercial. The potential of the study area for each activity is computed using the algorithm embedded in AB-Metronamica and based on the above factors as follows and depicted in figure 20 and 21.

$$TP = \left((wz * Z) + (1 - wz)\right) * (wn * N + A + ws * S) * 1000 \qquad \text{Equation 14}$$

With $\quad N = \min(1, \max(0, (R * P + b)/a))$

And $\quad R = (-\log(random)^{\alpha}$

Where: TP is total potential for an activity, wz is weight given for Zoning, Z is zoning, wn is weight given for neighbourhood, A is accessibility, ws weight given for suitability, S is suitability, and α is randomness factor.

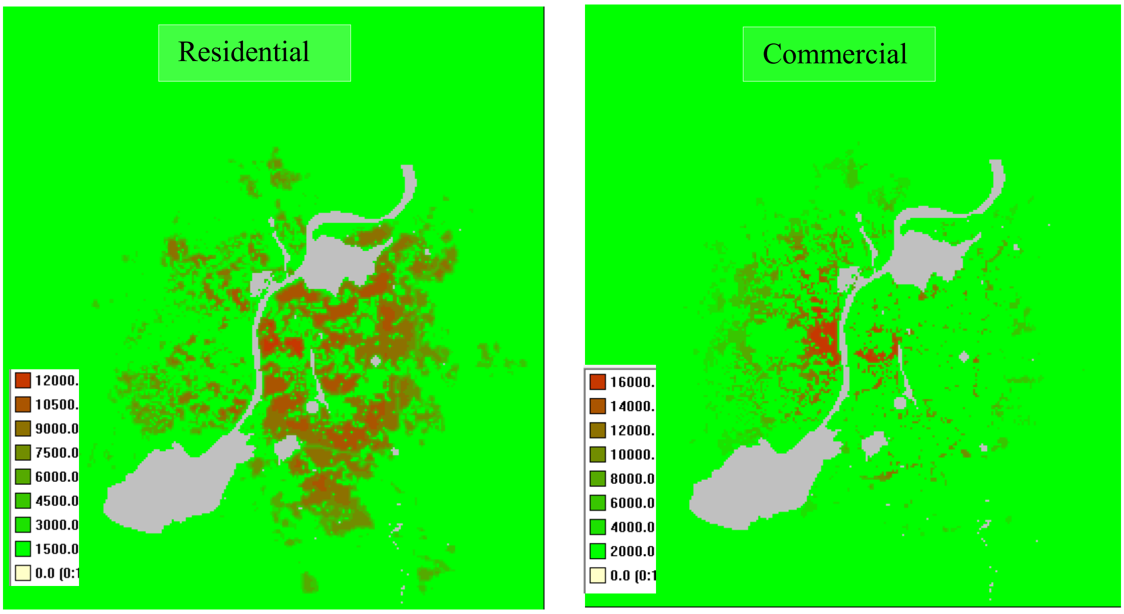


Figure 20: the potential of cells to accommodate activities residential and commercial

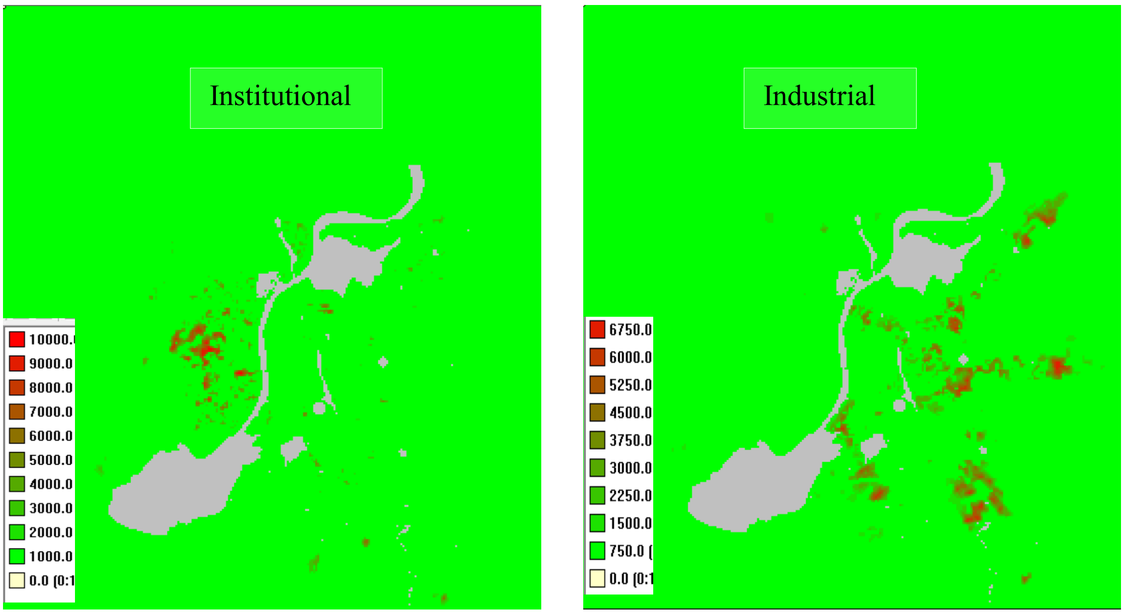


Figure 21: the potential of cells to accommodate activities (institutional and industrial)

In the figure above the potential of each activity is shown. The potential for residential and industrial is higher at the centre of the city where CBD and access points were introduced and assigned weights in the accessibility parameter setting. The potentials of industrial and institutional are higher at their respective associated land uses. The allocation of activities is carried out in the model in accordance with the potential of each cell. But the potential decreases with distance from the locations of the factors contributing to the potential computation.

5.2.5. Macro Model

The demand in the model is set separately for residential, commercial, institutional and industrial activities. The demand for residential (table two) is the number of population while the demand for commercial, industrial and institutional is jobs related to each activity. The projection for the future years is based on the current pattern of population and economic growth.

Activities	demand in the year		
	2000	2011	2035
residential	3507178	4137488	4400510
industrial	434578	466193	496984
commercial	724864	777597	828954
Institutional	380008	407653	434577

Table 2: current and projected demand of activities

5.3. Simulation Results

The simulation of activities is carried out from 2000 to 2020. As it could be seen from the output bellow (fig. 23a, 23b, 24a and 24b) the simulated activities are distributed over the study area according to the potential of the cells to accommodate activities. The potential of cells in the canters of the city is high and that resulted in increasing the number of activities. The potential decreases with distance from city canters and from areas where the potential is higher for a particular activity. The decrease in potential resulted in decreased number of activities allocated. This reflects the decrease of density with increasing distance from the centres which agrees with empirical analysis in section 5.1 and displayed in figure 16.

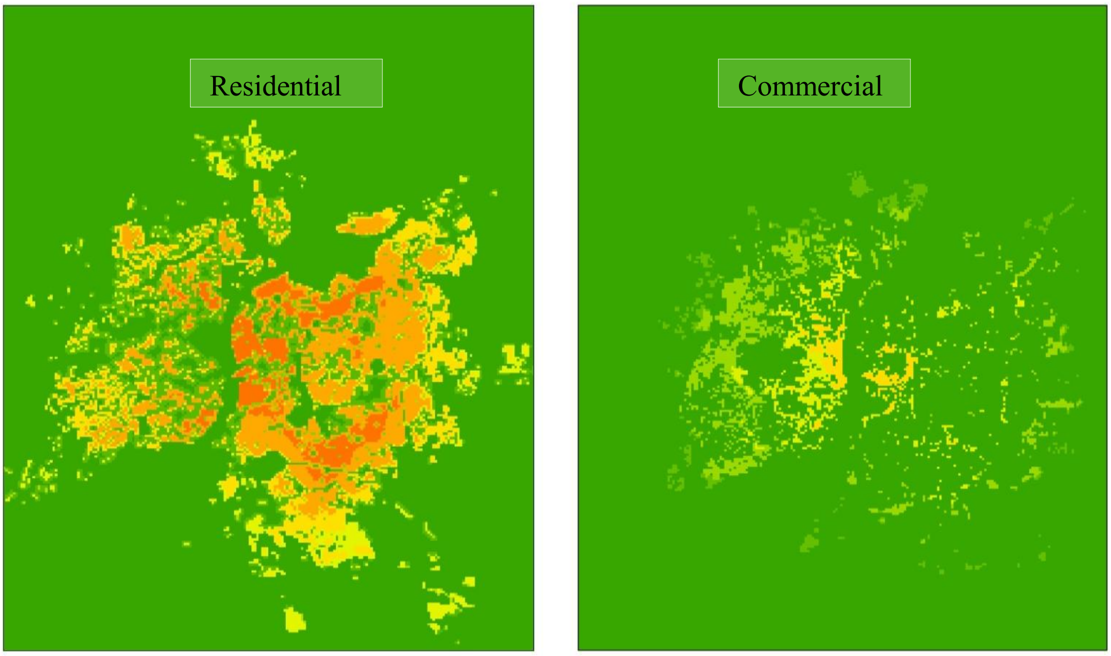


Figure 23a:Concentration and distribution of activities in 2010 (residential and commercial)

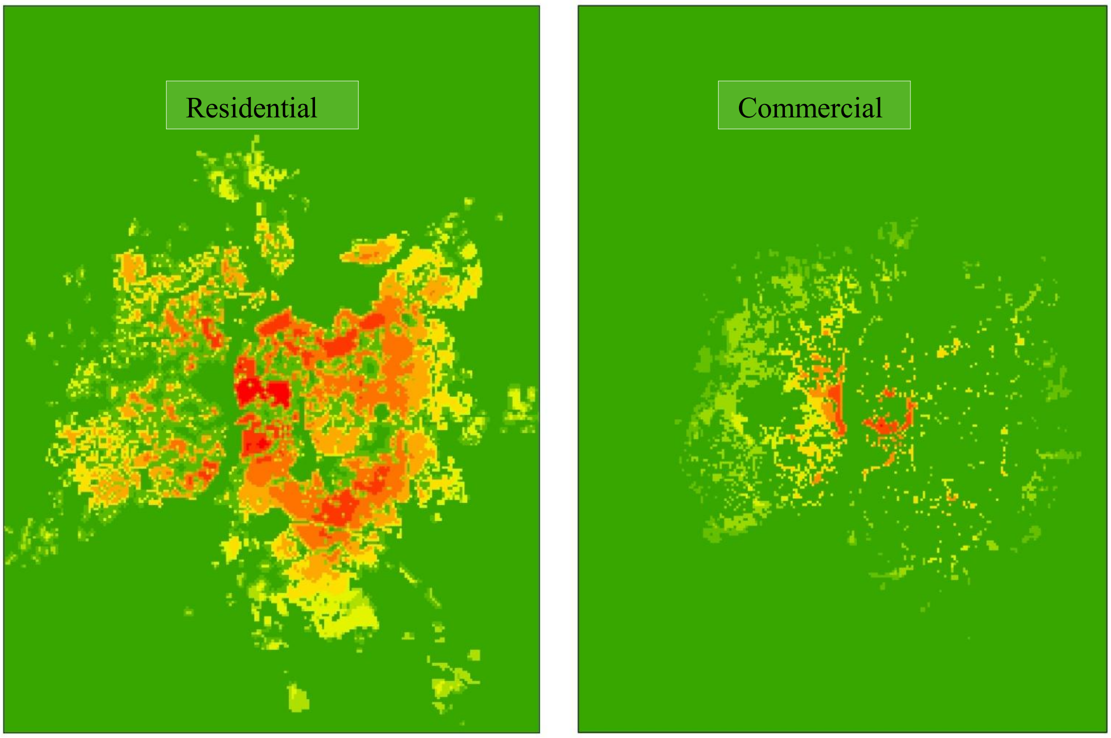


Figure 23b: concentration and distribution of activities in 2020 (residential and commercial)

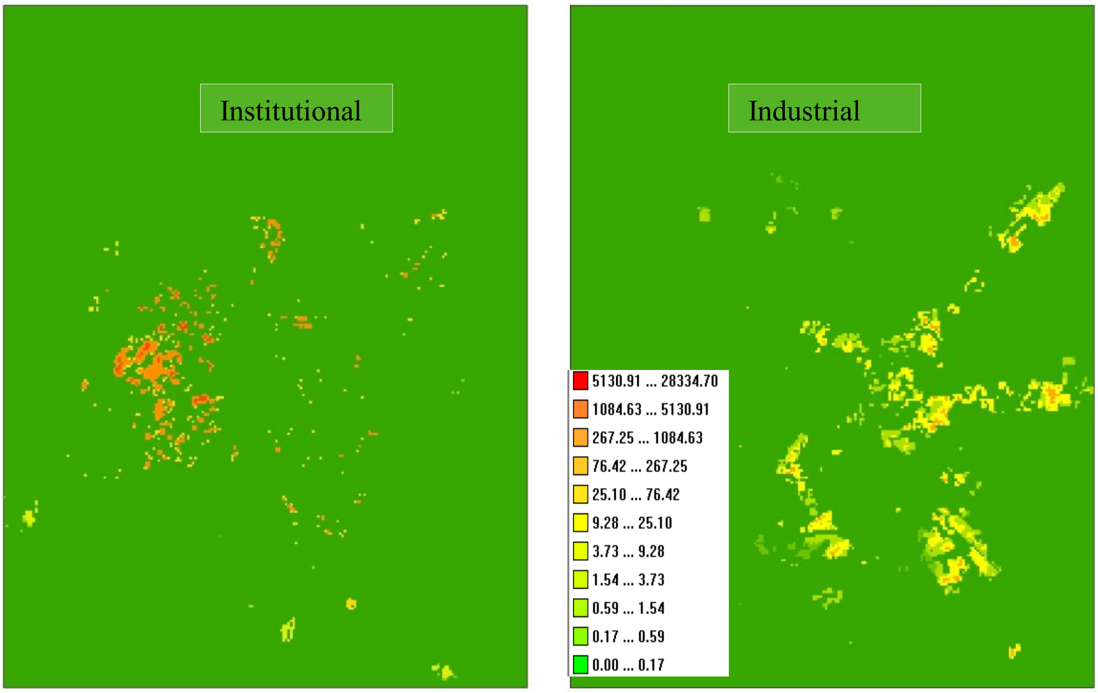


Figure 25a: concentration and distribution of activities in 2010 (institutional and industrial)

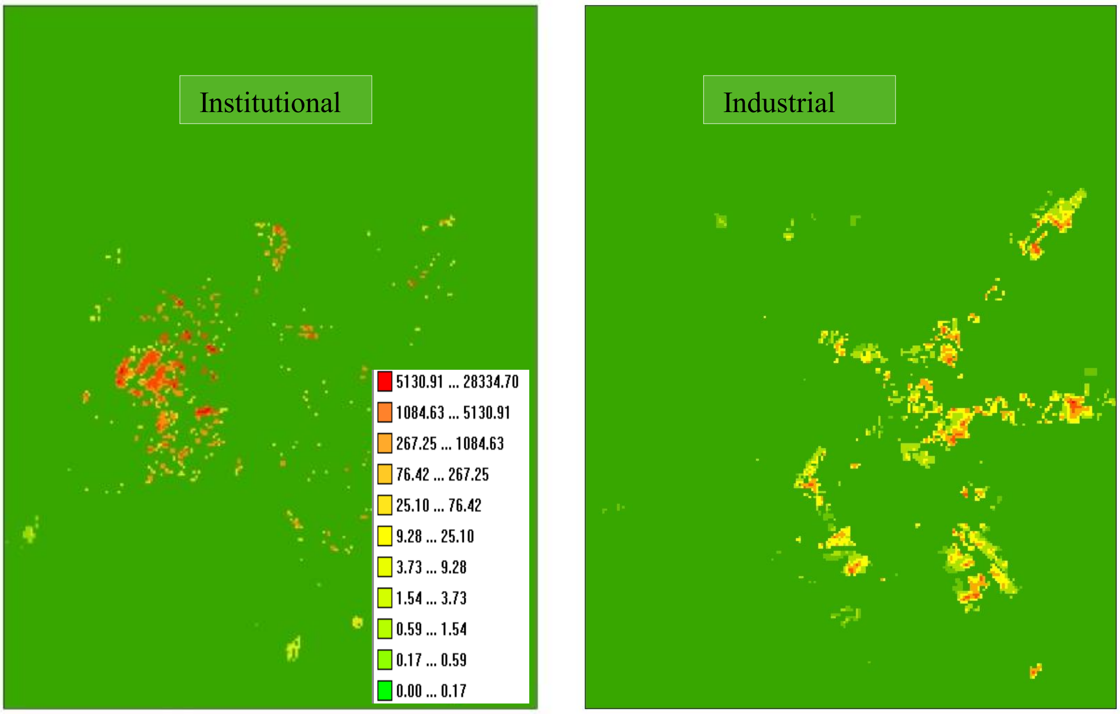


Figure 25b: concentration and distribution of activities in 2020 (institutional and industrial)

5.4. Discussion of Simulation Results

The activity distribution at the initial stage of the simulation doesn’t take into consideration the full potential of the cells. Rather activities are evenly distributed and as the model runs the activities are redistributed and the allocation of new demand is also carried out according to the potential of cells. This implies that the AB-Metronamica model takes the potential of cells gradually. As per the current setting of the model, to get the simulation of a particular year the modelling process has to be set some steps prior to the year. In this case a result that is closer to reality is obtained from 2010 on. This is checked against the population density distribution from the empirical data. Another precaution has to be taken when running the model for long period as this will keep on accumulating activities at higher potential points which is not the case in reality. Particularly in the case of the modelling area Ahmadabad, the area with high potential is found in the walled city where the empirical data analysis shows high density relative to other three regions. However, this density is falling over time as the concentration of activities is rising in the other two regions. The later scenario of the city is well reflected during the process of modelling while the decline in the centre was not captured. The following figure (fig. 26) shows how activity concentration is decreasing from the centres to the outskirts of the city.

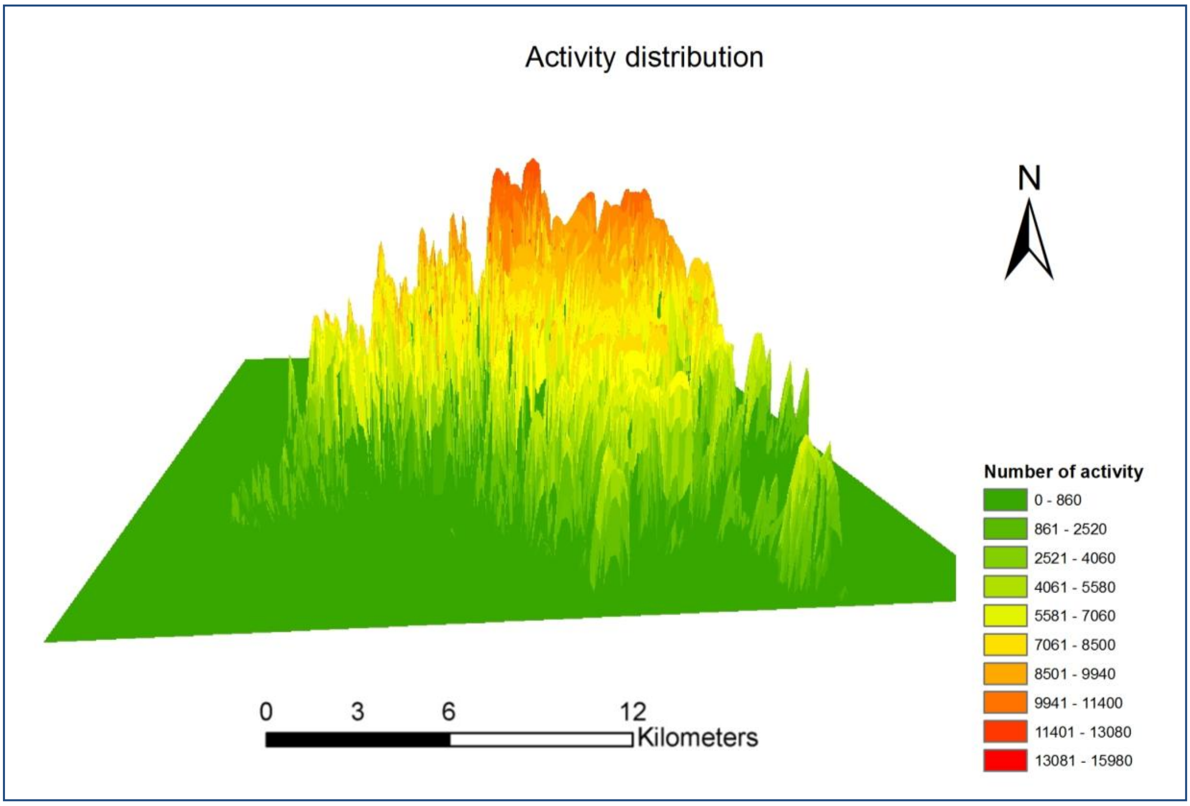


Figure 26: 3D visualization of density gradient

5.5. Conclusion

The simulation in AB-Metronamica shows that with time the activity increases in all cells whereby the new demand is allocated to cells in proportion to their potentials. The potential in the centres of the city is higher but decreasing with distance which implies that the number of activities allocated by the model is higher at the centres and decreases out ward. This makes the model very useful as it goes hand in hand with the empirical analysis which shows the density in the centres is higher and goes down with distance. On another hand the continues increase of activities allocation at places of higher potential disagrees with the empirical analysis that shows density in the centre decreases after reaching some maximum level. So to capture this reality it is preferable to run the model till the maximum number of activity in the centre is reached. Another way of dealing with this is by creating multilayer system in the AB-Metronamica whereby the national and local demand is determined separately. This would pave a way to divide the modelling area into different regions and define the national and regional level demand and rate of growth separately. By doing so the maximum possible activity a region can accommodate, the growth and decline rate can also be set separately. Basically since the growth of a city doesn't happen uniformly over its entire area, dividing to its regional level in the process of modelling helps to reflect the local reality of each part.

This section has dealt with modelling changing urban form. The following section will deal with how these changes in urban form affect transport systems.

6. Analysis of The Effect of Urban Form on Transport System

6.1. Overview of Urban Form-Transport Relation

The transport system is an integral part of the urban environment and it is characterized by the overall orientation and organization of the urban system itself. It can be affected by many elements that urban environments comprise of such as the structure of an urban environment, demographic distribution, social and economic factors etc. The complex interaction of socio-demographic factors, physical elements and travel behaviour requires a sophisticated study approach since straight forward relationships between urban form cannot be assumed given heterogeneous urban population such as in cities like Ahmadabad. Constraints levied by the physical environment may be reimbursed or resisted by individual circumstances. This implies that urban form effects may not be equally important for all sectors of the population.

In transport planning modelling plays a central role since conducting experiment on existing infrastructure is virtually impossible. The modelling process has to take into consideration many factors to produce a result which is closer to reality. The modelling process can be used to detect changes in travel pattern due to changes in urban environment such as a case in Ahmadabad where several development processes is happening (AMC and AUDA 2006). The development processes bring about a change in urban form such as density, street pattern, distance to city centre etc. Development in cities or change in urban form and change in demography often require changes in the transportation network (Cao, Strauss *et al*. 1998) . Cao *et al*. (1998) claim that urban form is implied at all steps in the traditional transport modelling process. In trip generation the elements of urban form that implied are land use, socio-economic and demographic. The criteria of grouping these elements in urban spatial form are density, homogeneity and concentricity. In trip distribution computation, travel time impedance, personal preference, and socio-economic elements are implied. The criteria of grouping them as a particular type of urban form are connectivity, density patterns and density gradient. The modal split modelling process considers transportation policy, auto ownership, residential density, income, distance from CBD and services. The categorization criteria of these into urban spatial form are density pattern, density gradient and sectorality. (homogeneity, directionality, connectivity, density pattern, density gradient, concentricity and sectorality are defined in section 2.1) Finally, the traffic assignment modelling process needs to put into consideration geometrics, transportation network, and capacity of the roads. These are categorized to urban spatial form based on directionality and connectivity.

As it is discussed earlier, density is one of the indicators of urban form and its effect on transport system is to be analysed. In section 5, urban form is modelled using AB-Metronamica that provides the output as numbers of activities per cell. Using the dynamics of activity distribution the consequential effect on transport is assessed. First the number of trips generated, and then the probability of making trips by a particular mode and the modal split computation is carried out.

6.2. Trip Generation

The first step of analysing how transport is affected by urban form begins with determining the number of trip generated. Trip generation is a function of population, demographic factors such as age and sex, employment, job, economic status etc. In AB-Metronamica the distribution of population and jobs is simulated (figures 22 and 23) based on expected changes in urban form. The jobs are related to commercial, institutional and industrial activities.

To analyse the number of trips generated and its changing with the change in the concentration of activities and their distribution the concentration and distribution of activities has been simulated and each activity is assigned a parameter for their contribution to trip generation. However, in computation of trip generation since there is no data available to determine the parameters of each factor hypothetical values, but reasonable, are considered and these hypothetical values can be replaced when the actual values are computed from empirical data. From the total population the percentage of workers is taken and the home based trip, which is home to work and work to home is calculated. For the trips created by job related activities home to job and job to home is calculated. In this case the jobs are commercial, institutional, and industrial.

Trip Purpose	Trip generation		Trip attraction	
	parameter	unit	parameters	Unit
home to work	0.46725	trip per person	0.85025	Trip/Job
work to home	0.97825	x Trip attraction	0.97825	x Trip Production
home to business	0.9358 x job (30.62)		0.9358 x job (30.62)	
business to home	1.7337 x job (5.69) + 0.7533 x job 22.1)		1.7337 x job (5.69) + 0.7533 x job(22.1)	
home to school	1.00833	trip per student	1.00833	x Trip/student
school to home	0.97733	x Trip attraction	0.97733	x trip attraction
home to other	0.36025	Trip per person	0.1079 x pop(11.8) + 0.2127 x job(11.46) - 21.2	
other to home	0.3495	trip per person	0.1079 x pop(11.8) + 0.2127 x job(11.46) - 21.2	

Table 3: parametres for calculating trip genration (adopted from (Shamsul 2008)

The result of trip generation is shown below in figure 27 which is changing over time with change of distribution and concentration of activities. The number of trips generated is higher at places where number of working population, commercial, industrial and institutional activities are denser.

The depictions in the above two figures show that the number of trips generated are higher where the concentration of activities is higher. It is also showing the dynamism along with the dynamics of activities whereby the number of trips increased following the number of activities overtime.

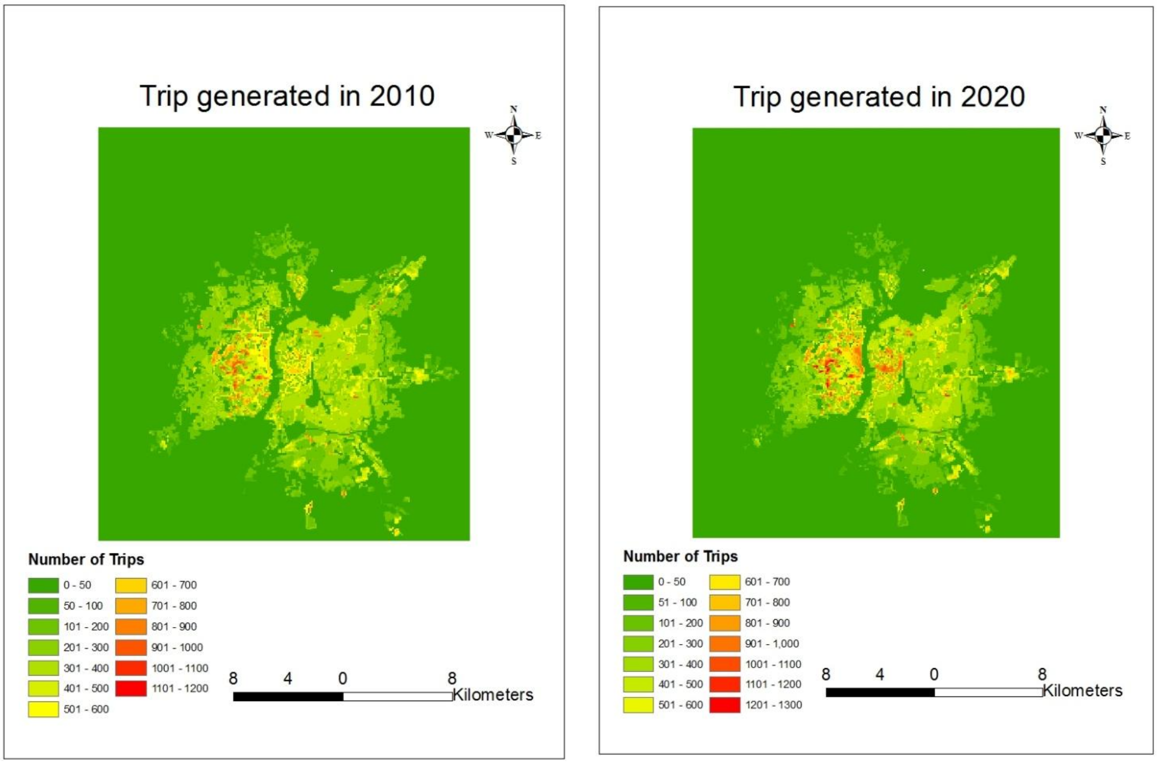


Figure 27: trips generated in 2010 and 2020

6.3. Modal Split

Choice of mode basically hinges on several factors. These factors include income, availability of cars, costs associated with driving, availability, cost and quality of service of public transport, trip purpose, distance to city centre and density of activities. Though it is important factor, to absolutely link the effect of urban density to travel mode is a complicated matter(Lee and Moudon 2006). The reason is quantifying the characteristics of the built environment related to modes of travel in particular remains a major challenge since it requires greater details and precision than what is required to understand automobile travel behaviours. Another complication is the tendency for the urban attributes to be highly correlated and the resulting multicollinearity of variables led to common use of factors which are often difficult to translate to policies and intervention. For instance some high density area is characterized by accommodating people with low income whose dependency on public transport or non motorized means is prevalent. On the other hand, the increase in activity increases the opportunity within close range that can be reached by even non motorized means of transport and this can have decreasing effect of personal automobile dependency (Lee and Moudon 2006).

To analyze how changing urban form changes mode choice, density distance from city centres, income and auto ownership are employed. From TAZ empirical data the correlation analysis of each of the above factors is carried out and the correlation factors are assumed as utility or disutility depending on how (positive or negative) they are correlated. Then using binomial logit model the probability of a person choosing a mode type is computed. The logit model is given as:

$$P_i = \frac{e^{u(i)}}{\sum_{r=1}^{n} e^{u(r)}} \qquad \text{Equation 15}$$

Where: P_i is the probability of using mode i

$u(i)$ is the utility of mode i,

$u(r)$ is the utility of mode r and

n is the number of modes in consideration

The utility factors are summed up to compute the probability of a person choosing a particular mode using the binomial logit model. Then the utility of each mode is given in the following equations.

Utility of car = 0.437*I + I + 0.138*Nc + Nc – 0.045*d + d + 0.42*S + S

Utility of bus = -0.124*I + I – 0.021 Nc + Nc + 0.146*d + d – 0.003*S + S

Where: I is income in rupee, Nc is the number of cars, d is density in people per Km^2 and S is distance from the city centre in Km.

The parameters are derived from correlation analysis of number of trips, income, density, and distance from the city centre

The setback is many of the input data needed are not available per cell but rather per TAZ. The data from TAZ is therefore used, which resulted in providing the same value for all cells within a TAZ.

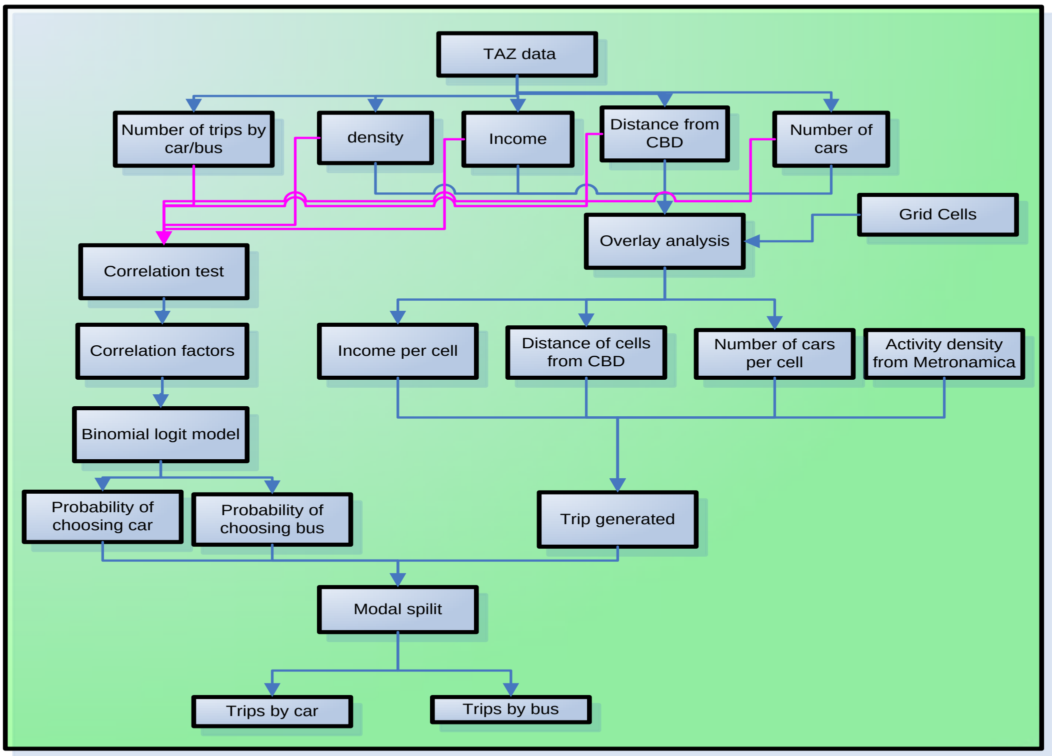


Figure 28: driving correlation factor and modal split computation

By using the logit model (eqn. 15) the probability of a person choosing a particular mode of travel is calculated. From the results shown below, areas with high income group and high number of cars show high probability of making trips by personal automobile. On the other hand in highly populated areas the probability of taking public transport is higher than that of personal vehicle.

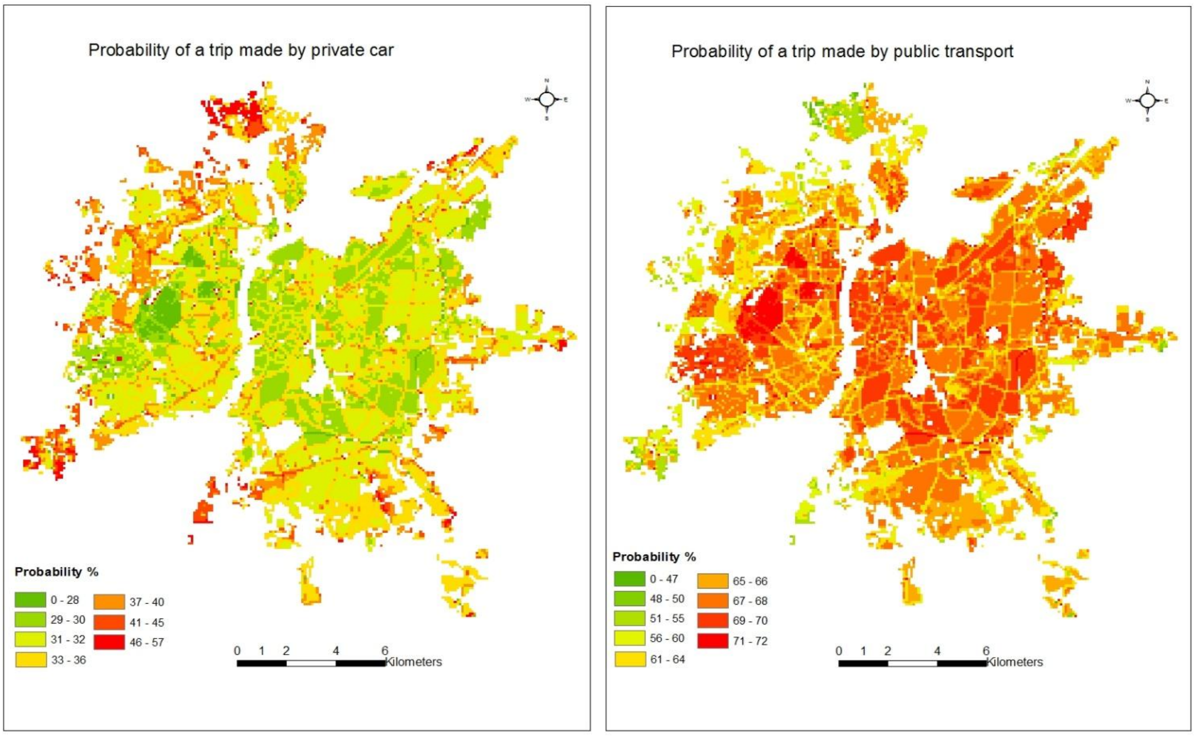


Figure 29: probability of trips made by private car and public transport in 2010

from figure 29, it can be observed that as the distance from the city centres increases the probability of depending on automobile increases while that of public transport goes down. Using the probability of a trip maker choosing a particular mode and the total number of trips generated, the amount of trips made by each mode type can be calculated as follows using logit model (equation 10).

$$\text{Trips by car} = P_c * T$$

$$\text{Trips by bus} = P_b * T$$

Where: P_c and P_b are the probability of a person making trip by car or bus respectively

T is total trip generated

The predicted number of trips made by each mode is displayed in the following maps.

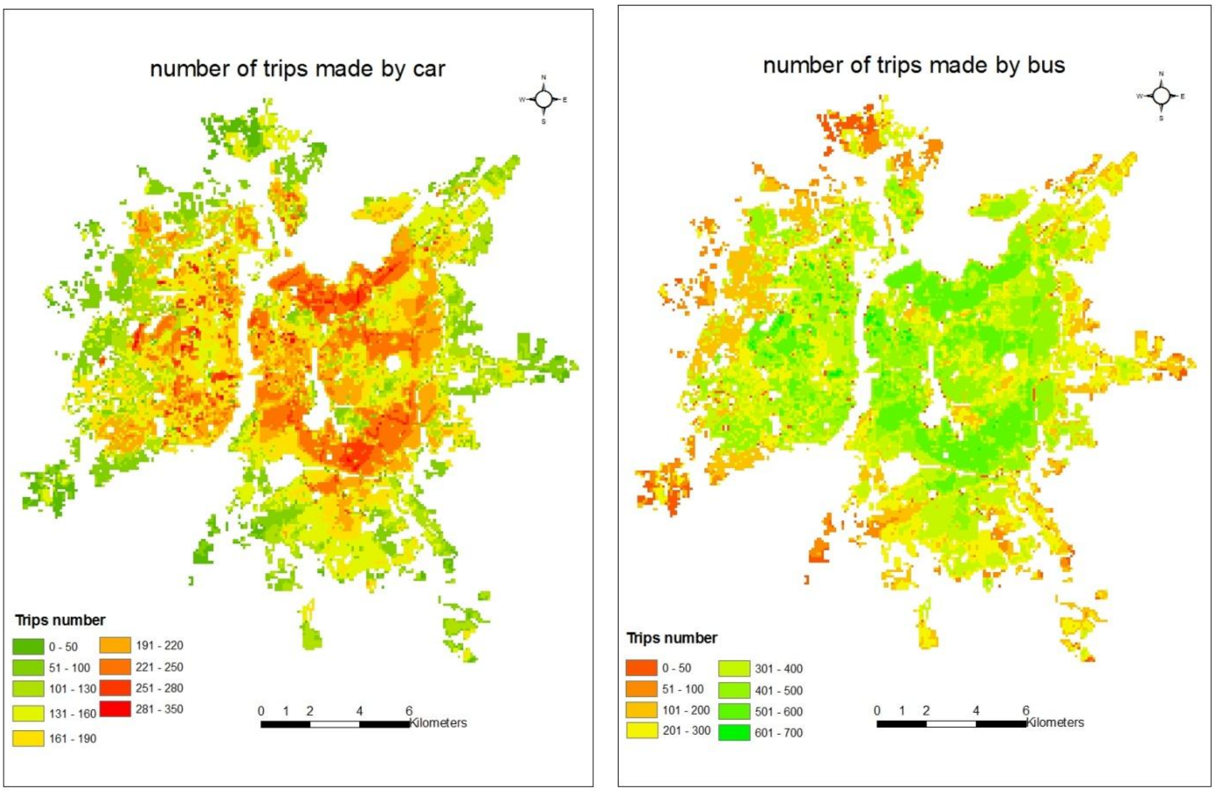


Figure 30: number of Trips made by cars and public transport in 2010

The absolute number of trips made by each mode, as they could be observed from the above displayed figure, is higher at the area of higher density of activities. However, when the relative ratio of number of trips made by car and density of activities is considered, it is greater in the areas of higher income group dwellers but less in densely populated areas. On the other hand, the number of trips made by bus is higher in higher density areas but decreases with decreasing density.

6.4. Computing Amount of Emission

In the previous sections the computation of trip generation, probability of making trips by different modes, the trips made by each mode and the number of each modes have been carried out. Since the basic idea was to understand which type of urban form finally contributes to high pollution by encouraging public transport and discouraging automobile dependency, at this step the emission by each mode and the total emission is calculated. The computation has taken into consideration a single trip from each cell to CBD. The computation is carried out according to the following equations and the result is displayed in fig. 29, 30 and 31

$$bus\ emission = f_b * N_b * D_{CBD} \quad \text{Equation 16}$$

$$car\ emission = f_c * N_c * D_{CBD} \quad \text{Equation 17}$$

$$Total\ emission = car\ emission + bus\ emission$$

Where: f_b is emission factor of bus, N_b number of buses from a cell, D_{CBD} is distance from a cell to CBD, f_c is emission factor of car and N_b is number of cars from a cell.

The result computed below in fig 31 and 32 compares the amount of emission by car and bus. It can be seen clearly that the largest share of emitting polluting gas is attributed to automobiles. The Emission goes up as the distance increases from the centre to the out skirt. This can be because of two reasons: the increment in trip length and the number of cars. On the other hand as the distance increases the density of activity goes down a situation that encourages automobile dependency.

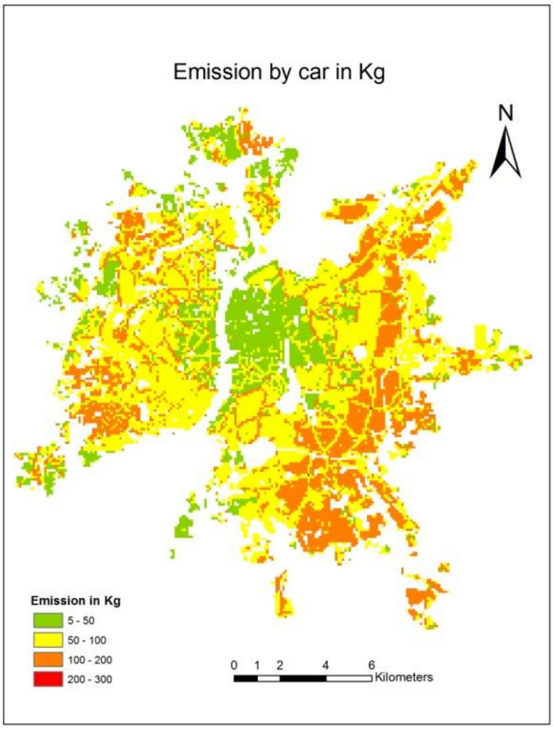


Figure 31: amount of emission by car

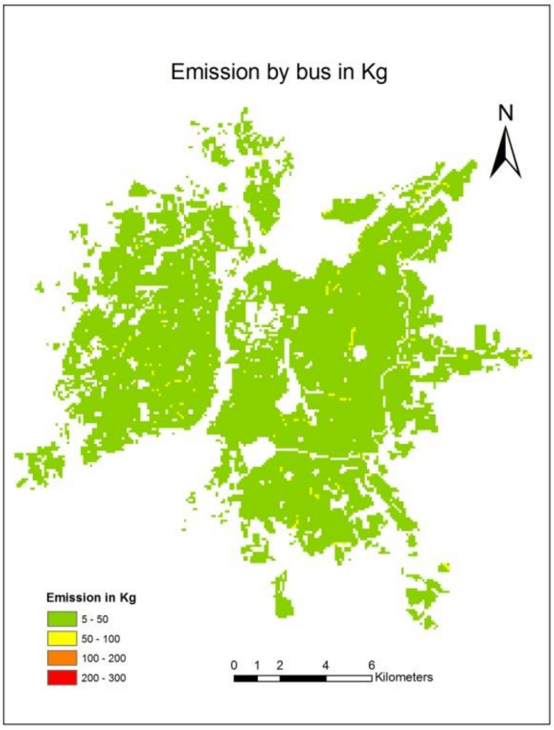


Figure 32: the amount of emission by bus

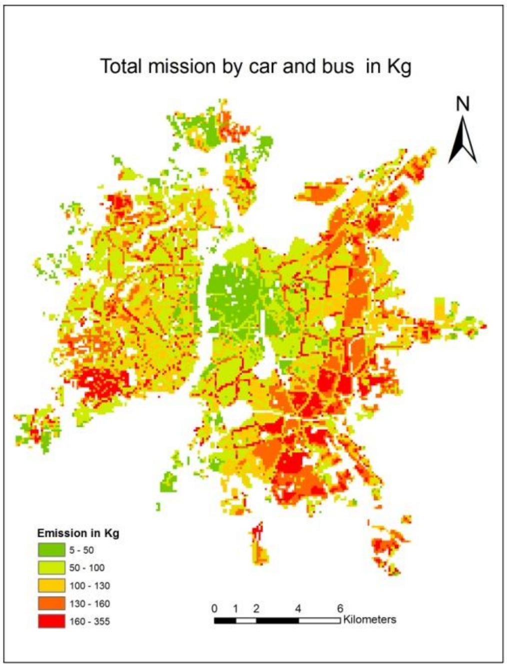


Figure 33: total emission by bus and car

Figure 33 displays the total amount of emission by both modes to make trips from the cells to CBD. It shows that as distance from CBD increases the total amount of emission goes up. Areas, where high income group dwell also show increment in emission. In section 6.2 it has been discussed that the number of trips generated increases with density which implies that trips generated in the Walled city is higher. However, due to closeness to the opportunities the trips length goes down which has implied impact of reducing emission.

6.5. Discussion

With time the total trip generated is seen to increase all over the area. This is particularly because of the increment in number of activities. For instance in figure 27 there is a clear increment of number of trips generated along the river side, Ashram road in western Ahmadabad and along the bus rapid transit system between Rameshwara Mahadev and Narol Naroda routes and in the vicinity of Samrat Nagar in the eastern Ahmedabad. These can be attributed to the dynamics in the city induced due to the Sabarmati river side development , a project that will result in thousands of commercial related jobs, the enhanced bus rapid transit system in the city and the emerging of new business corridors in the east (AMC and AUDA 2006).
As it is modelled in AB- Metronamica, the concentration and distribution of activities are changing over space and time. Since trip generation is a function of these activities, the dynamics of urban form is inducing dynamics in trips generation.
Except there is no enough and complete data to clearly say the reason behind, from the available data analysis, though it is weak, there is positive correlation between density and public transport and negative correlation between density and trips made by personal car. However, highly populated areas are predominantly occupied by people of low income and the lower the income the more public transport is utilized. Therefore, the negative correlation between automobile dependency and density, and positive correlation between public transport use and density might be the result of autocorrelation resulted from negative correlation of density and income. With distance the probability of taking public transport goes down though this might have been caused by other factors such as the availability of public transport at the outskirt of the city. And besides, the western part of the city is characterized by low density and high income residential. This characteristic of the city

has contributed for high probability of dependence on private car as it is depicted in figure 28.

6.6. Conclusion

Though other factors can contribute, the effect of activities' density is observed at a significant level on transport. The increase in number of activities in an area increases the trip frequency which will have an incremental effect on total trip generation. Beside trip generation, the effect of density on mode choice is observed whereby higher density tends to favour public transport over private mode of transport over time. But this could be attributed to other factors such as socio economic that need to be assessed very carefully based on empirical facts. Moreover, the increment in the number of trips made by car and as the distance from the city centre increased, the total amount of emission increased.

The modelling of activities' density in AB-Metronamica paved a way to independently assess and compute the effect of each activity separately. It gives an opportunity to know how many activities are present and directly use them in computation of transport elements such as trip generation and modal split.

7. Conclusion and Recommendation

7.1. Conclusions

This research is about modelling urban form dynamics and how these dynamics are affecting the transport systems in Ahmadabad, India. The whole process of the research has been divided in to two phases. The first phase dealt with modelling urban form dynamics and the second phase dealt with the impact of these dynamics on the transport systems.
To conceptualize and carry out the modelling tasks, first a description of urban form is explored from literature and the concept of density of urban development is operationalized. Then, modelling tools that can execute this modelling concept were searched for and among several modelling platforms AB-Metronamica was chosen. Following this previous work done by Deepty Jain (2009) has been reviewed. In her work, she discovered that the model distributes activities uniformly over the study area and thus concluded that the model did not reflect the reality of the city. To deal with this problem, this study first discussed how urban form can be described. Based on the description, how urban pattern of Ahmadabad has been evolving was explored. Then the concept of development density is employed and the density pattern of the city is analysed through an SPSS curve fitting process. The density of the city showed a pattern of monotonously falling away from the city centres. So, to capture this behaviour in the modelling process the CBD and sub-centres as well as access points have been introduced to increase the potential of cells in these locations since the model allocates activities according to this potential.
The second phase of the research investigated the impact of urban form on the transport system. The indicator of urban form used here is density of activities. To find the impact first empirical data was studied. Hence, the correlation between activities' (residential, commercial, institutional and industrial) density, distance from the city centre, income and transport mode choice was obtained. The correlation factors and densities of activities as simulated in AB-Metronamica were then used in computing the probability of choosing a particular type of mode (seen as one of the most important transport characteristics when discussing sustainability). Home based trip generation was calculated considering all the activities and was then multiplied with the mode choice probability to compute the number of trips made by each mode. Further, the number of cars and buses was calculated based on the average number of passengers they carry. Finally the amount of emission by individual modes and total emission has been computed.
The data needed for the research was not complete since no field work has been conducted. Most of the data are secondary and only found at a lower resolution. The output from AB-Metronamica is at a resolution of 100 by 100 metres but population, economic and transport data are at the TAZ level which is much larger than the 100 by 100 metre cells. To overcome this, the TAZ layer and the grid layer were overlaid and these data were transferred to the cells homogenously. As such the same value for all cells within a TAZ is assigned and those cells overlapped with the boundary of the TAZ got values from both neighbouring TAZ, and had to be adjusted manually. Another challenge was not having transport parameters such as the trip generation rate of the land uses of Ahmadabad. Instead the parameters from a Kuala Lumpur study have been used throughout this research. The choice will have an impact on the analysis since the two cities differ in terms of social and economic factors. The choice of parameters from Kuala Lumpur is primarily due to availability and secondly,

because both cities are experiencing fast economic growth; a factor that contributes a lot to urban form dynamics and mobility.

In spite of the predicaments faced in the availability of proper data, based on what has been done above the study can conclude the following.

Modelling urban form using activity based modelling in AB-Metronamica generally gives a result that is closer to reality. With all the needed data and knowledge of the modelling area, very good results can be obtained. Generally it is user friendly that allows users to develop scenarios to predict and explore how the contemporary dynamics of urban environment would unfold in the future. On top of that, the model gives an opportunity to model different activities separately and produces their outputs, which in the later stages, can be used to assess the impact of each activity on transport separately. But this should be handled vigilantly as the sum of the individual effect is not necessarily equates to the combined effect of the whole system.

However, the model has the following limitations:

- The model does not have multilayer CA that helps to have two stages of modelling at the national and local levels. Its purpose is to deal with the city as whole and capture the dynamics of the city in different parts according to their locality.
- The model distributes activities uniformly irrespective of the cells' potentials at the beginning of the modelling period.
- The potential of the cells is not fully computed at the starting period but grows over time. This deters one from starting modelling from a particular year in question.

The impact of urban form on transport is observed to be that the increment in density favours public transport over private modes of travel. Thus, change in density induces change in transport though this could be attributed to other factors such as socio-economic which are not fully dealt with in this study because of the unavailability of data. As some parameters have been adopted from Kuala Lumpur, Malaysia, the results produced may not fully reflect the social and economical realities in Ahmadabad. Finally it has been observed that the total amount of emission goes up as distance increases from city centre.

7.2. Recommendation

The impact of urban form on transport is a complicated matter, especially in developing nations. Though it is an important factor, to directly link the effect of urban density to travel mode can lead to the wrong conclusions. Quantifying the characteristics of the built environment related to modes of travel remains a major challenge, since it requires greater details and precision than that which is required to understand automobile travel behaviours. Another complication is the tendency for the urban attributes to be highly correlated and the resulting multicollinearity of variables could result in the common use of factors which would be difficult to separate and translate to policies and intervention. Having this in mind, to fully understand the impact of urban form dynamics on transport, further research should be carried out the framework set out in this work and proper data collected from the field. Such data should be as precise and detailed as possible since autocorrelation of urban variables may lead to wrong conclusions. This would allow a vivid depiction of how urban form and its dynamics can affect transport.

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