MSc Thesis

# Title: Spatial assessment of transit oriented development in Ahmedabad, India


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# Abstract

Urbanization is an integral part of economic development. In India especially, rapid economic growth and urbanization have led to formation of slums, deterioration in environment, congestion etc. A sustainable strategy is thus required to maintain the economic growth and alleviate the problems arising due to the growth. Transit oriented development which is an integrated approach to land use and transport planning is one such strategy.

Transit oriented development (TOD) is defined as a high density, mixed use type of development close to transit services. Indian cities traditionally have high density and mixed use type of development. In such a context, TOD might already be a reality in some form. Thus the current research investigates the concept of transit oriented development in an Indian context.

Spatial multi criteria evaluation (SMCE) is a decision making model that uses inputs from multiple stakeholders and uses multi criteria to arrive at decisions. Since TOD requires co-operation between consumers, planners, administrators, designers etc. SMCE is the ideal tool for such an analysis. The other advantage of SMCE (or in general multi criteria methods) is that with a sensitivity analysis, stakeholder bias can be eliminated. As such, for the research SMCE is selected as the framework for analysis.

An SMCE framework has been used to develop a TOD score for the study area of Ahmedabad (the BRT corridor) using which it has been determined that greater portions of the city is already close to being TOD. Especially, the inner walled city with high density, mixed use type of development ranks very high on the TOD score (69%). The outer corridors on the other hand have a more or less suburban type of development and hence rank very low on the TOD score. These regions have great potential in terms of re-development.

## Acknowledgments

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*"All work and no play makes Jack a dull boy"* – a popular saying. I would like to thank all my friends for ensuring that I was not a Jack.

I am what I am today due to the love and encouragement of my family. I owe them everything.

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# 1. Introduction

The global percentage of urban population has been steadily increasing in the twentieth century. According to the World Bank, more than 60% of the world population will be living in urban areas in the year 2030[1]. India will not be an exception to this growth. In India, the problem of urbanization is aggravated by the concentration of economic opportunity in few cities. This creates the problem of extreme concentration and thus the creation of very large cities. By 2025, 22% of the urban population will be living in 9 cities[2]. Such large concentrations create pressure on facilities such as transportation, housing, and other products required by the population. As such, there is a need for good planning and policy framework for the cities to grow sustainably.

Urbanization is an integral part of economic development. Rapid economic growth and urbanization in India have led to formation of slums, deterioration in environment, congestion etc. A sustainable strategy is required to maintain the economic growth and alleviate the problems arising due to the growth. Sustainable development can be defined as *"any social and economic development that does not harm the environment"* [1]. Transit-oriented development (TOD) which concentrates development near and around transit systems to promote transit ridership is one such sustainable development strategy.

There are many ways in which TOD promotes sustainable development. First and foremost, as already mentioned in the previous paragraph, it reduces auto usage by providing a transportation alternative. Secondly, land use planning and urban design improve the accessibility for non motorized traffic and help promote alternatives to the auto; reduction in automobile use reduces obesity and other negative health effects as well [2]. Concentrating jobs and other activities around transit improves the accessibility of the economically weaker section, i.e. the poor, as well as the disabled etc. Thirdly, concentration of activities along with urban design and land use planning also helps in reducing air pollution. Concentration of activities and land use planning help in creating a good distribution of activities within a neighbourhood; but in order to be successful, the area must be approachable and attractive to users (different people have different standards to use the same space). A balance is needed between achieving the most efficient system and recognizing community goals. Urban design is the key mechanism in achieving this balance [3].

While TOD has received a lot of attention in the US and other developed countries the same is not the case in India. Traditionally, Indian cities are dense and urban travel is predominantly by walking, cycling and transit. With the government investing in metro rail systems and bus rapid transit systems in many cities, TOD can be a viable option for these cities.

The city of Ahmedabad is the largest city in the state of Gujarat and the seventh largest in India. It is the commercial heart of the state, contributing nearly 60% of the total productivity of the state[4]. Increasing populations in the city has resulted in transportation and environmental problems. In order to alleviate some of these problems, the city has recently invested in a bus rapid transit

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[1] World Urbanization Prospects: The 2007 Revision Population Database. http://esa.un.org/unup/
[2] World Urbanization Prospects: The 2007 Revision Population Database. http://esa.un.org/unup/p2k0data.asp

system, Ahmedabad bus rapid transit system (ART); the investment is expected to boost transit ridership.

Since Ahmedabad is already a dense city, it could be possible that with this transit investment, a TOD type of development is already achieved. This study first investigates the existing development in Ahmadabad to determine if transit-oriented development (TOD) exists in some form. Secondly, what policy and planning measures can help improve the degree of TOD-ness in Ahmedabad?

# 2. Problem Statement

The city of Ahmedabad is the seventh largest city in India and the largest in the state of Gujarat. The city is spread over 440 sq. km and accommodates over 5 million people which is expected to grow to 11 million by 2035. The city also has registered vehicle strength of 1.4 million, which is growing at the rate of 8-10% per year [4]. This rapid growth in automobiles has resulted in congestion, and air pollution. In order to solve these problems the city has recently invested in a bus rapid transit system. The city has also become a centre of opportunities, with more and more people from regional areas moving into the city looking for jobs. These people often lack the skill to get a good steady job and cannot afford to live within the inner city, instead choosing to live around the periphery of the city (as the cost of living in the inner city is usually very high) where the transit services are poor [5]. Since transit is the main mode of travel for the urban poor, their mobility and accessibility is limited. Thus there is a need for inclusive planning to improve the socio-economic status of all citizens. Transit investment can help to increase the access to opportunities, and in conjunction with good land use planning and policies can achieve sustainable urban development.

The city of Ahmedabad has recently invested in a bus rapid transit system. But this investment alone is not sufficient. Around the world, integrating land use and transport planning has been recognized as the way to achieve sustainable development. If transit has to be the driver in urban development, transit ridership needs to increase. Many factors such as zoning policies, land use distribution, transport policies etc. play a role in increasing ridership. The current study assesses the sufficiency of transit investment and other factors influencing transit ridership for achieving sustainable urban development in Ahmedabad.

## 2.1.Land use and transport policies in Ahmedabad

The rapid economic growth happening in India is mainly through the service and industrial sectors. Both of these sectors operate mainly in urban areas, and as such the state of these areas is crucial. Transportation is a crucial link for sustaining the growth and also for a smooth running urban region. To improve the transportation links and alleviate some of the problems, the central government has launched a new National Urban Transport Policy (NUTP). Some of the objectives of this policy include:

- An integrated approach to land use and transportation planning
- Encouraging an equitable distribution of road space; concentrating on people rather than vehicles
- Improving access to business and production sites
- Encouraging greater use of public transport and non-motorized traffic
- Reduction in air pollution by changing travel patterns, improved technology, stricter norms etc.

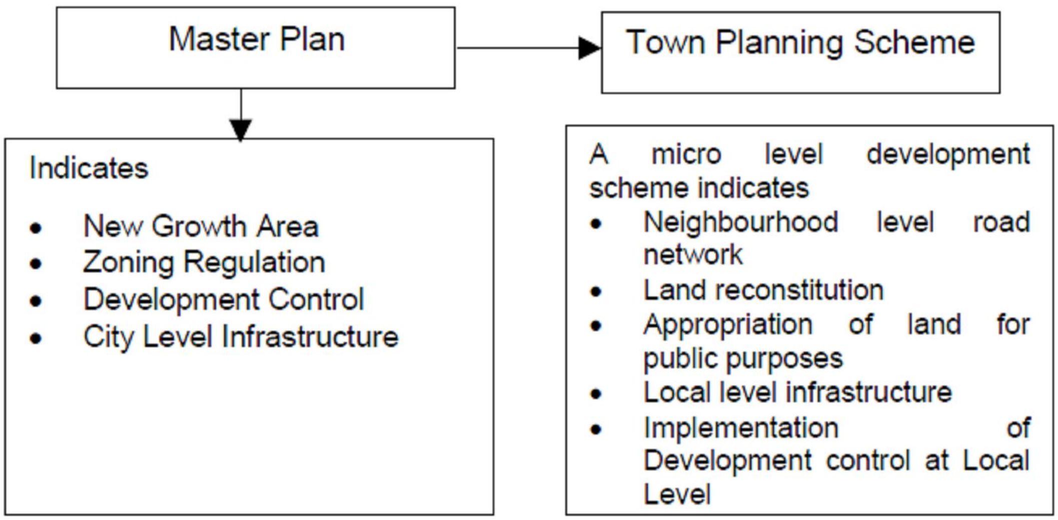
These are only a few of the objectives. The whole list is presented in the document by the Ministry of Urban development [6]. Using this policy as a framework, state governments can manage their urban regions. In Gujarat, the state government has developed an urban transport policy, focusing on economic growth, environmental improvements and social equity; in other words a plan for sustainable development. The objectives of the Gujarat urban transport policy include: [7]

- To address issues relating to the planning, design, construction, operation, maintenance, management and development of all forms of urban transportation in an economically efficient, equitable and sustainable manner.
- To ensure provision of an adequate quantity and quality of urban transportation services.
- To accelerate the development of urban transportation infrastructure with appropriate legal, regulatory, institutional and financial measures.
- To make institutional changes necessary to consolidate publicly- owned urban transportation facilities in major urban areas and to improve service delivery.
- To develop the legal and regulatory framework to allow consolidation and to improve the prospects for private sector participation.
- To establish priorities for urban transport, from highest priority to lowest priority, as follows:
    - Mass transport.
    - Non-motorised transport such as bicycles and pedestrians.
    - Intermediate public transport such as auto-rickshaws and taxis.
    - Personalised motor transport such as motorcycles and cars.

The Gujarat state government has developed the local policies using the NUTP as a framework. For example; with respect to space management on roads priority is being given to public transport, consolidation with respect to land use to improve service delivery etc.

Since the current project deals with land use as well as transport, an insight into land use policies is essential as well. Gujarat unlike most other states in India has a unique way of dealing with urban development and land management. Land acquisition act of 1894, transfer of development rights, joint sector method of allowing license to private developers to construct dwelling units, master plan (development plan) are some of the land development schemes in practice. Gujarat uses the Development plan and Town planning scheme mechanism. According to the Land acquisition act, the Government of India can acquire land from any individual for public purposes. The main disadvantages of this method are that it takes an inordinately long time for acquiring land and the fact that the compensation paid to the land owner is not up to market standards. The other issue is with respect to disparity between the people who own the land being acquired and the people whose land adjoins the acquired land. This latter group of people enjoy the benefits of increased property value as well as the market value of the land, whereas the former enjoy neither [8]. The Gujarat town planning and urban development act (GTPUDA), 1976 provides for a mechanism to address these issues using a development plan-town planning scheme (DP-TPS) method. The relationship between the development plan (master plan) and the town planning scheme is shown in Figure 1.

Figure 1: Development Plan-Town Planning Scheme




Source: [9]

The scope of the DP is to promote development or redevelopment of urban areas with a view on regional development. It identifies the different type of land uses to be developed in the area, reserves land for public use, identifies the road network and street pattern, and also identifies the stages for implementation. The TPS on the other hand is a micro level scheme focussing on a community scale. The TPS is similar to a land pooling technique in that land from owners within the community is pooled together and after redevelopment is distributed back to them. Usually the TPS covers a land of around 100 hectares.

From the objectives of the NUTP it is clear that the national government is pushing for promotion of public transport. The Gujarat UTP is pushing for concentration of activities in addition to public transport as a means of improving service delivery. The state of Gujarat also wants to promote economic and equitable development. These are in line with the research objective of the current project.

## 2.2.Research objective

The overall objective of the study is to assess the potential of the current BRT investment in Ahmedabad for achieving sustainable urban development goals. TOD is investigated as a potential strategy for achieving such sustainable urban development.

### 2.2.1. Objective 1

To define sustainable urban development and TOD and investigate the potential of TOD for achieving sustainable urban development

**Research questions**

- What is sustainable urban development (SUD)? What are the goals of SUD?
- What is TOD? What are the goals of TOD?
- Do the goals of TOD align with the goals of sustainable urban development?

### 2.2.2. Objective 2

To determine whether the current urban form and transport development on and around the BRT corridor in Ahmedabad can be characterized as a TOD type of development

**Research questions**

- What are the different types of transit development?
- How can a case be differentiated between TOD and non-TOD type of development?
- What is the framework under which the case can be spatially evaluated?
- How can the framework be used for assessment? (Model)
- How does the current case rank on the evaluation framework?
- What form of development exists in Ahmedabad?

### 2.2.3. Objective 3

To investigate the changes that need to be made to make the current development a TOD or a more successful TOD.

**Research questions**

- Which criteria from the evaluation framework can be selected for improvement in the current case?
- Is there a correlation between different criteria? If so, how does it affect the selection?

### 2.2.4. Objective 4

To investigate the policy and planning barriers that needs to be overcome in order to implement the changes

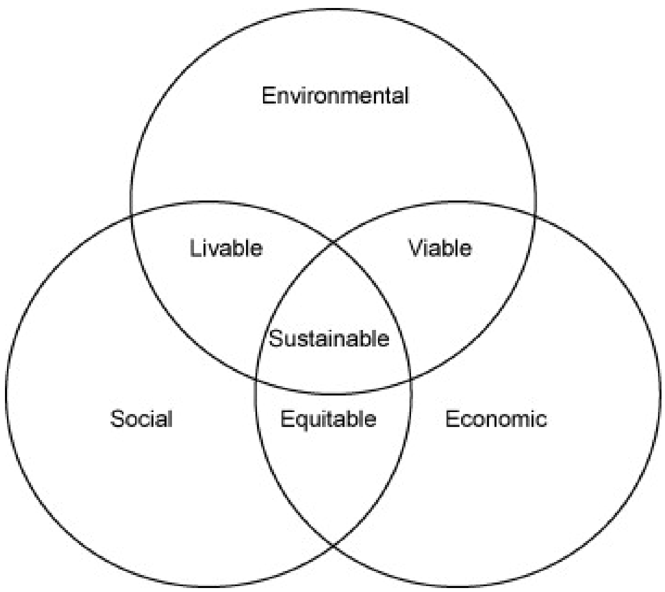
**Research questions**

How can these barriers be overcome, in order to implement the changes identified in the previous step?

# 3. Background Literature

The idea of sustainability or sustainable development dates back to 1969 where the mandate of the IUCN defined it as the management of humankind's natural environment and resources to achieve highest sustainable quality of life [10]. Since then the concept has been evolving. In the Brundtland report, *Our common future*, it is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition is also vague; beneficiary oriented development is imperative for any development process to be successful [11]. The concept can be better defined by operationalizing the concept in three goals: economy, environment and society. Figure 2 shows these three goals; development should be viable, equitable and liveable [12].

Figure 2: Sustainable development




Transportation increases the mobility of people and it is implicitly assumed that mobility is linked to wealth [13]. But increased mobility comes at a cost; greater use of natural resources and hence increased environmental pollution. Thus for sustainable development, a balance is required between the two. Mobility contributes to increase in wealth by increasing the number of economic opportunities that can be reached. An alternative strategy for economic development would be to increase the ease of reaching opportunities while keeping the use of automobiles to a minimum. This would ensure economic development and also a control of environmental pollution. This is the concept of sustainable transport, transport planning to achieve a balance between the three goals of sustainable development [14].

Sustainable transport can be achieved in three ways: implementing technology, pricing and financing, integrating land use and transport [15]. Technology can help in reducing emissions, pricing and financing management can reduce traffic volumes, and integrated land use and transport planning can be used to promote alternate modes of transport such as biking, walking, transit. While technology and pricing management strategies try to address the problem of travel demand, land use and transport strategies try to address the need for travel and thus offer a better alternative to planning.

Transportation affects land use in terms of locations of firms, housing, commercial activities etc. Similarly land use affects transportation in terms of travel patterns. Thus it is necessary to consider the two as complementary. Table 1 lists the different land use factors that influence travel and their impacts.

**Table 1: Land use factors**

| Factor | Definition | Travel Impacts |
|---|---|---|
| Density | People or jobs per unit of land area (acre or hectare). | Increased density tends to reduce per capita vehicle travel. Each 10% increase in urban densities typically reduces per capita VMT by 2-3%. |
| Mix | Degree that related land uses (housing, commercial, institutional) are mixed | Increased land use mix tends to reduce per capita vehicle travel, and increases use of alternative modes, particularly walking for errands. Neighborhoods with good land use mix typically have 5-15% lower vehicle-miles. |
| Regional Accessibility | Location of development relative to regional urban center. | Improved accessibility reduces per capita vehicle mileage. Residents of more central neighborhoods typically drive 10-30% fewer vehicle-miles than residents of more dispersed, urban fringe locations. |
| Centeredness | Portion of commercial, employment and other activities in major activity centers. | Increased centeredness increases use of alternative commute modes. Typically 20-50% of commuters to major commercial centers drive alone, compared with 80-90% of commuters to dispersed locations. |
| Connectivity | Degree that walkways and roads are connected and allow direct travel between destinations. | Improved roadway connectivity can reduce vehicle mileage, and improved walkway connectivity tends to increase walking and cycling. |
| Roadway design and management | Scale, design and management of streets. | More multi-modal street design and management increases use of alternative modes. Traffic calming tends to reduce vehicle travel and increase walking and cycling. |
| Walking and Cycling conditions | Quantity and quality of sidewalks, crosswalks, paths and bike lanes, and the level of pedestrian security. | Improved walking and cycling conditions increases non-motorized travel and can reduce automobile travel, particularly if implemented with land use mix, transit improvements, and incentives to reduce driving. |
| Transit quality and accessibility | Quality of transit service and degree to which destinations are transit accessible. | Improved transit service quality increases transit ridership and can reduce automobile trips, particularly for urban commuting. |
| Parking supply | Number of parking spaces per | Reduced parking supply increased parking |

| Factor | Definition | Travel Impacts |
|---|---|---|
| and management | building unit or acre, and how parking is managed. | pricing and increased application of other parking management strategies can significantly reduce per capita vehicle travel. Cost-recovery parking pricing (charging motorists directly for the cost of providing parking) typically reduces automobile trips by 10-30%. |
| Site design | The layout and design of buildings and parking facilities. | More multi-modal site design can reduce automobile trips, particularly if implemented with improved transit services. |
| Mobility Management | Various programs and strategies that encourage more efficient travel patterns. | Mobility management policies and programs can significantly reduce vehicle travel by affected trips. Vehicle travel reductions of 10-30% are common. |

Source: [16]

The relationship between transport and land use can be used to achieve many planning objectives. Various transportation demand management strategies change land use patterns directly to achieve a change in travel behaviour. Some of these strategies are shown in Table 2.

**Table 2: Transportation/land use demand management**

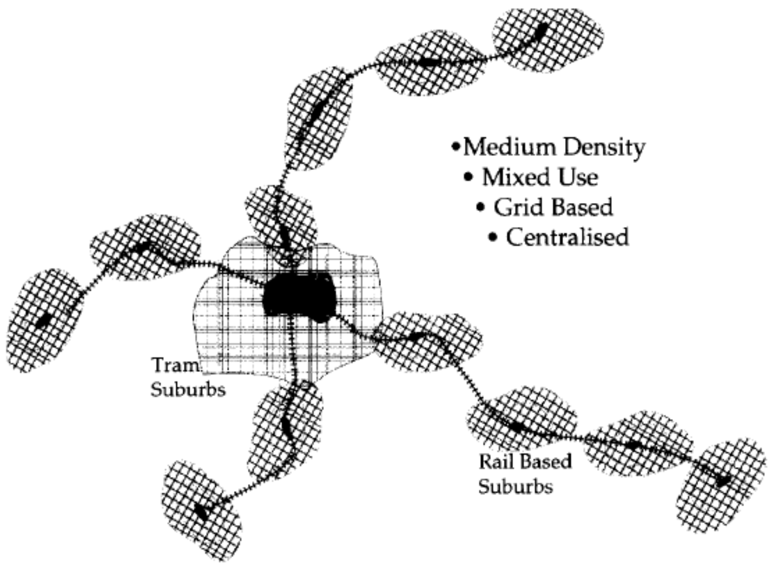
| Strategy | Scale | Description |
|---|---|---|
| Smart Growth | Regional and local | More compact, mixed, multi-modal development |
| New Urbanism | Local, street and site | More compact, mixed, multi-modal, walkable development. |
| Transit-Oriented Development | Local, neighborhood and site | More compact, mixed, development designed around quality transit service, often designed around transit villages. |
| Location-Efficient Development | Local and site | Residential and commercial development located and designed for reduced automobile ownership and use. |
| Access management | Local, street and site | Coordination between roadway design and land use to improve transport. |
| Streetscape | Street and site | Creating more attractive, walkable and transit-oriented streets. |
| Traffic calming | Street | Roadway redesign to reduce traffic volumes and speeds. |
| Parking management | Local and site | Various strategies for encouraging more efficient use of parking facilities and reducing parking requirements. |

Source: [17]

## 3.1.Definition of TOD

Transportation planning plays a key role in urban development. Overdependence on automobile can cause sprawl, longer travel distances, congestion etc. Urban development strategies such as Urban development philosophies: new urbanism, traditional neighbourhood planning, and transit oriented development (TOD) offer an alternative to the use of private automobile. They share three common objectives – (1) reduce the number of motorized trips; (2) increase the share of trips that are non-motorized; and (3) of the motorized trips that are produced, reduce travel distances and increase vehicle occupancy levels [18]. Focusing on the built environment by changing density, diversity and design can help achieve these objectives.

Figure 3: Transit city




Source: [19]

Figure 3 shows a transit city, which incorporates high density, mixed-use development around transit stations. Curitiba in Brazil, Bogota in Colombia, and Arlington County in the USA are some examples of such cities. In such transit cities (or transit-oriented cities) urban landscape is used to leverage transit services. Some of the definitions of TOD include:

- High density mixed use development around transit stations[20]
- High residential or mixed use development around transit corridors [21]
- High density development within walking distance of transit stations [22]

All of these definitions include the 3D's (Density, Diversity and Design) of Cervero and Kockelman [18]; diversity in the form of mixed use development, density in form of residence and jobs, and design in the form of good street connectivity for pedestrians.

### 3.1.1. The role of density, diversity and design

Density is the most important land-use predictor of ridership rates [23]. In this case, density refers to population or employment density. Kockelman also found a direct relation between density and transit mode choice [24]. Other studies have found a direct relation between congestion and density, and an inverse relation between density and auto use [25]. The distance between activity locations also plays an important role in mode choice. Hence, activity density, defined as the number of local desirable non-work activity locations is an important consideration [25].

Urban design helps in increasing accessibility to transit services and hence, helps in increased transit use. In these definitions, urban design focuses mainly on increasing walking accessibility. This means that development borders will be small (e.g. 400m around stations). Transit use can also be leveraged by designing for good modal connections, such as between regional transit and rapid transit, bike and transit, etc. [26]

A rich mix of choice is a defining feature in the best neighbourhoods [27]. Different activities within walking distances can help people complete many activities in one trip (i.e. trip chaining). Similarly, housing options can help people from different social levels live in the same communities and not move to poor accessible regions (which are more affordable). Hence, TOD needs to provide affordable housing for the economically weaker sections and other people who might depend on transit for mobility as well.

## 3.2. TOD and sustainable urban development

Table 3 shows some of the strategies for achieving sustainable development. The strategies range from land use to transportation, housing etc. Overlaps also exist between the different classes of strategies. Transit oriented development as defined in the previous sections helps achieve each of these objectives. For example, high density development promotes job creation and community development; pedestrian accessibility and transit development improves transportation link; affordable housing and zoning policies improve social equity and housing and urban design. Thus TOD is a viable strategy to achieve sustainable development. The whole concept of sustainable development and TOD is linked in Figure 4. The figure shows the core strategies of TOD (i.e. the 3 D's Density, Diversity and Design) and how they are linked to the three dimensions of sustainability.

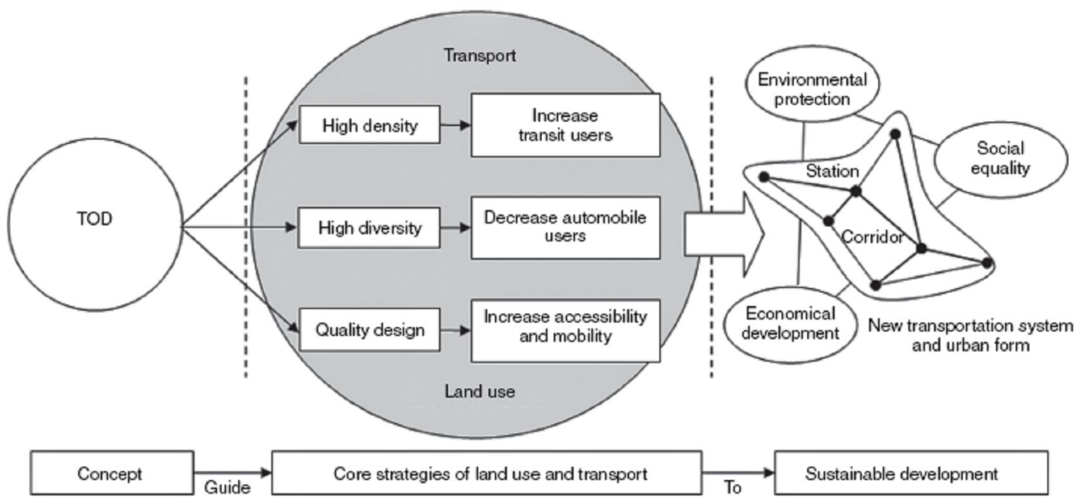
**Table 3: Strategies for sustainable development**

| Strategy | Examples |
|---|---|
| Land Use and Community Development | • Preservation, Rehabilitation, and Redevelopment of Central Cities and High Density Inner Suburbs<br>• Infill in Cities and Suburbs — Increased Density, Mixed Use<br>• Reusing Brownfields, Recycling Buildings<br>• TODs and PODs as the Paradigm for New Developments<br>• Quality of Life: Attention to Crime / Schools / Services /Amenities<br>• Recycling / Precycling / Composting Programs |
| Transportation | • Access vs. Mobility — Basic Concepts<br>• Bike- and Pedestrian-Friendly Cities<br>• Transit, Paratransit, Ridesharing<br>• Telecommuting / Teleconferencing<br>• New Technologies for Improved Efficiency: evs, Traffic Control Systems, Transportation Information Systems<br>• Prices and Subsidies Aligned with Sustainability |

| Strategy | Examples |
|---|---|
| Housing and Other Building Designs | • A Range of Choices<br>• Energy Efficient Buildings<br>• Edible Landscaping<br>• Natural / Indigenous Plants |
| Business/Job Creation | • Business Leadership<br>• Community Economic Development<br>• Clean / Safe Technologies |
| Social Equity | • Aligning Taxes and Subsidies with Sustainable Development<br>• Equitable Distribution of Resources |

Source: [28]

Figure 4: TOD and sustainable development




Source: [29]

## 3.3.What is TOD and what is not?

Another form of development that is close to TOD is transit adjacent development (TAD). Cervero et al. define TAD as development that is close to transit services, but does not use the proximity to promote transit ridership [20]. Even though both forms of development have the same principles, TOD is considered a better option; TOD increases transit ridership by using land use planning to leverage transit use, whereas TAD just focuses development near transit. As G.B. Arrington of PB PlaceMaking says, “Within the family of TOD, you might say there are two ‘brothers’ – TOD and his ‘evil brother’ TAD”[30]. Table 4 shows the difference between TOD and TAD.

Table 4: TOD vs. TAD

| Transit oriented development | Transit adjacent development |
|---|---|
| Grid street pattern | Suburban street pattern |

| Transit oriented development | Transit adjacent development |
|---|---|
| Higher densities | Lower densities |
| Limited surface parking and efficient parking management | Dominance of surface parking |
| Pedestrian- and bicycle–oriented design | Limited pedestrian and cycling access |
| Mixed housing types, including multi-family | Mainly single-family homes |
| Horizontal (side-by-side) and vertical (within the same building) mixed use | Segregated land uses |
| Office and retail, particularly on main streets | Gas stations, car dealerships, drive-through stores and other automobile-focused land uses. |

Source: [31]

## 3.4.Evaluation of TOD

An evaluation framework for TOD is not only essential for assessment of existing sites but also for future planning measures. According to Dittmar and Ohland [27], TOD projects have five main goals:

- Location efficiency – key factors defining location efficiency include density, accessibility to transit services, pedestrian friendliness.
- Value capture – frequent high quality transit, good connections between modes,
- Rich mix of choices – different land use types: commercial, retail, residential etc., range of housing options
- Place making – pedestrian friendliness, safety, street connectivity, zoning policies
- Resolution of tension between node and place – developing a transit node (transit station) as an activity centre; design for pedestrian friendliness, mix of uses to promote trip chaining etc.

Cervero and Kockelman selected the following indicators in a regression analysis to evaluate the influence of built environment (3D's) on travel behaviour [18]:

- Density
    - Population density: population per developed acre
    - Employment density: employment per developed acre
    - Accessibility to jobs
- Diversity
    - Dissimilarity index
    - Entropy
    - Vertical mixture
    - Intensity of land use categories
    - Activity centre mixture
    - Proximities to commercial-retail uses
- Design
    - Street design and connectivity
    - Site design

The present research models the link between land use and transport by using the above three indicators. While the indicators can explain the relationship between land use and transport, they might not be sufficient to evaluate TOD. The objective of TOD is not only achieving sustainable transport; TOD provides people the opportunity to live, work, shop and relax. Hence, community development by providing affordable housing can be considered an essential part of TOD as well.

Evans et al. [32] developed a "TOD index" as a tool to characterize a successful TOD project (Table 5). The table has indicators for transport as well as land use. Thus it adds one dimension to the 3 D model of Cervero and Kockelman. This method though is used for determining the success of TOD. Indicators such as property value, public perception are post development indicators whereas most of the others can be used for a pre development study for assessment.

**Table 5: TOD Indicators**

| Indicator | Category | Percentage Identifying as "Very Useful" | Secondary Ranking |
|---|---|---|---|
| Transit ridership (e.g., boarding) | Travel behaviour | 70 | 1 |
| Population/housing density | Built environment | 67 | 2 |
| Employment density (e.g., number of jobs per acre) | Economic/Built Environment | 53 | 2 |
| Qualitative rating of streetscape (i.e., pedestrian orientation, human scale) | Built environment | 77 | 3 |
| Mixed-use structures (number or square footage) | Built environment | 60 | 4 |
| Pedestrian activity counts | Travel behaviour | 77 | 5 |
| Number of intersections or street crossings improved for pedestrian safety | Built environment | 60 | 5 |
| Estimated increase in property value | Economic | 63 | 6 |
| Public perception (e.g., administered survey) | Social diversity/Quality | 63 | 7 |
| Number of bus, ferry, shuttle, or jitney services connecting to transit station | Travel behaviour | 63 | 8 |
| Number of parking spaces for residents, tenants, visitors, commuters, and shared | Travel behaviour | 53 | 9 |
| Estimated amount of private investment | Economic | 57 | - |
| Number of convenience or service retail establishments (e.g., dry cleaners, video rental) | Economic | 53 | - |
| Estimated amount of private investment by type of land use | Economic | 52 | - |

Boarnet and Compin used interviews and analysis of the zoning and land use patterns around station areas to study TOD in San Diego [33]. They were able to conclude that TOD projects are incremental in nature and that an alignment of goals of local and vision of regional authorities is necessary for a successful project.

Lin and Li defined regional planning for TOD as a Land-use Design Problem (LDP) [34]. The regional planning defines the structure of land based on transit and the distribution of activity centres in a city. They conducted a survey with scholars and planners to identify the objectives of TOD. Based on the survey they selected four objectives and developed a mathematical model for the study. The four objectives selected were

- Improve environment quality
- Maximize interaction convenience between activities
- Maximize transit ridership
- Increase accessibility of non-residential activities

Dockmeci et al. consider a multi objective model for land use planning based on two alternatives [35]

- Maximization of return
- Minimization of sum of weighted distances among different land-use units

Using the model, they were able to design the optimal distribution of different land use categories. They concluded that for the accessibility objective, most of the activities are distributed around industry and commerce whereas for the return objective the activities are distributed around recreational and commercial areas. They also recommend an increase in alternatives and land use categories to find a more optimal distribution of land use categories.

The objective of the study is assessing Ahmedabad for TOD. But the assumption is that TOD is a strategy for sustainable development. Hence TOD should be assessed within the sustainability dimensions. Turcu identified 5 different approaches to measure sustainability in literature [36],

- Ecological footprint – a spatial unit related to the tract of land needed to support it
- Material intensity per unit of service – the mass of material input per total units of service delivered by the good in its lifespan
- Energy approach – converting input flows into a common energy equivalent
- Cost benefit analysis – comparison of financial values of cost of achieving sustainability to the benefits
- Indicators and indexes – signs and signals which should be monitored to predict a good future

Of the five approaches listed above, the first three are eco-centric in that they try to measure sustainability on the basis of resources. Cost benefit analysis balances the cost against benefit and does not consider the individual. The main criticism of the indicators and indexes method is that it is highly dependent on the availability of data.

For the analysis of TOD outcomes the data for many indicators on travel behavior, built environment etc are easily collected. Hence, the use of indicators and indexes is the most suitable option for the current research. Multi-criteria analysis is a tool that can be used to develop indexes from indicators.

### 3.4.1. Multi criteria decision making

Decisions are made when a person wants to (or does not want to) perform an action, or when choosing to do it in a particular manner. Traditionally first type of decisions (how people make decisions) fall under the category of prescriptive theory and the second type (how people ought to make decisions) under normative theory [37]. In both of these theories, a mathematical model is used to replicate the decision making environment and study the decision process.

A normative decision is defined as the selection of an optimal solution for a given situation. Linear programming, dynamic programming, hypothesis testing, multi-criteria decision making are some of the models that can be used in order to arrive at the solution. In multi criteria decision making (MCDM) process, given a set of alternatives and a set of decision criteria, the best alternative is chosen [38].

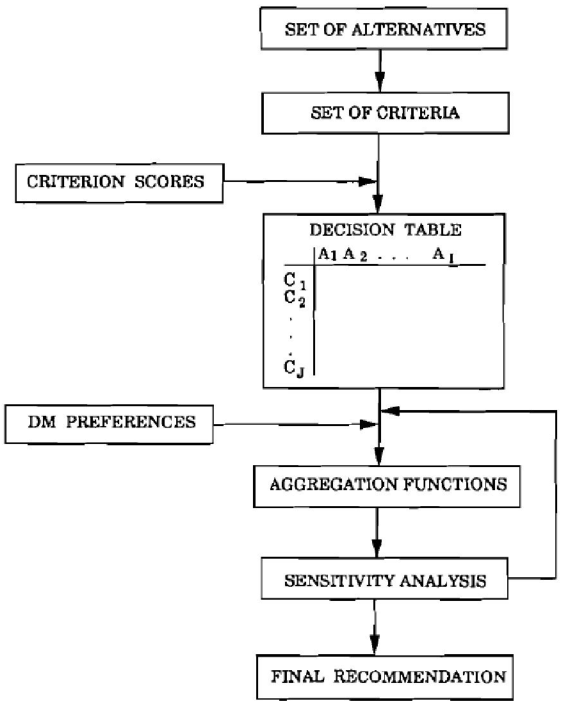
MCDM can be broadly divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM). In MODM, an optimal solution is designed from a set of conflicting objectives [39]. In contrast, MADM deals with the problem of selecting an alternative from a set of alternatives which are characterised by their attributes [40]. All MADM problems have the following characteristics [39]

- Alternatives – a finite set of alternatives
- Multiple attributes – also referred to as goals or criteria, define the problem. Each problem can have several attributes.
- Incommensurable units – each attribute might have its own unit of measure
- Attribute weights – define the relative importance of each attribute
- Decision matrix – a matrix (Table 6) with columns indicating attributes and rows indicating alternatives. Each element in the matrix $a_{ij}$ represents the performance rating of the $i^{th}$ alternative with respect to the $j^{th}$ attribute

Table 6: Decision matrix

| Criteria | c1 | c2 | c3 | … | cn |
|---|---|---|---|---|---|
| Weight | w1 | w2 | w3 | … | wn |
| Alternative | | | | | |
| A1 | a11 | a12 | a13 | … | a1n |
| A2 | a21 | a22 | a23 | … | a2n |
| A3 | a31 | a32 | a33 | … | a3n |
| . | . | . | . | … | . |
| . | . | . | . | … | . |
| . | . | . | . | … | . |
| Am | am1 | am2 | am3 | … | amn |

Figure 5: Multi attribute decision making




Source: [41]

A general form of MADM is shown in Figure 5. The decision matrix (Table 6) is a crucial part of the decision making process. It is clear from Figure 5 that the analysis and recommendation is entirely based on the decision matrix.

Since most planning decisions are spatial in nature, Geographic Information Systems (GIS) are an option for use in analysis. GIS is a technology which enables the automation, analysis and management of spatial data. Cowen defined GIS as a decision support system involving the integration of spatially referenced data in a problem solving environment [42]. Thus the ultimate goal of GIS is to provide decision support based on spatial data.

It has already been defined that decision making involves the selection of an optimal solution from a set of alternatives and decision criteria. GIS can help in the determining the set of alternatives and decision criteria. The integrated approach of GIS and MADM methods is generally classified as spatial multi criteria evaluation (SMCE).

Most spatial decisions deal with locations. Two types of questions that can arise when dealing with locations or spatial decisions [43],

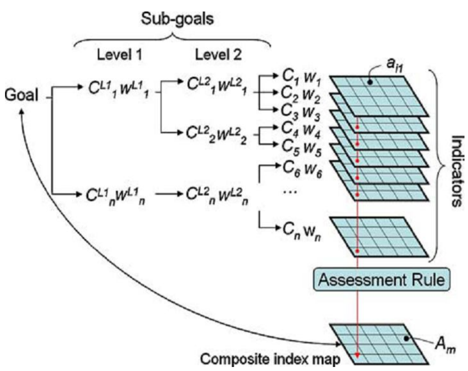
- Given an activity, what site (location) is best?
- Given a site (location) what activities can take place?

The first question identifies the best location for a known activity, and the second identifies the possible activities in a given site. Both of these questions have a spatial component and conflicting objectives in terms of different locations or different types of objectives. Thus spatial multi-criteria evaluation (SMCE) is an ideal method for analysis for these questions. SMCE is nothing but a MCA with an explicit spatial component.

**SMCE model and analysis**

The figure below shows the stages in spatial multi criteria analysis. The main objective of the study is divided into sub objectives which are further divided into criteria and indicators that measure these criteria. Finally weights are identified for each of these indicators and based on these weights and indicators values, a final composite value is determined which is used to analyse the goal.

Figure 6: General form of a SMCE model




Source: [44]

## 3.5.Case studies

Discussions about TOD in the previous sections have been completely theoretical in nature. In order to understand the concept better and to determine possible barriers and successful elements, two case studies are presented in this section. Since the focus of the research is a developing country (India), the case studies selected are also from similar context (Brazil and Colombia).

### 3.5.1. Curitiba

Curitiba is one of the fastest growing cities in Brazil. Despite the rapid urbanization, it is internationally recognized as an environment friendly city. Innovative transit systems, preservation of cultural heritage, increase in number of open spaces and green parks etc. have all contributed to a substantial increase in quality of living [45].

One of the key concepts of urban planning in Curitiba was a shift from radial concentric growth to a linear growth pattern. The plan sought to decongest the inner city by reducing employment density and promoting development along the structured axis: north south direction. This plan allowed for subsequent expansion of transit and structural axes. Land use planning in the city encourages mixed use and higher density development along the structural axes. In plots situated close to the structural axes volume of construction 6 times the size of plot is allowed (FAR[3] = 6). As the distance from the structural axis decreases, the value of FAR decreases contributing to a mix of high density high-rise and low density low-rise buildings. The state also acquired land in close proximity to the

[3] FAR or Floor area ratio is the same as FSI (floor space index).

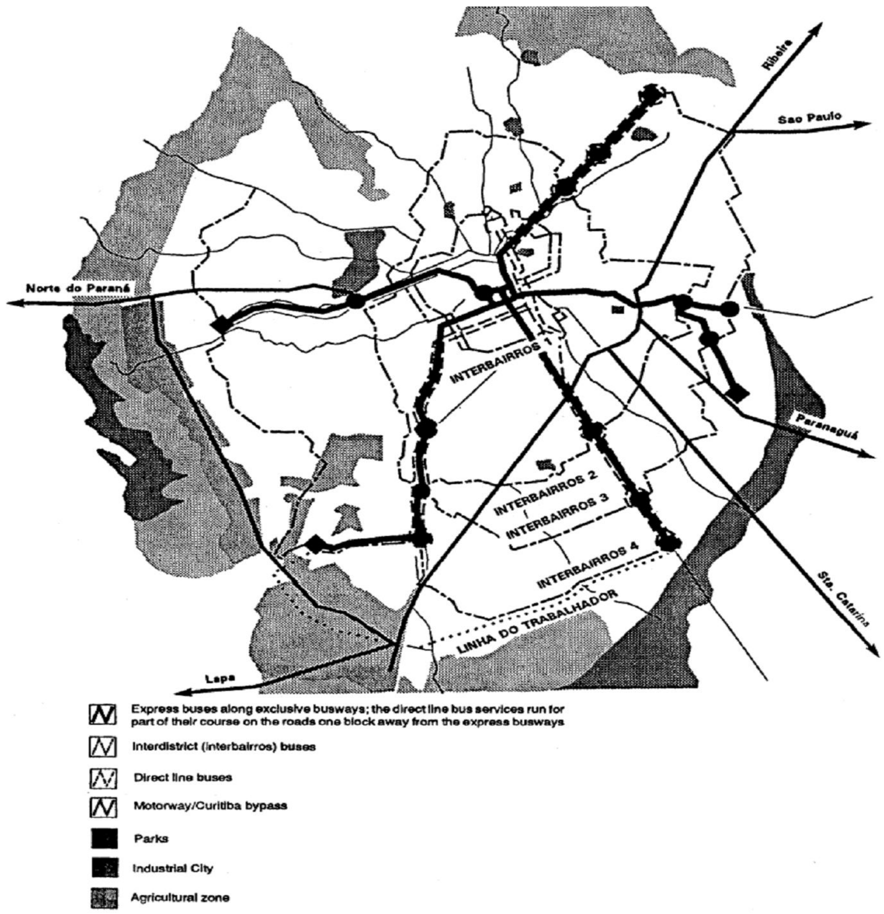
transit axes prior to their construction. This land was used to create housing for lower-income households which ensured social equity [46].

The structure of the road network and transit system is another reason for the success of the Curitiba model. Four types of roads form the skeletal structure of road network (): Structural axes, priority links that links traffic to the structural axes, collector streets that have commercial activity with all types of traffic and the connector roads, which link the structural axes to the industrial city. One of the key elements of the transit system is the ease of transfer between local and express buses. Integration of local, district and express buses, terminals on express lanes to allow transfers between the fast and slow transit, and a single fare for all buses are some of the reasons for the ease of transfer.

The highlights of the Curitiba model are

- An integrated approach to urban transportation
- Zoning policies to promote development along transit corridors
- A clear hierarchy of road network
- Good modal connections between different bus systems
- Land use planning to focus on pedestrians
- Affordable housing

Figure 7: Integrated transport network in Curitiba




Source: [45]

### 3.5.2. Bogotá

Another successful example of an integrated land use and public transport system is the Transmilenio in Bogotá, Columbia. Whereas Curitiba is a medium sized city, Bogotá is a large metropolis with a population of over 7 million people. The Transmilenio system is similar to the Curitiba model in that there are exclusive bus lanes and express as well as normal buses. Accessibility to the transit system is improved by an extensive bicycle network, focus on pedestrianism and good integration between express and feeder buses. The fare is standard for any trip on the transit system and it is free to travel in the feeder buses. The difference is that in Bogotá the transit system is fit to the existing development whereas in Curitiba development was remodeled along the transit axes. This is one of the main criticisms of Transmilenio; it consolidates existing land use patterns and development, with all its associated problems. But, otherwise the model is successful in terms of economic returns, social equity, increasing mobility of the population and meeting transport demands.

### 3.5.3. Reflection

Bogota and Curitiba are two of the more successful implementation of BRT systems. The success element of Bogota is in the focus of pedestrian and bicycle as access mode to the BRT. But in Bogota, changes were not made to the cityscape unlike Curitiba. In Curitiba a transit first policy is aggressively pursued by focusing development along the transit axes. Thus Bogota focuses on the access to the BRT and Curitiba focuses on the accessibility. Both projects are land use and transport strategies which promote public transit use, thus in principle they are both TOD.

## 3.6.Conclusions

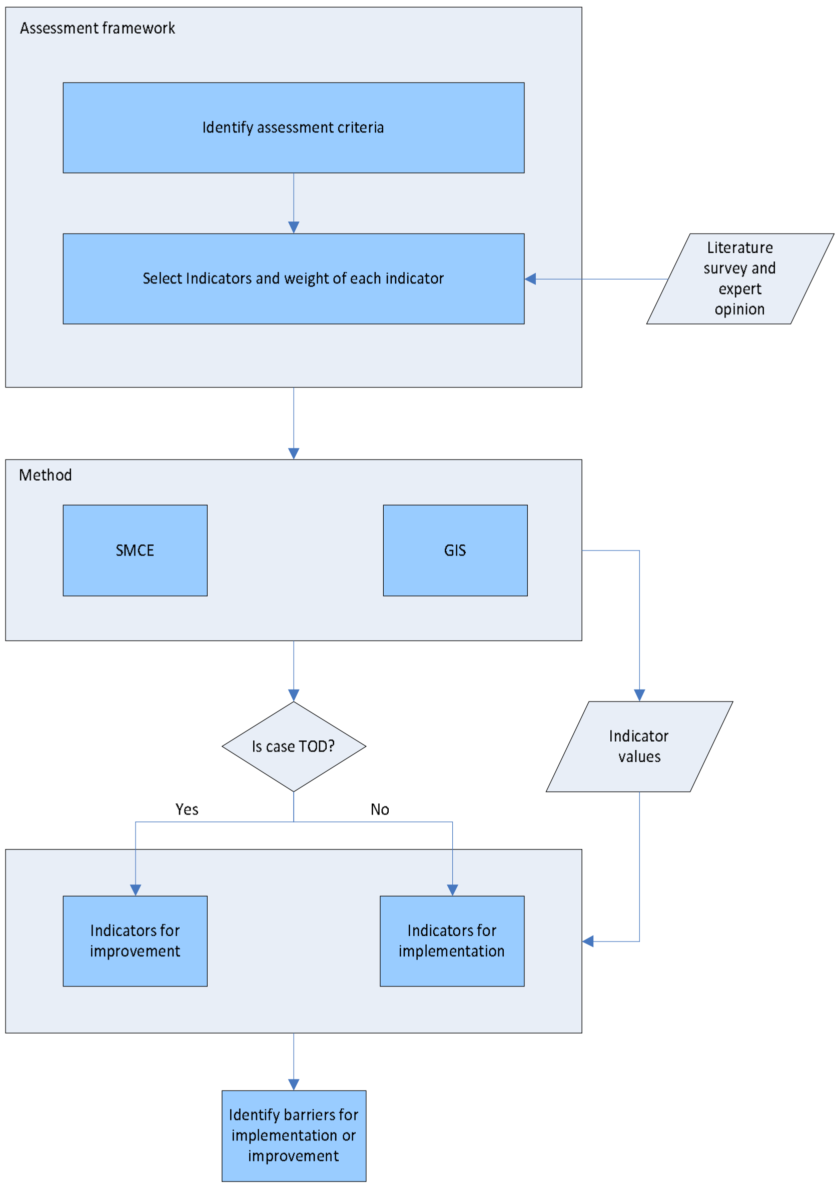
There have been many instances of using transit investment as a driver in urban development. One such strategy is transit oriented development (TOD). TOD is the name used for cases where transit investment and land use planning have been integrated to promote transit ridership. The only goal of TOD is not transit ridership; reduction in vehicle miles travelled (by promoting walking, biking and transit), improve accessibility (more activities close to transit) etc are also possible by TOD investment. Whereas there are many definitions of TOD, the essence is the same *integration of transit and land use planning.*

In literature methods such as a land use design problem, it is measured using regression analysis, using a “TOD index” etc. has been used to measure the success of TOD. The objective of the current research is not to measure the success of TOD but to evaluate the urban development around the BRT in Ahmedabad. Hence, multi criteria decision analysis is used as the research method. MCDA is multi-disciplinary, is amenable to quantitative as well as qualitative indicators. Also by the process of sensitivity analysis, biases can be removed

# 4. Research framework

So far we have established that TOD can be a strategy for achieving sustainable development. Also, in the literature review it has been established that SMCE is the ideal method for achieving the objectives of the current project. The different stages in answering the four research objectives of the study (Chapter 3) are shown in Figure 8.

Figure 8: Research framework




In this research framework it is assumed that TOD goals lead to sustainable urban development; the justification for this is provided in the section on literature review (Section 3). Knowing that TOD can promote SUD, the next question to answer is whether Ahmedabad is a TOD; if yes can it be improved to be more sustainable and if not, can it be made into a TOD. In order to assess the study area, a framework for assessment needs to be defined. This framework is heavily linked to the method of evaluation. For the study, spatial multi criteria evaluation (SMCE) is used as the research method. In the next section the different criteria for evaluation based on the goals of sustainable urban development are defined. These criteria are then used to define the indicators for measurement. The indicators chosen are based on a western perspective. Hence there is a need to verify if the same indicators are suitable in an Indian context. An expert survey/discussion will be conducted for determining the suitable indicators and they will be asked to rank the indicators based on importance. This ranking will be used to assign weights to the different indicators. Since the institutes selected represent academics, planners, civil engineers and policy makers, it is assumed that different stakeholder opinions will be covered.

## 4.1. Assessment framework

The indicators that are shown in Table 7 are based on the three goals of sustainable development and ways of achieving them by TOD. Threshold values are included in the table for some of the indicators. These values are based on mainly American studies and hence might not reflect perfectly with the local situation. In the expert discussion (and/or mailing), the values for each of the indicators will be identified.

Table 7: Pre-selected list of indicators

| Goal(s) | Criteria | Purpose | Indicators | Threshold |
|---|---|---|---|---|
| Economy | Increased proximity to transit stations | Proximity of jobs and housing to transit stations increases transit ridership. | Number of Jobs | 100 employees/acre [47] |
| | | | Number of housing apartments | 15 dwelling units/ acre [48] |
| Economy/Social | Availability of high quality transit services | Presence of high quality transit services reduces trip times and hence increase transit ridership | Number of high quality transit services available | |
| | | | Integration between services by timetable and physically | Qualitative measure |

| Goal(s) | Criteria | Purpose | Indicators | Threshold |
|---|---|---|---|---|
| Social | Affordable housing/ transport for people at different income levels | By providing housing for people of all social structures, the economically weaker sections are not pushed away from transit vicinity. Similarly the transport options and cost. | % of household budget for housing | (expert opinion) |
| | | | % of household budget for transport | (expert opinion) |
| Social/Environ mental | Traffic calming measures to limit vehicle speeds and improve safety | Traffic calming measures to limit vehicle speeds in these centres increases the safety of pedestrians and cyclists, thereby increasing their modal split. | Number of traffic calming features | |
| | | | Street connectivity | The number of roadway links divided by the number of nodes. A minimum of 1.4 is necessary for good connectivity [49] |
| | | | Vehicle speeds | |
| Social | Improve the Safety and security at station areas | Providing sufficient lighting, safe parking facilities for bikes etc at station areas increases the approachability of these areas. | Lighting at stations | Qualitative |
| | | | Quality of parking facilities at station | Qualitative |
| | | | Public perception of safety | Qualitative |
| Environment | Design for cycling and walking | Urban design which encourages walking and cycling helps in reducing | Bicycle lanes | Bicycle lanes on main approach roads |

| Goal(s) | Criteria | Purpose | Indicators | Threshold |
|---|---|---|---|---|
| | | emissions and improving the liveability | Bicycle parking facilities | Yes or No |
| | | | Ped shed | Percentage of pedestrian walkways compared to road stretches |
| Social/Environmental/Economic | Mixture of commercial/ recreational and residential or business | Good mixture of different land uses encourages trip chaining and the reduction in need to use the private vehicle esp. along with design for walking and biking | Entropy Index | Entropy Index [47]<br>0 – similar<br>1 – completely dissimilar |
| | | | Suitability Index of retail services | |
| | | | Number of parks and other recreation centres | |
| Environmental | Parking management | Parking management to limit the number of private vehicles reduces VMT and hence improves the environment | Number of parking slots<br>• Residents<br>• employees | |
| | | | Availability of on-street parking in near vicinity of BRT corridor | |

## 4.2.Research method

In this section the methods used to answer the different sub objectives of the study are discussed.

### 4.2.1. Objective 1

The first objective is a proof of the underlying assumption, i.e. TOD is a possible strategy to achieve sustainable urban development. This objective is achieved by literature review (Section 3)

### 4.2.2. Objective 2

This study uses SMCE and GIS to develop a model using indices based on the criteria and indicators.

Table 7 lists a pre selection of indicators and different criteria for the SMCE model. The list might be incomplete and in order to complete it, an expert opinion survey will be conducted.

Most of the indicators that have been pre-selected are spatial in nature and are easily implemented using the SMCE tool, ILWIS 3.3. The inputs for the tool are raster maps of the study area (criteria data), the constraints are the different weights of the criteria and output is a map containing the extent to which the criteria are met. Most of the data for assessment are spatial in nature and can be easily input into it. The tool also provides provision for inputting non spatial data as criteria.

The suitability analysis option in the SMCE tool will be used to design the model. Once the model is setup, data can be input to determine the type of development that exists in Ahmedabad. To setup the model, the indicators are first classified as benefits, costs and constraints of TOD. Benefits contribute positively to the index whereas costs contribute negatively. Poor performance of one factor (either benefit or cost) can be overcome by good performance of another factor. On the other hand, a constraint is an absolute necessity for the analysis; poor performance cannot be offset by another constraint. Hence in the model to distinguish the study from a Transit focussed development, the distinguishing factors (determined by literature survey) will be specified as constraints.

### 4.2.3. Objective 3

The next step is to determine the type of interventions necessary in Ahmedabad. The intervention can be in the form of land use restructuring (residential, commercial, employment development) or planning intervention (urban design features) or policy interventions (zoning and parking) etc. The interventions are determined by the deficient criteria determined in the previous step. For each deficient criterion, the indicators that need to be improved are identified.

A sensitivity analysis on the SMCE model can help in identifying the possible interventions. Sensitivity analysis can be performed by either focusing on the goals (adding /deleting), or criteria (adding/deleting/rescaling etc) [50]. The sensitivity analysis will be conducted using the SMCE tool. The suitability of the study area in the previous step will be somewhere between 0 (not suitable) to 1 (suitable). The selected indicators can be modified to bring the suitability closer to 1.

### 4.2.4. Objective 4

The final step in the project is to identify possible policy and planning barriers and solutions to overcome them. Based on the changes that have already been identified by sensitivity analysis, possible barriers and recommendations for overcoming them will be discussed. To comprehensively identify the barriers, a survey on site along with interviews might be essential. Due to constraints of funding and time, the barriers will not be discussed in depth but a more general recommendation will be provided.

# 5. Results and Discussion

In the previous chapters, it has been established that TOD is a strategy for sustainable development (objective 1 of study) and that SMCE is the framework for assessment. A pre selection of indicators has also been made which will be used to develop the final model. This chapter will answer the other objectives of the study (Chapter 3) and provide recommendations for future improvements.

## 5.1.Study area

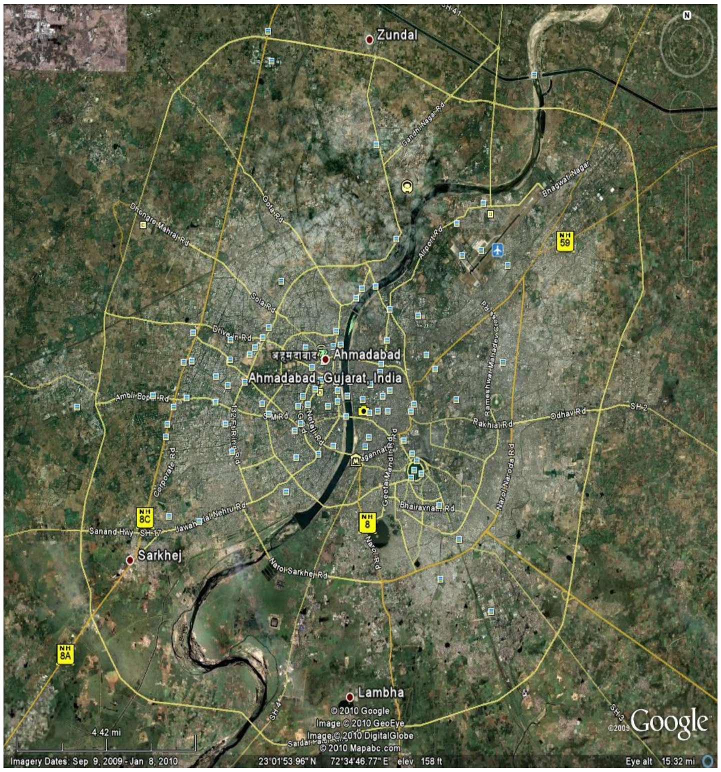
Ahmedabad spread over 440 sq km is the largest city in the state of Gujarat and the seventh largest in India (population of 5.2 million). The former state capital is currently the commercial heart of the state. In addition to being a commercial centre, it is also an industrial centre with chemical and textile industries. In the 20th century it established itself as the textile heartland and was famously known as the "Manchester of India".

Figure 9: Location of Ahmedabad in India


Source: [51]

The city, established around the river Sabarmati is mainly divided into two parts, the old city (east of the river) and the new city (west of the river). While the city has grown rapidly over the years, in comparison to the other cities of similar size in India such as Bangalore, Hyderabad etc, the growth has been more concentrated around the inner city resulting in fewer sprawls [52].

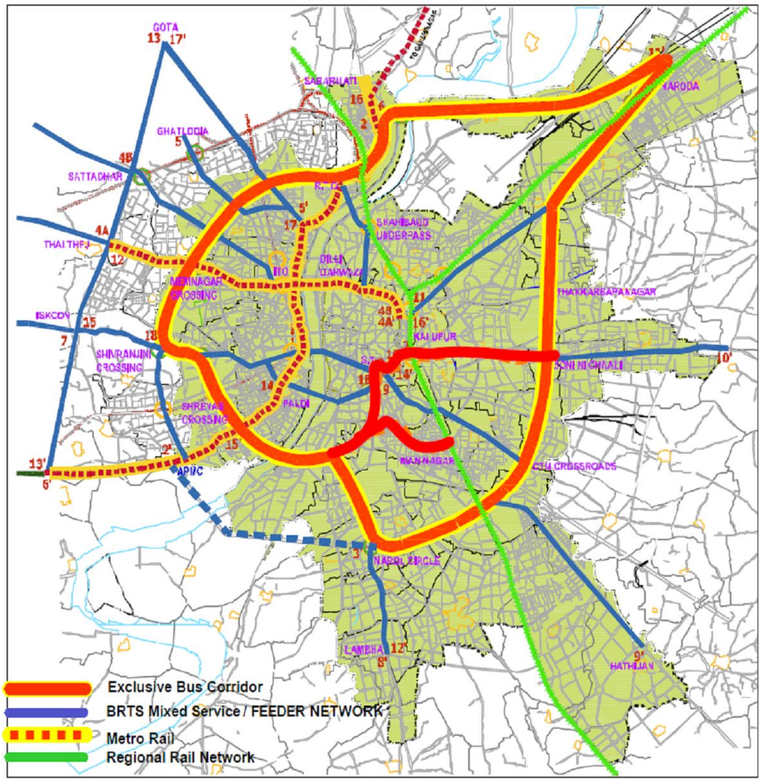
**Figure 10: Ahmedabad city**




Source: Google Images

The growing nature of the city has forced a rethink on the existing transport modes within the city. Recognizing that none of the existing modes truly satisfy the needs of a growing city, the government has taken the initiative to invest in a BRT system (Ahmedabad Bus rapid transport- ART). A total of 155 kilometres have been identified for the ART corridor which will be completed in three phases [53]. Currently a part of the phase-1 of the project has been completed and is in operation.

Figure 11: ART corridor




Source: [53]

## 5.2.Data and tools

The data used in the study are of two types: GIS data and interview data (for the indicator weights). The GIS data used for analysis is entirely secondary data. The secondary data has is part of the Volvo Research and Educational Foundations (VREF) sponsored project at ITC: Land, urban form and the ecological footprint of transport: application of geo-information to measure transport-related urban sustainability in Ahmedabad.

Table 8 shows the different GIS data files used for the study purpose. The data for number of jobs in the Land use shape file has been obtained based on a spatial operation with ArcGIS. The jobs data is available at a TAZ level and a proportion of the number of jobs is assigned to each block in the Land use file. The entire ART phase 1 corridor is not under operation, but since the plan has been approved and construction will be completed sometime in the future, it is taken as the reference for analysis.

Table 8: ArcGIS data

| ArcGIS Shape file | Type | Purpose |
|---|---|---|
| ART phase 1 | polyline | the phase one of the BRT line is used to create the study zone (500m around it) |
| ART phase 1 bus stops | point | this file is used to determine the accessibility to the BRT |
| Ahmedabad roads | polyline | this file is used in accessibility and walkability measurement |
| TAZ layer | polygon | this file has information regarding income groups, trip information and pavement information |
| Land use | polygon | This file has information regarding land use type, population and job information. The polygons are of 100mx100m size |

The tools used in the study include:

- ArcGIS 9.3 – for developing maps to use with ILWIS
- ILWIS 3.6 – for conducting the SMCE analysis
- Excel – for performing actions on dbf files for ArcGIS
- XTools extension for ArcGIS (one month freeware license) – for performing certain calculations on ArcGIS

In order to determine the ranks of the indicators for the SMCE model, a group discussion was conducted. The questionnaire used in the group discussion is provided in the Appendix 1. The group of experts were first asked to fill out the questionnaire and then a group discussion session was conducted to understand the reasoning behind the ranking. The experts[4] involved in the discussion included:

- Mr. Gururaja Budhya, Urban research centre, Bangalore, India
- Dr. Neeraj Mishra, University of Amsterdam, Netherlands
- Dr. Javier Martinez-Martin, ITC, Netherlands
- Mr. Anil Lad, Deputy Commissioner, Kalyan Dombivilli, India
- Mr. P.S. Vastrad, Deputy Commissioner, Hubli-Dharwad, India
- Dr. Ranjit Mitra, School of Planning and Architecture, Delhi, India

[4] The people involved in the project are not from the area of Ahmedabad. Ideally a group of people from the municipality in Ahmedabad would have been interviewed, but due to budget restrictions, they could not be contacted. The people mentioned in the list were in Enschede for a conference on participatory planning at the ITC and hence could be interviewed.

## 5.3. Discussion

### 5.3.1. Indicator analysis

The indicators chosen for the study are listed in Table 9. The indicators shown in the table are based on a literature survey and a pre-selection (

Table 7). Not all of the pre selected indicators have been used in the study (Table 10). Some of the indicators could not be included due to non availability of data and some indicators were used in different forms (based on data availability). This has been indicated in the table.

Higher densities indicate a greater transit ridership and as such density (residential and job) indicators are used as a driver for Transit development. The accessibility indicator using travel times is used to determine the relative ease of using the rapid transit from different parts of the study area. While ordinary travel time is not a very good indicator of accessibility, limitations in terms of availability of data, time and resources have implied that it was used in the current research.

High diversity in land use can promote trip chaining and a sense of community. More commercial and retail outlets within a walking distance from homes would mean that people need not use the private automobile as much. Similarly such activity centres around transit stations can help people to shop on their way back home from work. Two indices are used to measure commercial/retail accessibility; one, the commercial areas within 500m of residential centres and two, the commercial areas within 500m of transit centres.

Dissimilarity index, i.e. the proportion of similar neighbouring grid cells [18] is used as an indicator of the diversity of land uses. In this index, each grid cell is compared to 8 neighbouring cells and a point is awarded to each similar neighbouring cell.

Figure 12: Dissimilarity index

| | | |
|---|---|---|
| C | C | C |
| C | R | R |
| C | C | C |

For example, consider Figure 12; the shaded cell has 8 neighbouring cell. The land use type for the shaded cell is R (residential). In the neighbouring cells there is 1 other R and 7 C (commercial) types. Thus the dissimilarity index for that particular cell is 1/8. In this index, a value of 1 indicates a completely homogenous distribution and a value of 0 indicates completely dissimilar distribution. This index is used as an indicator of heterogeneous land distribution.

The other indicator for diversity used in the study is social diversity. This is defined as the distribution of people by income levels. A good social diversity is essential for a TOD type of development and sustainable development. If for example only low level income groups live within the TOD communities, it would mean that they live in these communities out of necessity rather than choice. For social equity, people from different classes should have the option of making choices. Thus a good social distribution is essential for social equity. In order to measure social distribution, the GINI index is used. The GINI index is a measure of statistical dispersion developed by and named after Italian Corrado Gini. It is commonly used as a measure of inequality of wealth and income. The GINI index varies from 0 and 1 where 0 corresponds to equal distribution and 1 to complete inequality. In the current study, a GINI value of 0 means there are equal proportions of all groups of people and a GINI value of 1 implies that one group completely dominates.

The design set in the SMCE includes indicators to measure the quality of street network, pedestrian network, quality of street lighting, and number of open/green spaces. Intersections play a key role in traffic management. More intersections indicate that there are not many long stretches of roads, which further means that vehicles cannot reach high speeds. Thus higher safety levels can be achieved by having more intersections. The other indicator of street network used in the study is the number of entry points or access points into the neighbourhood. More entry points indicate that the streets are better connected with less cul-de-sacs and dead ends. This also means that pedestrian access and biking accessibility is increased. Similarly, quality of street lighting (km stretch of roads with lighting per acre) encourages pedestrianism by providing a safer environment for walking. Finally, green and open spaces encourage a sense of community and provide opportunities for recreation and social interaction.

**Table 9: Selected indicators**

| **Density** |
|---|
| Density of jobs (#jobs/ acre) |
| Density of population (#people/ acre)<br>Ratio of jobs to population (#jobs/person) |
| Access to BRT (travel time to BRT stops from different parts of study area) |
| **Diversity** |
| Dissimilarity index (number between 0 and 1) |
| Commercial index<br>a. Commercial areas within 5 min walk of residential areas<br>b. Commercial areas within 250m of transit stations |
| Social distribution (GINI value between 0 and 1) |
| **Design** |
| Street network<br>a. Number of intersections<br>b. Grid pattern (number of 4 way intersections/total number of intersections)<br>c. Number of access points |
| Pedestrian network (km of paved roads/ acre) |
| Green/open spaces |

**Table 10: Preselected list of indicators (Background Literature)**

| Indicators | Selected for study (Yes/No) | Reason for not selecting |
|---|---|---|
| Density of jobs (#jobs/ acre) | Yes | |
| Density of population (#people/ acre) | Yes | |
| Accessibility to BRT (travel time to BRT stops from different parts of study area) | Yes | |

| Indicators | Selected for study (Yes/No) | Reason for not selecting |
|---|---|---|
| Integration between services by timetable and physically | No | Data availability |
| % of household budget for housing (Social equity) | No (But used the economic divisions of people) | Used as a different indicator |
| % of household budget for transport (Social equity) | No (But used the economic divisions of people) | Used as a different indicator |
| Number of traffic calming features | No | Data availability |
| Vehicle speeds | No | Data availability |
| Lighting at stations | No | Data availability |
| Quality of parking facilities at station | No | Data availability |
| Public perception of safety | No | Lack of budget to travel to Ahmedabad |
| Bicycle lanes | No | Data availability |
| Bicycle parking facilities | No | Data availability |
| Number of parking slots | No | Data availability |
| Availability of on-street parking in near vicinity of BRT corridor | No | Data availability |
| Commercial/Retail index | Yes | |
| Street network | Yes | |
| Ped Shed | Yes | |
| Number of parks and open spaces | Yes | |

Indicators selected in the study are quantitative in nature and thus each of them can have a value. For ease of evaluation, each indicator is normalized to a value between 0 and 1. The relative importance of these indicators might not be the same in the study area. Thus each indicator is evaluated to determine the importance.

Table 11: Land use distribution

| Land use type | Percentage |
|---|---|
| Industrial | 11.49 |
| Residential | 59.72 |
| Commercial | 12.8 |
| Green | 12.23 |
| Institutional | 3.4 |
| Water bodies | 5.9 |

Source: GIS data

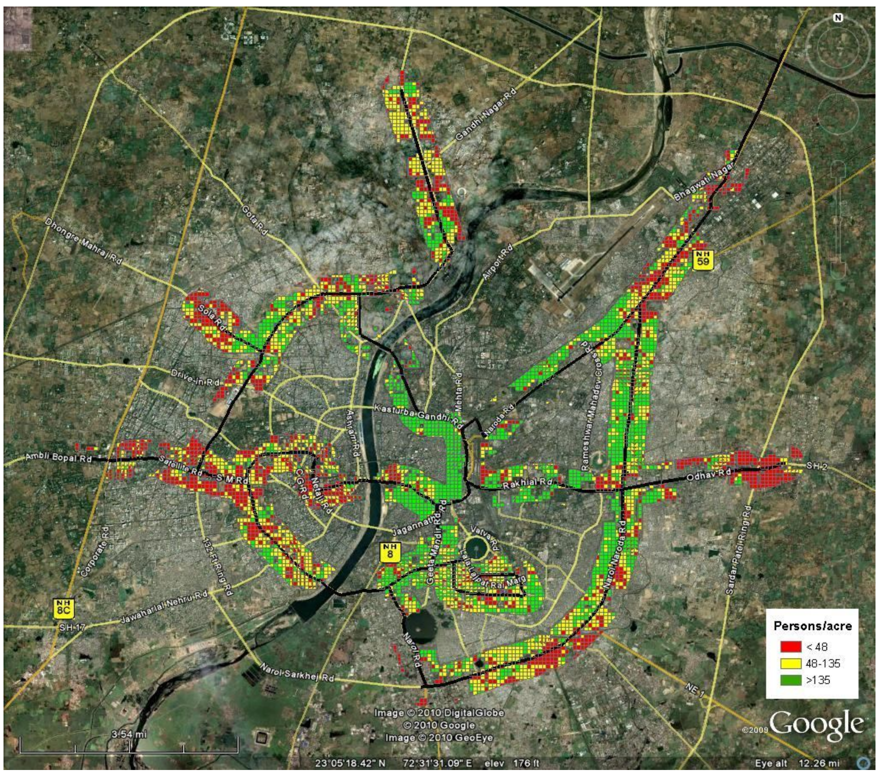
Table 11 shows the existing proportions of different land use types within the study zone). Residential land type dominates the study area by a large proportion. This would mean that there is greater possibility for planning a residential type of TOD.

In order to understand the study area and the influence each indicator has on it, the following sections discuss the indicators individually.

### 5.3.1.1. Population density

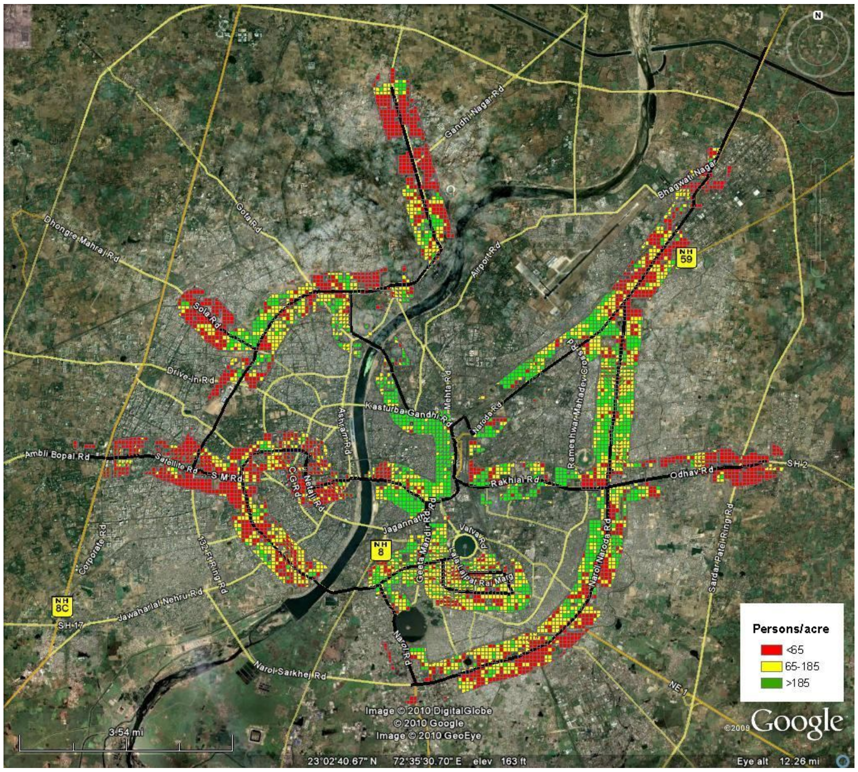
Does population density have an influence on TOD type of development? In America, with a suburban style of development or elsewhere with lower densities within cities, increase in population density can play an important role in increasing transit ridership. But traditionally, Indian cities are already high density areas. Hence design considerations with respect to density might not be the same in India and the US. For example, according to [54], a minimum of 12 dwelling units/ acre is necessary for rapid transit. Considering on average a 4 person household, this would be 48 persons/ acre. The Florida department of transport (FDOT) developed a TOD guideline [55] where they recommend 135 persons/ acre as ideal in an urban core region and a value between 100-145 persons/ acre for general urban regions. Figure 13 shows the map of the study area developed using these cut off values (48 and 135). From the figure it can be seen that most of the region is above the lower cut off. Hence the minimum requirement for rapid transit is already satisfied

**Figure 13: Population density by American cutoff values**



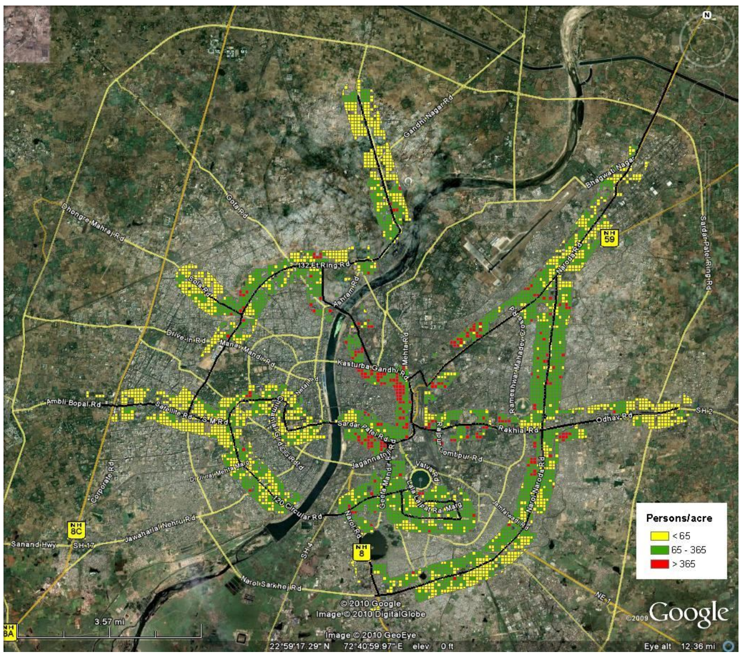

In the study area the mean population density is 125 persons/ acre. This is well within the range recommended by [55]. Also, the standard deviation is 120 persons/ acre. Assuming normal distribution and considering half a standard deviation as the standard error, the cut-offs would be 65 and 185. In other words, we would expect most of the region to be between these two cut-off values. Figure 14 shows a map drawn with these cut off values. In the figure it can be seen that there are more regions of low and high density (red and green regions). This indicates that there are some very high density regions that contribute to the mean.

**Figure 14: Population density by standard error**



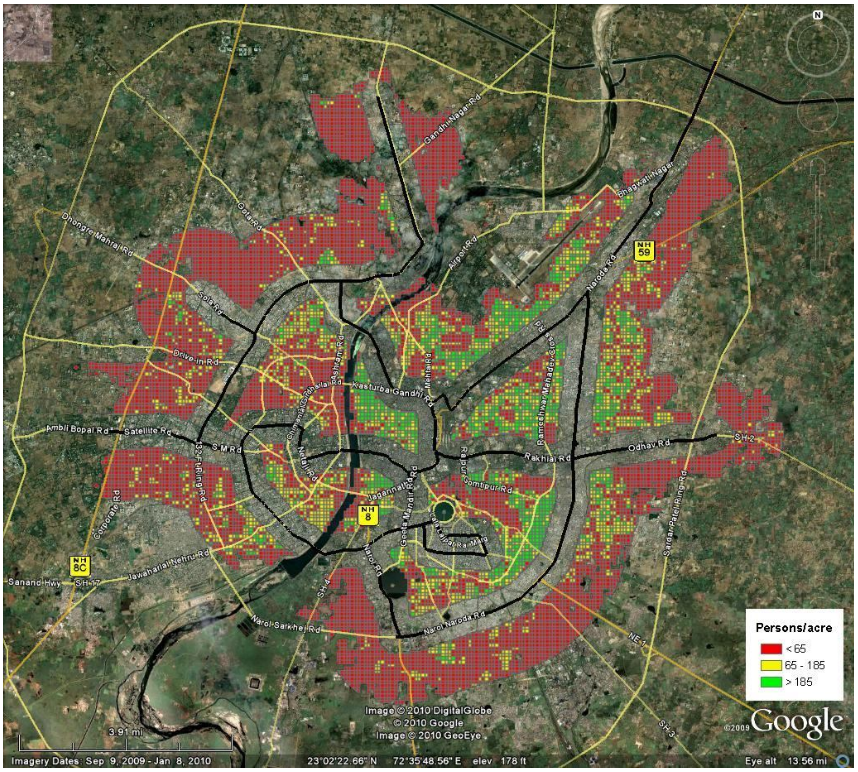
In India there is a high possibility that the regions of very high density are slum type of development. In order to investigate this, a map with the upper cut-off of twice the standard deviation from the mean was developed (Figure 14). In this map, values between 65 and 355 are considered has a green value (or a “good” value). This type of classification is interesting because a very high density can indicate a low standard of living, which is a deterrent for residents. While density is being investigated here, a better indicator for living comfort would be to use the floor to space index (FSI). Since the data for FSI is unavailable, this indicator is not being considered in the research, and is only provided as a note.

**Figure 15: Population density with "good density" values**




The study boundary of 500m has been chosen similar to a study conducted by CEPT institute. Would choosing another boundary change anything? Considering 2km as the study boundary and using the same thresholds (65 and 185), a population density map was constructed (Figure 16). In the map, a great portion (around 60%) of the region is below 65 persons/ acre or low density. This would mean that as the distance from the BRT corridor increases, the density drops. Hence a study boundary of 500 meters is a better consideration for TOD development.

**Figure 16: Population density (#persons/acre) 2 km boundary**




### 5.3.1.2. Job density

The other density factor that influences transit ridership is job or employment density. According to the TCRP 102 [20], increasing densities from 5 jobs/acre to 60jobs/ acre increases the rail-commuting share by 52.1%. Ewing suggests for pedestrian and transit-friendly design, 25 jobs/acre for frequent, high quality transit and at least 50 jobs/ acre for light rail transit [56]. A job density map (Figure 17) for the study area was developed considering that the same thresholds hold good for BRT as well. It can be seen that the majority of the region is below the lower cut-off. But most of these regions are either completely residential or completely green (parks, water bodies etc). On excluding them we obtain Figure 18; we still see some low density regions, but it is greatly reduced.

Figure 17: Employment density

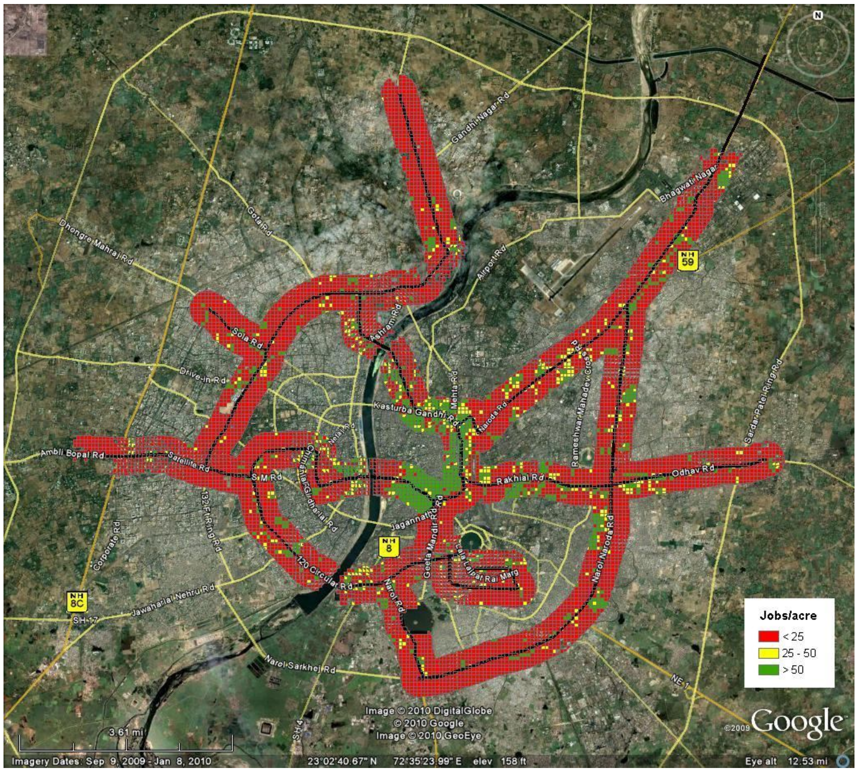
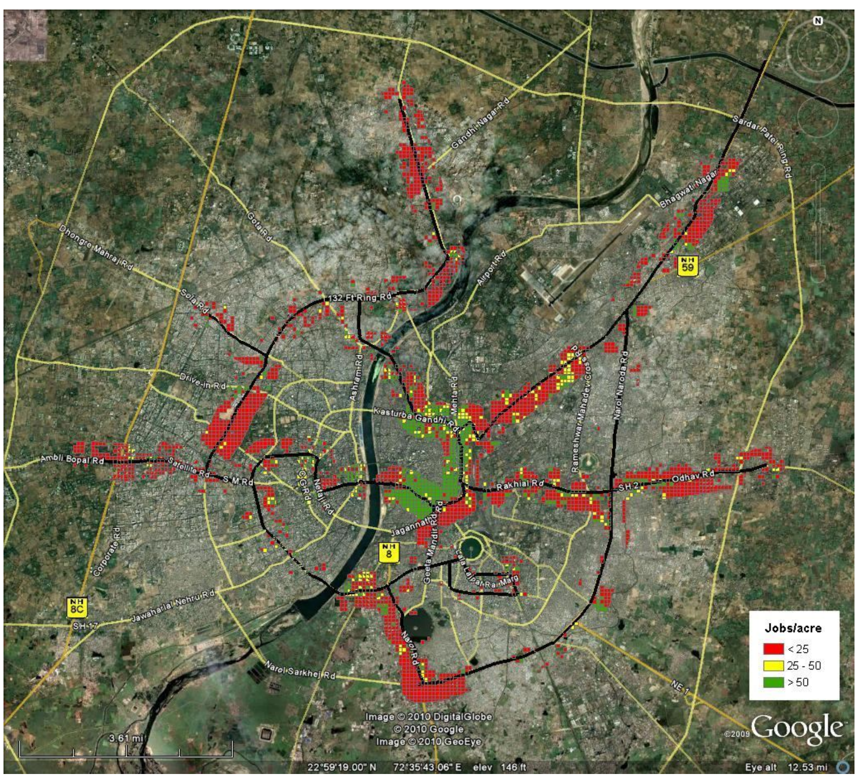
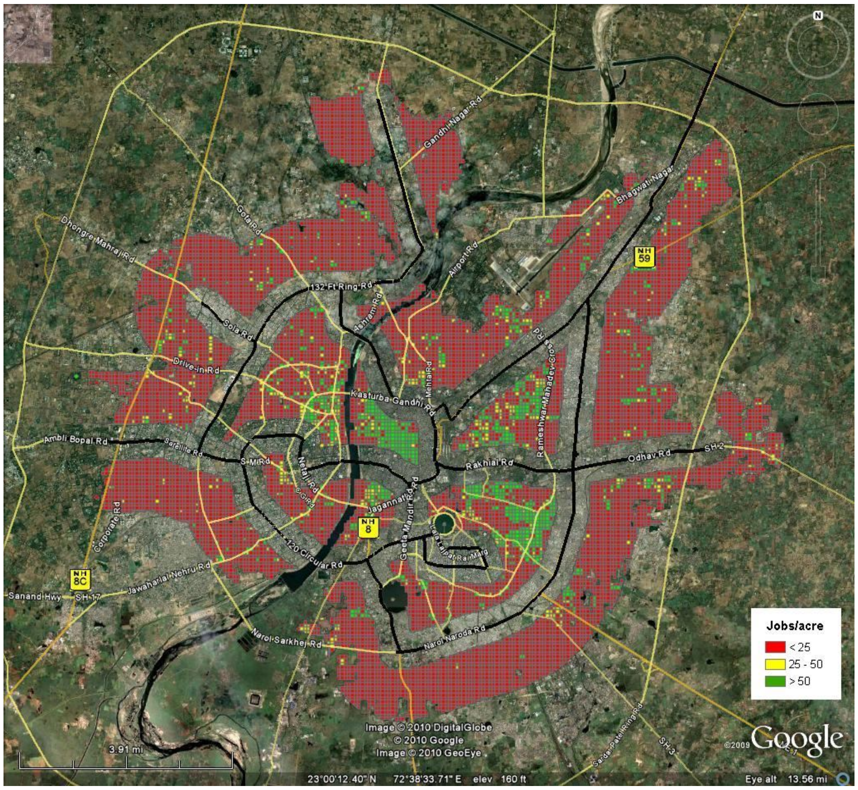



Figure 18: Employment density excluding single use residential and green areas



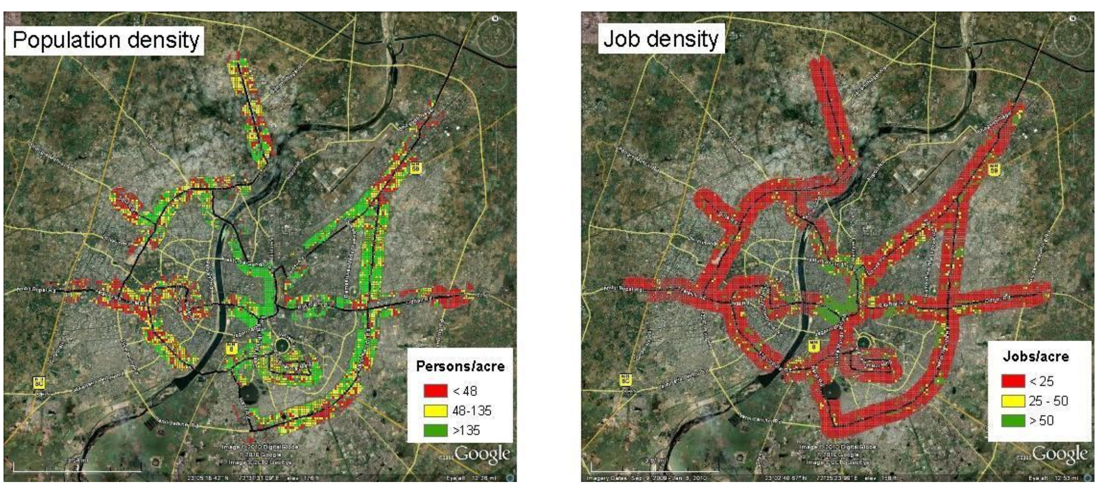
The same cut-offs were considered for a 2 km boundary instead of the 500 meters one. Figure 19 shows that there is not much change in terms of employment density, the majority of the region is below the 25 jobs/acre cut off.

**Figure 19: Employment density 2 km radius**



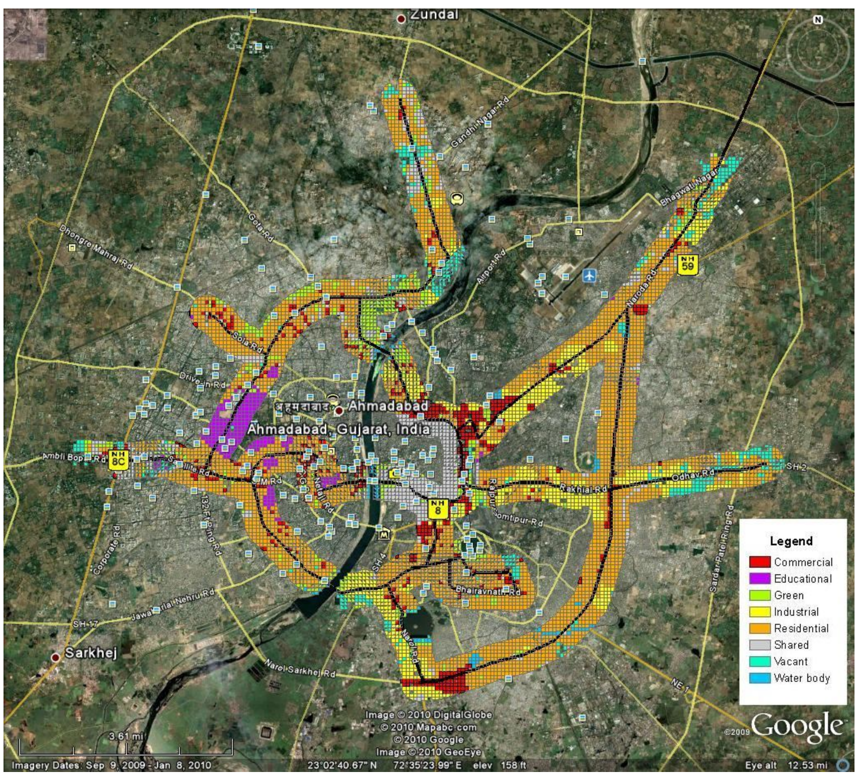

Considering the high density in the study area, it would be logical to assume that the job densities would be high as well. The fact that the majority of the region is in the low job density zone is an anomaly. The two densities are compared in Figure 20.

**Figure 20: Comparison job to population density**



One of the reasons for this could be the quality of data. The data for population has been collected for each of these blocks, whereas the data for jobs has not been. The number of jobs field in the data source has decimals which indicate that the value has been calculated based on some mathematical operation. The other reason for this anomaly could be the collection of job information. There is a chance that not all types of jobs have been registered during the data collection phase. The definition of job could be one that occurs only in services/industry. This might have removed the jobs at the commercial centres and at residential places. The other definition could be the number of hours worked per week. Many day workers in India do not fall under the income tax category and are hence do not pay taxes. Their work might not have been registered as jobs. According to the opinion of a few local experts, the region has a good job to work balance and people who live in these regions usually work there. We see in Figure 21 that the study zone is predominantly a single use residential zone. From this we could conclude that people live in this region and move to work in zones just beyond the 500m area. But from Figure 19 we see that even this is not true; the predominant portion of the region until 2km is red. From this it is apparent that there is a problem with either the definition of job or the quality of data. This is a limitation which cannot be improved upon in the given time frame of the research but is a potential area for improvement.

Figure 21: Land distribution




#### 5.3.1.3. Job/housing balance

Good jobs-housing balance can have multiple benefits including [57] –

- Reduced driving and congestion

- Reduced air pollution emissions
- Economic and fiscal benefits
- Quality of life benefits

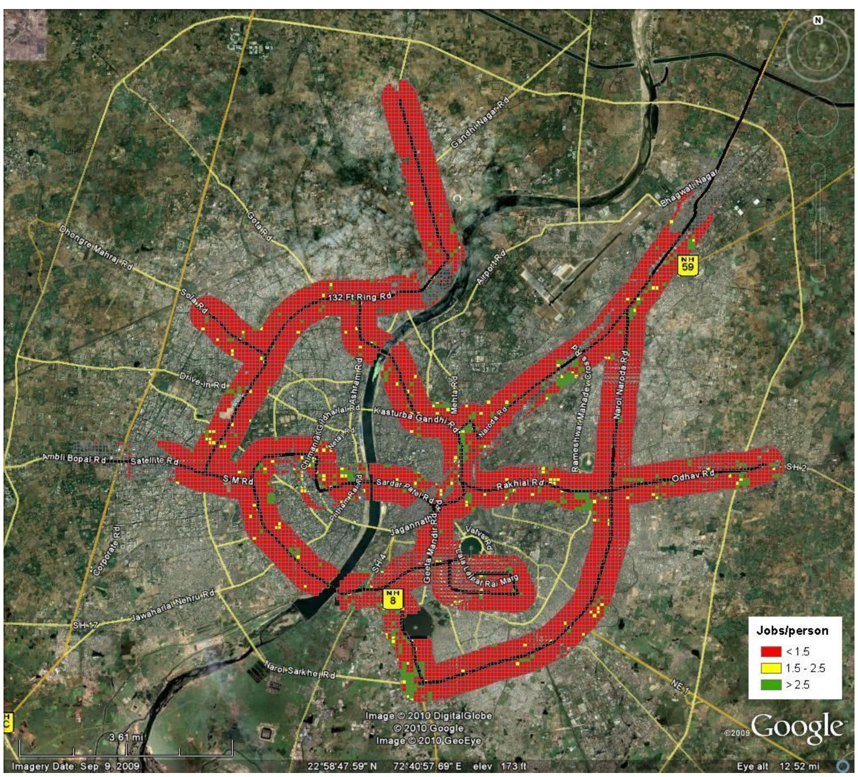
Job-housing balance can be measured quantitatively in three ways [58],

- Jobs to household units' ratio (jobs/resident),
- Jobs to housing unit ratio (jobs/dwelling unit) or
- Jobs to employed resident ratio.

In the current study, the first of these indicators is used as the quantitative measure for jobs/housing balance.

According to the FDOT [55], a jobs-housing ratio of 10 jobs per dwelling unit, is recommended for an urban core or 5 jobs/ dwelling unit in other urban areas. Considering a dwelling unit to house 4 people, the ratios become 2.5 and 1.5. Using these values as cut-offs, the map of the study area was developed (Figure 22). Most of the study region has a ratio below 1.5, which suggests poor jobs to housing balance.

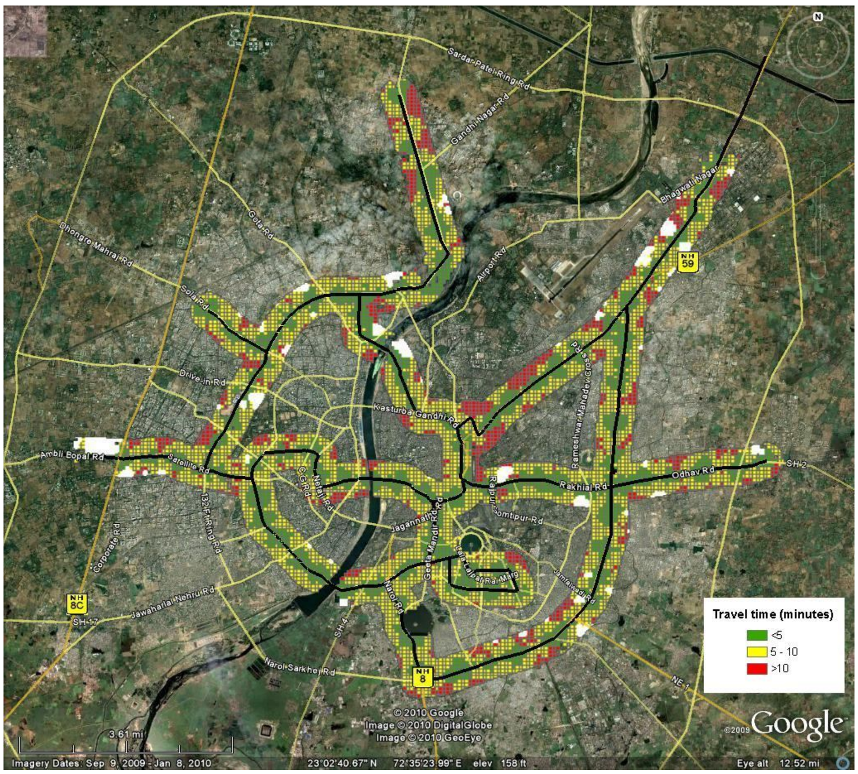
Figure 22: jobs to housing balance (# jobs per person)



#### 5.3.1.4. Access index

The transit industry standard is to have a transit boarding option within 5 minute walk. This standard has also been proved by research [59]. A similar cut-off of 5 minute and 10 minute is used in the study. Using an average walking speed of 4.8 kmph, the travel times from each block is estimated to the nearest BRTS bus stop. This is shown in Figure 23. It can be seen that even in a 500m radius, quite a lot of regions are outside the 5 minute zone. The travel time is calculated based on network distance and not the Euclidian distance.

Figure 23: Access Index




#### 5.3.1.5. Dissimilarity Index

In addition to density, diversity also plays a critical role in TOD. Mixed land use has many benefits such as –

- Reducing distances that need to be travelled for activities and hence promoting walking and biking [16],
- Mixed use development increases the mode share of transit [60], and
- Efficient use of infrastructure (shared parking, distribution of trips during different parts of the day, etc) [60]

In this study the degree of land use mix is estimated in terms of the dissimilarity index, accessibility of commercial centres, and social dispersion (mix of residents by income levels). Dissimilarity index is calculated by estimating the number of different land use types around each land grid. Figure 24 shows the dissimilarity index for the study area. It can be seen that the region has a more or less good mixture of land uses.

Figure 24: Dissimilarity Index

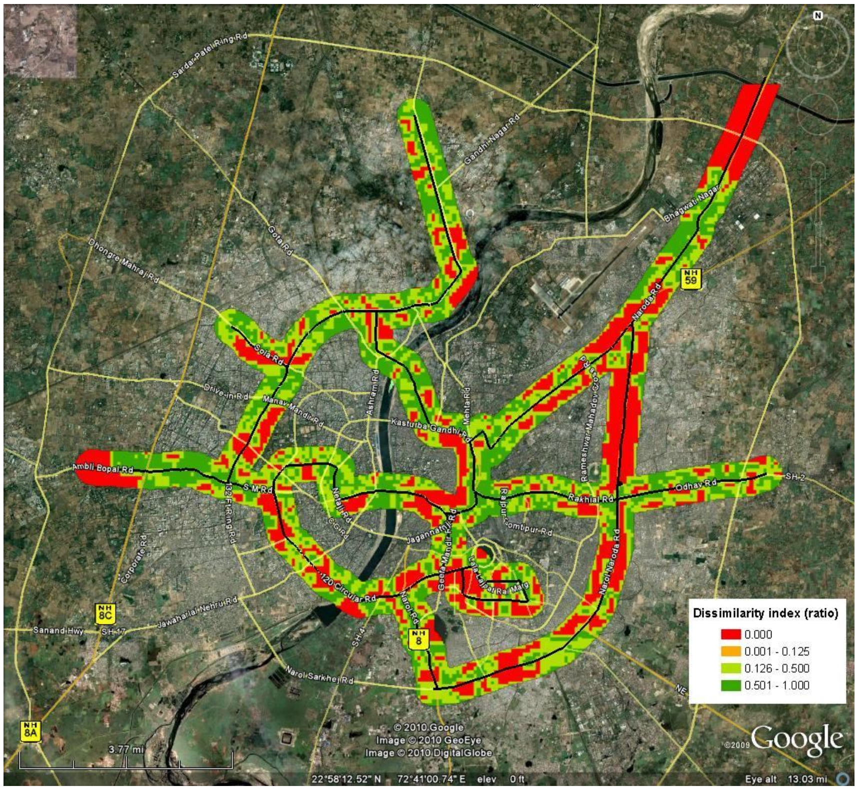



Table 12 shows the different land use and their distribution in the study area. The table also includes the desired land use distribution for an urban TOD according to Calthorpe [61]. Considering this as a standard, the study region satisfies 2 out of 3 thresholds. Thus the only change required would be to increase the job/commercial land use.

Table 12: Land use in study area

| Land use type | % study area | % Calthorpe |
|---|---|---|
| **Residential** | 59.13 | 20-60 |
| **Core/Employment** | | 30-70 |
| Commercial | 11.08 | |
| Industrial | 11.99 | |
| Educational | 3.53 | |
| **Public** | | 5-15 |
| Green space | 10.42 | |
| Water bodies | 3.83 | |

#### 5.3.1.6. Commercial Index

The idea behind increasing the diversity of land use is to promote shorter non-work trips. When the distance is sufficiently small, people are more likely to use alternate modes of travel (walk or bike). Commercial centres close to residential localities serve this purpose by not only reducing the trip distance but also allowing for the trips to be made in off-peak periods. Figure 25 shows the accessibility of commercial centres from residential areas. Here accessibility is measured in terms of (network) distance to destination. It can be seen from the figure that a large proportion of the study area has a good *'commercial accessibility'.* Similarly, allowing for commercial type of development around station areas can promote people to combine trips (trip chaining). They might be willing to take the bus to work and on their way back shop at the station area shops. Figure 26 shows the accessibility of these station areas. In the case of station areas, a distance greater than 250m has a greater cost than for the residential areas. This is because residences serve as activity centres where as station areas are only transfer points for a trip.

It can be visually concluded from Figure 24, Figure 25 and Figure 26 that regions with a more or less homogenous land mix have low commercial accessibility. Hence redeveloping these (station) areas to increase the commercial index will also improve land use diversity.

**Figure 25: Commercial accessibility (Residence)**

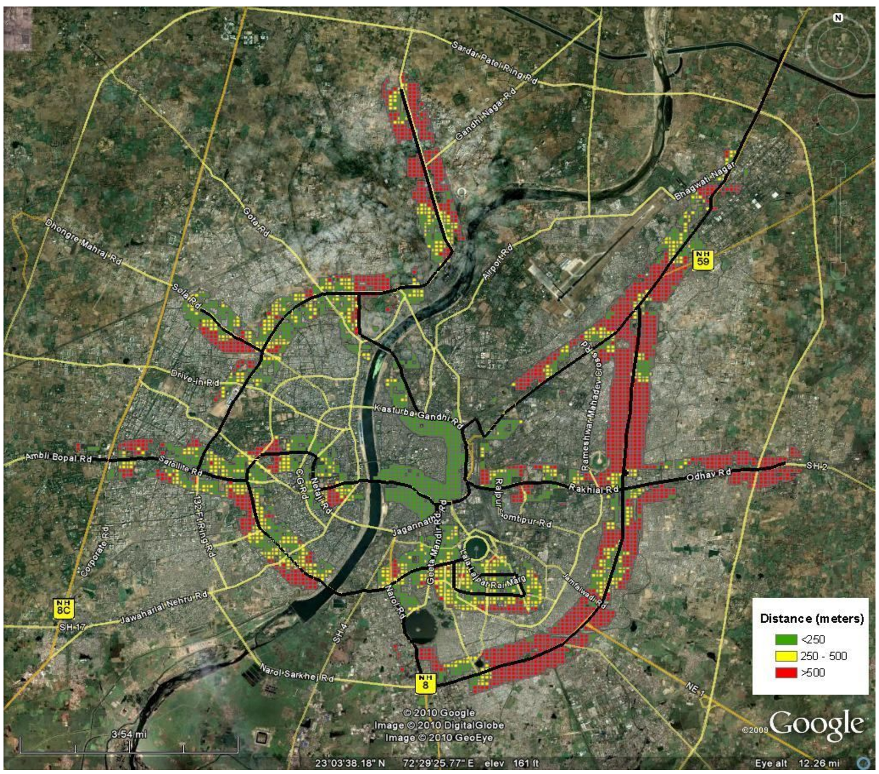
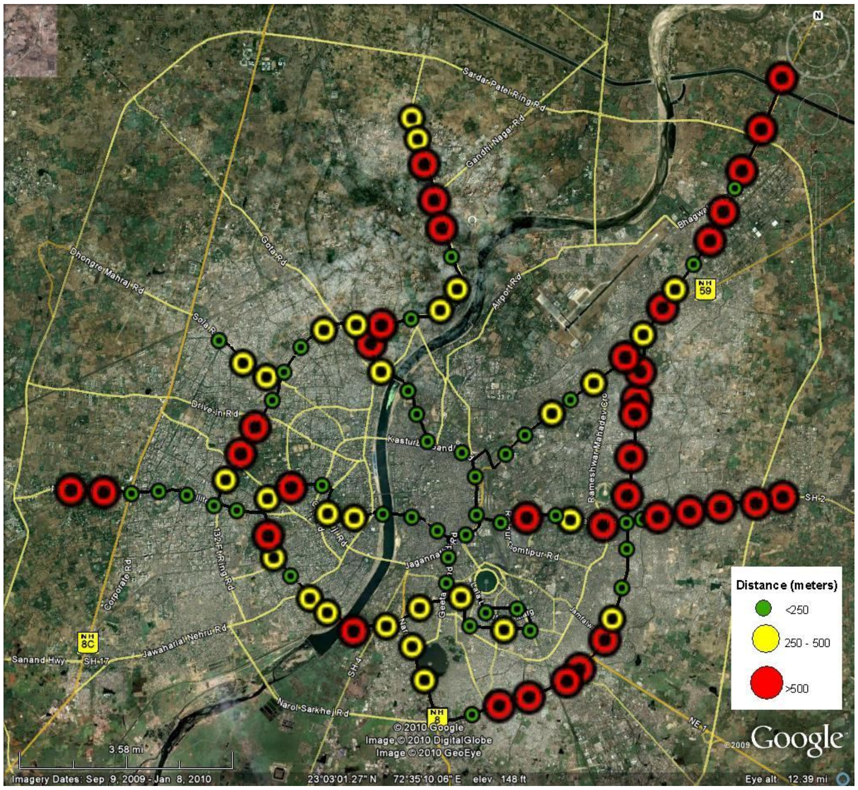


**Figure 26: Commercial accessibility (Station areas)**




### 5.3.1.7. Social dispersion

In addition to good land use mix, a good distribution in the terms of people living in the area is essential. If people from one particular group dominate the area, it could mean that either they are captives and cannot afford to live far from those areas (slums) or that the areas are high cost and others cannot afford to live there. The GINI index is used to measure the social dispersion.

The GINI index is a measure of statistical dispersion and is commonly used as a measure of inequality of income or wealth. The coeffecient ranges from 0 (perfect equality) to 1 (perfect inequality). In the current study, the population is divided into 4 groups based on income. The four groups are –

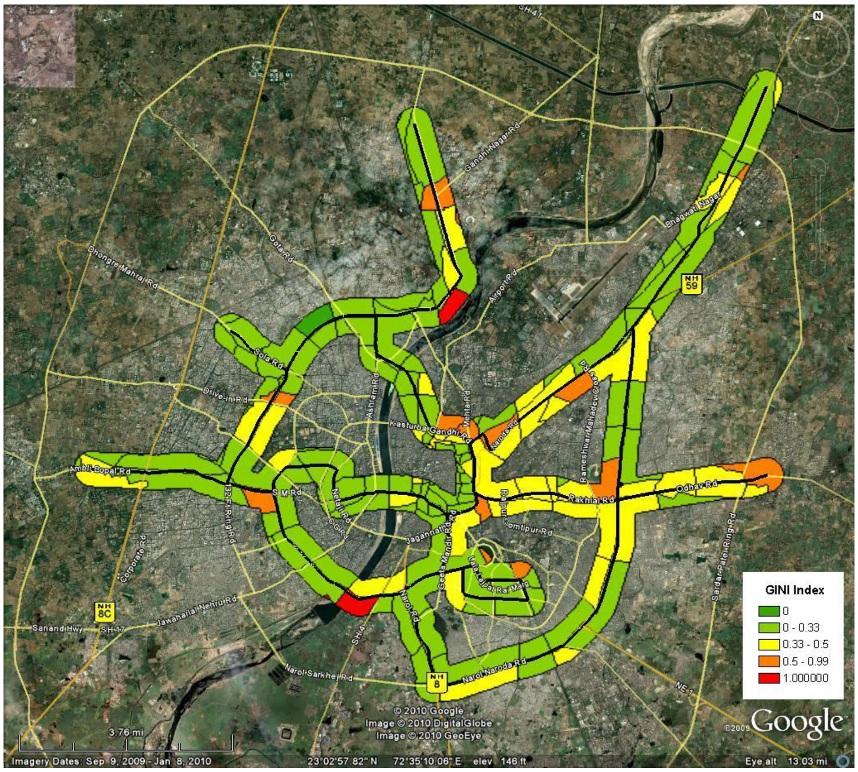
- EWS – economically weaker section
- LIG – lower income groups
- MIG – middle income groups
- HIG – high income groups

The central government in India recommends these 4 groups for city planning (urban housing, slum aleviation, etc.) and the state government defines the threshold for each group. In Gujarath, the thresholds are [62] –

- EWS – upto Rs. 3300 per month (Euro 55/month)
- LIG – Rs. 3301 to Rs. 7300 per month (Euro 55 to 121/month)
- MIG – Rs 7301 to Rs 14,500 per month (Euro 121 to 241/month)
- HIG – above Rs. 14,501 per month (above Euro 241/month)

The number of people in each group is available at a TAZ level. Figure 27 shows the GINI index calculated for the study area. It can be seen that a good portion of the area is already well distributed. Among the zones with high GINI index, a majority of them are regions dominated by the EWS and LIG groups. This could mean that these are slum type of development.

Figure 27: GINI index




### 5.3.1.8. Walkability

Another important aspect in TOD is the provision for pedestrian or bike access within the TOD neighbourhoods. While walkways and bike lanes are the basic requirement for improving access, design features such as street network, open public spaces, safety, street lighting etc. also form a critical part.

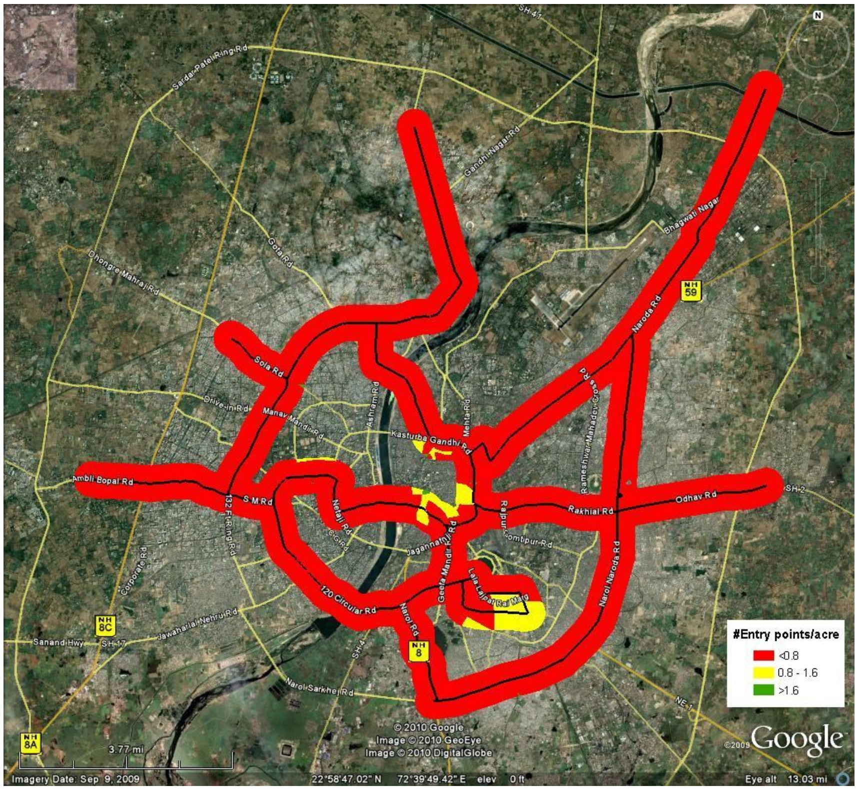
#### *5.3.1.8.1. Street network*

Street network is an important design parameter to improve the connectivity of the neighbourhood. The street network can be measured in terms of intersection density (number of intersections/acre) in each zone, grid pattern (percentage of four-way intersections) and access density (number of access points/acre). All the maps developed for these indicators are divided into three groups, the lower, middle and upper tericles.

**Access density**

In calculating access density, access is defined as the number of entry points into each neighbourhood. The number of access points is important to walkability in that it indicates more approaches into an area and less cul-de-sacs and dead ends. Figure 28 shows the access density for the study area. The intersection of the roads and the borders of each TAZ are taken as the entry point. The TAZ zone is taken as the intersect feature instead of the blocks layer since it is a larger region and hence helps determine access to a community rather than individual blocks. In the map, most of the region is red and has low access density and hence can imply poor connectivity. Poor connectivity in terms of street network is not always an indicator of low NMT trips. Later in the report the model share is analysed with respect to connectivity.

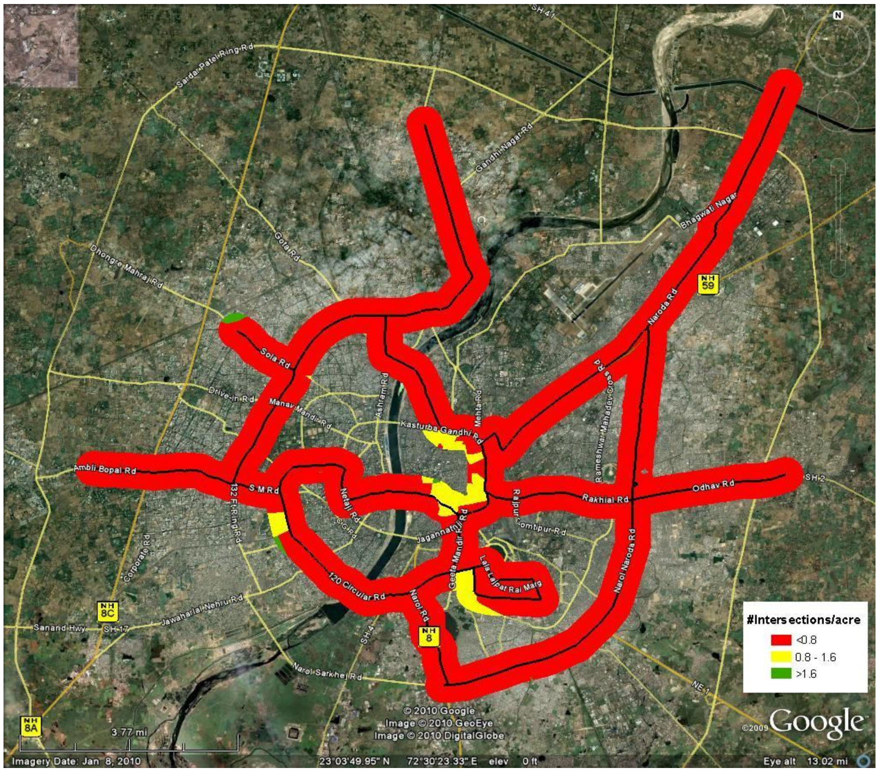
Figure 28: Access density per TAZ




**Intersection density**

Intersection density is defined as the number of road intersections within an acre per zone. Figure 29 shows the intersection density per TAZ in the study area. It can be seen in the figure that most of the region has low intersection density (red), which implies poor connectivity. From the figure we could conclude that in the region the number of walk or bike trips are very low.

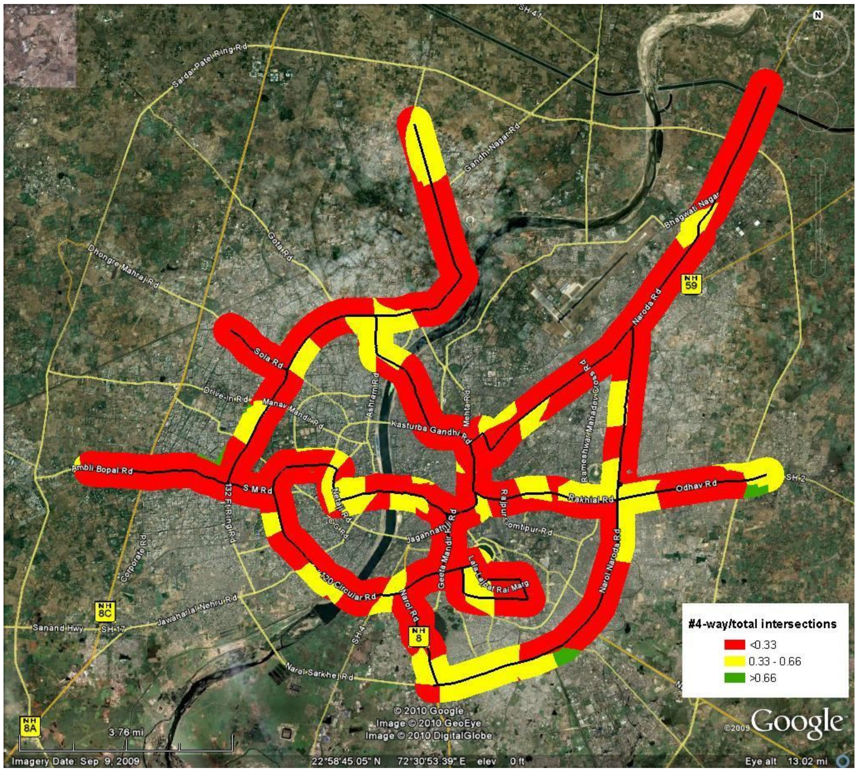
Figure 29: Intersection density per TAZ




### Grid pattern

A grid pattern where buildings are arranged into blocks with roads all around the block shows good approach to these buildings and hence good connectivity. In order to measure grid pattern using GIS, the number of 4-way intersections as a percent of the total intersections is calculated per zone. Figure 30 shows the output for the study area. Most of the region has only one in three intersections as 4-way intersections. Again it can be concluded that the region has poor connectivity and hence potentially has low walking and bike trips.

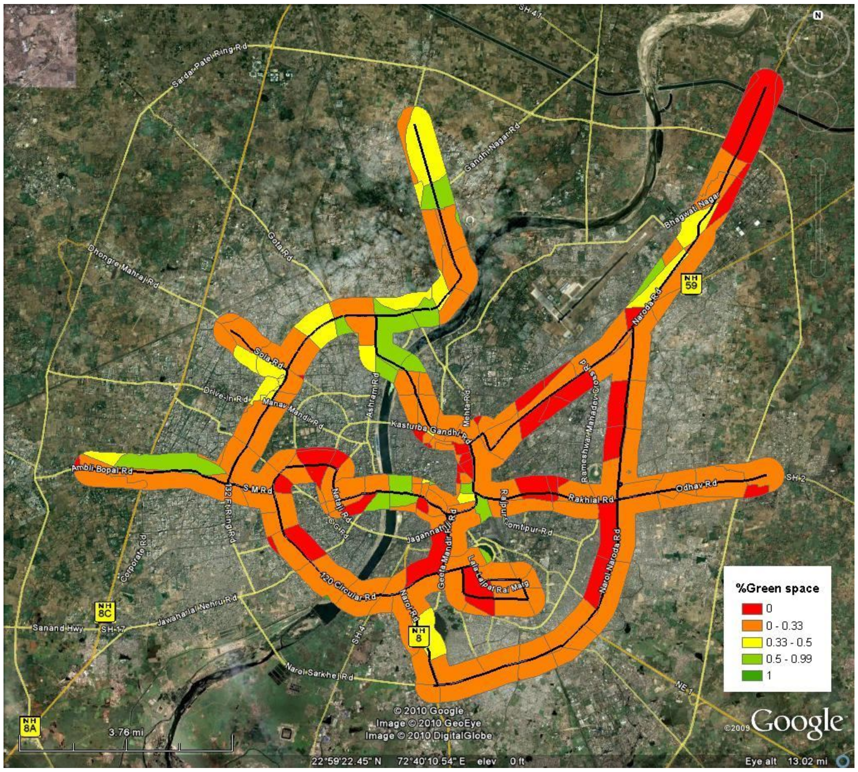
Figure 30: Ratio of four way intersections




### 5.3.1.8.2. Green spaces/ water bodies

The final design indicator considered in the study is the number of green spaces or water bodies. The hypothesis is that more number of open public spaces encourages people to walk. Figure 31 shows the percentage of area which is green in each zone. Again most of the region is under the low category. The general trend in the three indicators is that the study region is poor in terms of design features, at least when compared with the American/European standards

Figure 31: Percentage of green space per TAZ




## 5.4.SMCE Model

In order to assess the degree of TOD-ness in Ahmedabad a model is required. The model would use the indicators developed and analysed in the previous section as input. In the literature review section (Chapter 3) SMCE has been identified as the suitable framework for answering the research questions in the current project. In this section a model is developed using the above indicators and SMCE framework.

The overall objective of the study is to investigate the study area for sustainable development. Therefore the indicators developed in the previous section are first grouped under the three dimensions of sustainability: social, economic and environmental (Table 13).

In the table it can be seen that some of the indicators are entered multiple times (different themes). The reason for this is because they have an influence on multiple dimensions of sustainability in different signs or orders of magnitude. For example, green and open public spaces influence people to do more walk trips which has an influence on the environment (reduced car trips) and at the same time they can serve as places of social interaction and hence improve the social dimension of sustainability. Similarly, commercial index which is a measure of access to commercial places influences both the economic and environmental dimensions; with improved walk/bike access to commercial places, more people would be willing to travel to these using these modes and hence reduce the need for private car trips (environment) and more trips improves the business in the region which contributes to economic growth. Pavements help increase the ease of walking (social) and hence increase the number of walking trips (environment).

Table 13: Indicators for sustainable development

| Goal | Theme (weight) | Indicator |
|---|---|---|
| Sustainable development | Social (1/3) | Social dispersion |
| | | pavements |
| | | green/open spaces |
| | | Dissimilar index |
| | Economical (1/3) | Job density |
| | | Residential density |
| | | Accessibility index |
| | | Commercial index |
| | Environmental (1/3) | Street network<br>• Access density<br>• Intersection density<br>• Grid pattern |
| | | Commercial index |
| | | green/open spaces |
| | | pavements |
| | | Dissimilar index |

The next step in developing the SMCE model is to weigh the themes and indicators. Sustainability according to [1] is the union of the three dimensions, social, economy and environment. Hence to achieve sustainable development each of these dimensions is equally important. For this reason, in this study, the three dimensions are equally weighted (a third each).

The ranking of these indicators obtained from the group interview (Section 5.2) is shown in Table 14.

Table 14: Indicator ranks based on group discussion

| Indicator | Group ranking |
|---|---|
| Job density | 6 |
| Residential density | 4 |
| Accessibility index | 5 |
| Dissimilarity index | 9 |
| Commercial index | - |
| Social dispersion | 3 |
| Street network | 7 |
| Green/open spaces | 8 |
| Pavements | 1 |
| Public lighting | 2 |

In Table 14 the indicators for walking such as pavements and public lighting have a higher rank than those for density. This is in stark contrast to existing literature where density and diversity are considered more important than design features. The reason for this could be that in India, density and diversity are already high and design features are lacking. At the same time, the indicator for street network is considered more important than dissimilar land uses. One of the reasons for this could be that current land use is already considered highly diverse. In the previous section (5.3.1), it has been established that there are some regions where land use is homogenous. Also in the same section, it was concluded that there is not a very strong correlation between walking and street network. Thus there is a need to correct the ranks for the indicators. Based on the above group discussion and the analysis section, a TOD index ranking the different indicators in their themes was developed. The final SMCE model including the ranking is shown in Table 15.

Table 15: Final SMCE model

| Goal | Theme (weight) | Indicator | Rank |
|---|---|---|---|
| Sustainable development | Social (1/3) | Social dispersion | 2 |
| | | pavements | 1 |
| | | green/open spaces | 4 |
| | | Dissimilar index | 3 |
| | Economical (1/3) | Job density | 3 |
| | | Residential density | 1 |
| | | Accessibility index | 2 |
| | | Commercial index<br>• Residential<br>• Bus stop | 4 (individual indicators get equal weights) |
| | Environmental (1/3) | Street network<br>• Access density<br>• Intersection density<br>• Grid pattern | 5 (individual indicators get equal weights) |
| | | Commercial index | 3 |
| | | green/open spaces | 4 |
| | | pavements | 1 |
| | | Dissimilar index | 2 |

The ILWIS SMCE tool uses the above model along with the GIS maps already generated for analysing the TOD-ness of the study area. Before generating the output, three steps need to be completed in ILWIS:

1. Determining the criteria tree (indicator list and weights),
2. Assigning values to the indicators (maps), and
3. Standardizing the indicators

The first step is the SMCE model; the second, maps generated for each indicator. In the first step, while assigning weights to the indicators, the indicators are specified as either a cost or a benefit factor. A benefit factor contributes positively to the output, whereas the cost contributes negatively. To assign weights the rank ordering method is used. In this method the higher ranked indicators get a greater value than the lower ranked ones. It uses the following formula:

$W_k = \sum_{i=1}^{n+1-k} 1/[n(n+1-i)]$ (1)

The final step in the preparation of the ILWIS model is standardization. Standardization is the process of reducing each indicator to a value between 0 and 1 without dimensions. A value of 0 means the factor (indicator) has low utility and a value of 1 means it has high utility. There are many methods of standardization such as –

- Maximization – each pixel in map is divided by the maximum value.
- Interval – the minimum and maximum values are considered for standardization. The minimum value is taken as 0 and the maximum as 1; other values range between these two.
- Goal – the minimum and maximum values can be specified. Minimum specified values and values below that are considered as 0, maximum specified value and values above that are considered as 1.

Table 16 shows the standardization values and the method of standardization used for each indicator in the research model.

**Table 16: Indicator standardization**

| Theme | Indicator | Standardization method | Reasoning | Threshold |
|---|---|---|---|---|
| Social | Social dispersion | Goal | Social dispersion has a value of 0 when every social class have equal population in region and a value of 1 when one group completely dominates. Thus the goal of this indicator is to achieve a 0 and move away from 1 | ranges between 0 and 1 |
| | Pavement | Goal | Pavement indicator indicates the percentage of roads that are not paved in each zone. Thus the goal of the indicator is to bring it to 0. | Ranges between 100 and 0. |

| Theme | Indicator | Standardization method | Reasoning | Threshold |
| --- | --- | --- | --- | --- |
| | Green/open spaces | U-Shape | Green/open spaces indicate the percentage of area that is green or open in the zone. If the whole of the region is green, people do not live there or work there. Thus it cannot be a TOD region. Thus a U shape method is chosen for standardization wherein, the middle tercile is taken as the maximum value | Increases from 0 until 0.323 and then drops |
| | dissimilar index | Maximum | Dissimilarity index has a value of 1 when all grid cells are dissimilar to each other, and a value of 0 when everything is similar. The goal for the indicator is to reach a 1. Thus a maximization (to 1) is used as the standardization method | ranges from 0 to 1 |
| Economy | Residential density | Maximization | Residential density is important to transit ridership. The highest possible density leads to highest ridership. | Ranges from 0 until maximum |

| Theme | Indicator | Standardization method | Reasoning | Threshold |
|---|---|---|---|---|
| | Job density | Maximization | Job density is also a parameter to increase transit ridership. Again, the maximum possible jobs is desirable | ranges from 0 until maximum |
| | Accessibility index | Concave | Accessibility index gives a measure of nearness of bus stop to each residence. If a stop is within 5 min walk, it is very accessible; 5-10 min walk is slightly accessible and beyond 10 carries a heavy cost. Thus a concave method is used to define these thresholds | ranges from 0 until 5, then 5 until 10 and beyond 10 |

| Theme | Indicator | Standardization method | Reasoning | Threshold |
|---|---|---|---|---|
| | Commercial index | Convex | Commercial index is a measure of the ease of reaching a commercial/retail centre. In order to promote sustainable modes of transport, these should be within walking or biking distance. In India due to a lack of bike lanes, walking is a more common mode. Thus for this research, walking distance is taken as the standard. The walking comfort is high when one does not need to walk at all. But realistically, a distance of 500m is walkable, but beyond it, the comfort drops exponentially. Thus a convex method is used to define this behaviour | Ranges from 0 until 500m. A value of 1500m is considered as in accessible. Hence distances beyond 1500m has a value of 0 after standardization |
| Environment | Green/open spaces | U-Shape | Similar to the social theme | |
| | Pavement | Goal | Similar to the social theme | |
| | dissimilar index | Maximum | Similar to the social theme | |
| | Commercial index | | Similar to the economy theme | |
| | street network | | The three indicators of street network are all used to promote walking. In each case, an increase in indicator value improves the goal. Thus a maximum method is used for each. | |

| Theme | Indicator | Standardization method | Reasoning | Threshold |
|---|---|---|---|---|
| | access density | Maximum | | Ranges from 0 until maximum value |
| | intersection density | Maximum | | Ranges from 0 until maximum value |
| | grid pattern | Maximum | | Ranges from 0 until maximum value |

In order to develop the output a suitability map was constructed. A problem analysis map is used in situations where the impact of the indicators on the final output needs to be studies, for example in environmental impact assessment. In TOD analysis a similar situation exists; we would like to determine if the existing values of the indicators contribute to a TOD type of development. If all pixels in the output map are 1 then the region is TOD, and if all values are 0, the map is not at all a TOD. These are the extremes of the output map.

Based on the standardization and the SMCE model, the output in Figure 32 was generated. From the output we can confirm that the inner city region has a TOD score in excess of 50 or in other words the inner city is around 50% TOD. The outer corridors on the other hand have a low score (between 25 and 50). These regions are more suburban type of development.

But, the output generated is very much dependent on the ranking of the indicators. In order to test the validity of the model before making using the output to make recommendations, five different scenarios were tested in a sensitivity analysis (Table 17).

Figure 32: TOD in Ahmedabad (model 1)

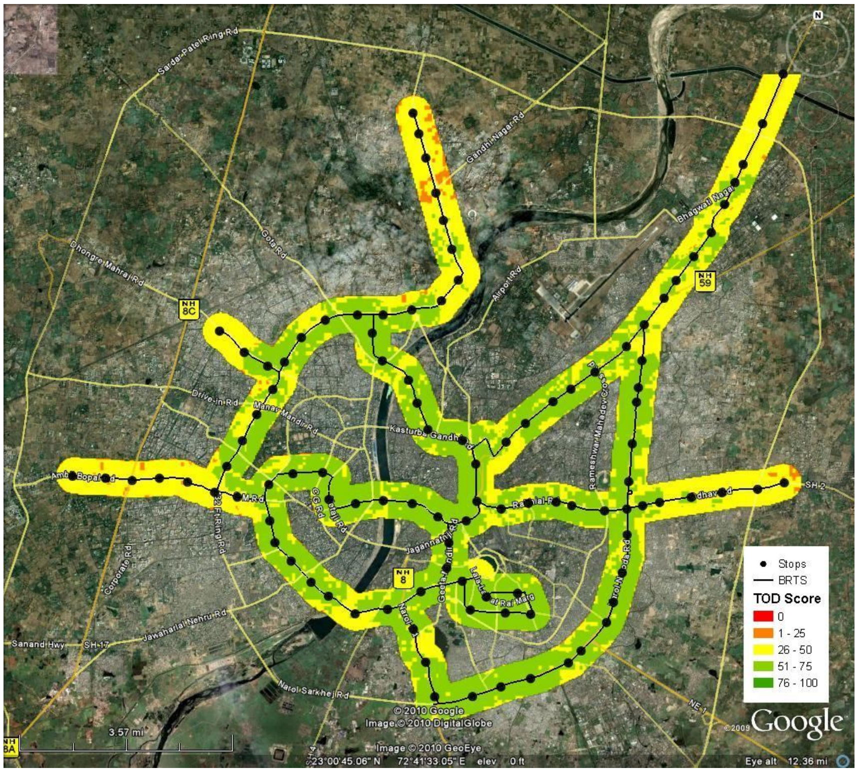



Table 17: Scenarios for sensitivity analysis

| Scenario 1 (Rank) | Scenario 2 (Rank) | Scenario 3 (Rank) | Scenario 4 (Rank) | Scenario 5 (Rank) |
|---|---|---|---|---|
| **Social (1)** | Pavements (1) | Pavements (1) | **Social (1)** | Reliability (1) |
| Pavements (1) | social dispersion (2) | social dispersion (1) | Pavements (1) | Frequency (1) |
| Social dispersion (2) | residential density (3) | residential density (1) | Social dispersion (2) | Safety (1) |
| dissimilarity index (3) | access index (4) | access index (1) | dissimilarity index (3) | Population density (2) |
| green spaces (4) | job density (5) | job density (1) | green spaces (4) | Job density (3) |
| **Economy (1)** | job housing balance (6) | job housing balance (1) | **Economy (1)** | Street network (4) |
| residential density (1) | Commercial index (7) | Commercial index (1) | residential density (1) | Pavements (4) |
| job density (2) | street network (8) | street network (1) | job density (2) | Green/open spaces (4) |
| accessibility index (3) | green open spaces (9) | green open spaces (1) | accessibility index (3) | Access index (4) |

| Scenario 1 (Rank) | Scenario 2 (Rank) | Scenario 3 (Rank) | Scenario 4 (Rank) | Scenario 5 (Rank) |
|---|---|---|---|---|
| job housing balance (4) | dissimilarity index (10) | dissimilarity index (1) | job housing balance (4) | Social dispersion (5) |
| commercial index (5) | Reliability (11) | Reliability (1) | commercial index (5) | Dissimilarity index (5) |
| **Environment (1)** | Safety (11) | Safety (1) | **Environment (1)** | Job-housing balance (5) |
| Pavements (1) | Frequency (11) | Frequency (1) | Pavements (1) | Commercial index (6) |
| dissimilarity index (2) | | | dissimilarity index (2) | |
| commercial index (3) | | | commercial index (3) | |
| green spaces (4) | | | green spaces (4) | |
| street network (5) | | | street network (5) | |
| **Transport (1)** | | | **Transport (1)** | |
| Reliability (1) | | | Reliability (1) | |
| Safety (1) | | | Safety (1) | |
| Frequency (1) | | | Frequency (1) | |

The scenario 1 is based on the final SMCE model developed in the previous section (Table 15) while, Scenario 2 is based on the indicator ranking obtained after the group discussion (Table 14). Scenario 3 is similar to scenario 2 but the indicators all have the same rank (and hence same weight). Scenario 4 is the same as Scenario 1, but the score for pavements and street network has been changed so that on standardization they return a value of 1 (best possible output). Scenario 5 is based on the TOD index developed by Evans et al. [32]. In the TOD index, the highest ranked indicator is transit ridership. Since the demand data for estimating transit ridership is not available for research, the transit indicators (reliability, frequency and safety), which influence transit ridership are considered as the transit indicators and hence get the highest rank in the model. Also in the model, qualitative rating of streetscape is one of the indicators. Street network, pavements, green/open spaces and access index are all criteria for measuring the streetscape and hence get equal ranking (rank 4) in. Similarly dissimilarity index, job housing balance and social dispersion which are criteria to evaluate mixed use and diversity, get the same ranking (rank 5 in the model)

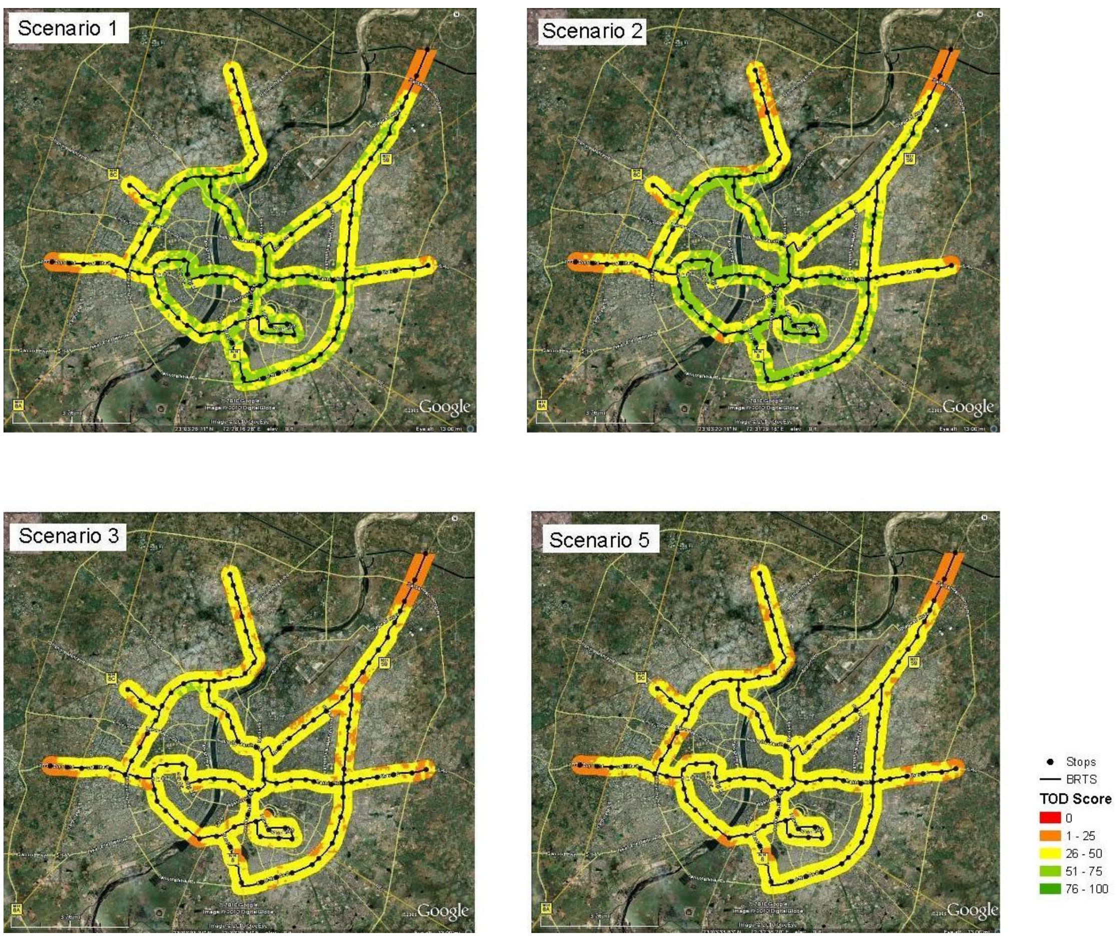
The descriptive statistics in Table 18 are obtained on running the above models on ILWIS. The maps for these scenarios are shown in Figure 33.

Table 18: Descriptive statistics

| Scenario | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Sum | 386161 | 348242 | 302499 | 405822 | 221634 |
| mean | 47.27 | 45.79 | 35.55 | 54.72 | 31.67 |
| Min | 0 | 0 | 0 | 0 | 0 |
| Max | 69 | 68 | 59 | 72 | 55 |
| SD | 9.129231 | 10.628644 | 8.040869 | 5.562323 | 5.219541 |
| % above 50 | 40.02 | 38.62 | 1.76 | 77.15 | 5.7e-4 |

The first scenario is obtained by dividing the indicators into the three sustainability groups and then ranking them based on the preference stated by the interviewees. The second model does not group the indicators and ranks them in a sequence. The third model weighs the indicators equally. The fourth model is similar to the first one, only replacing the walkability indicators with a value of 1 (very good walkability). The final model (model 5) is based on the TOD index developed by [32].

Figure 33: Four Scenarios of sensitivity analysis



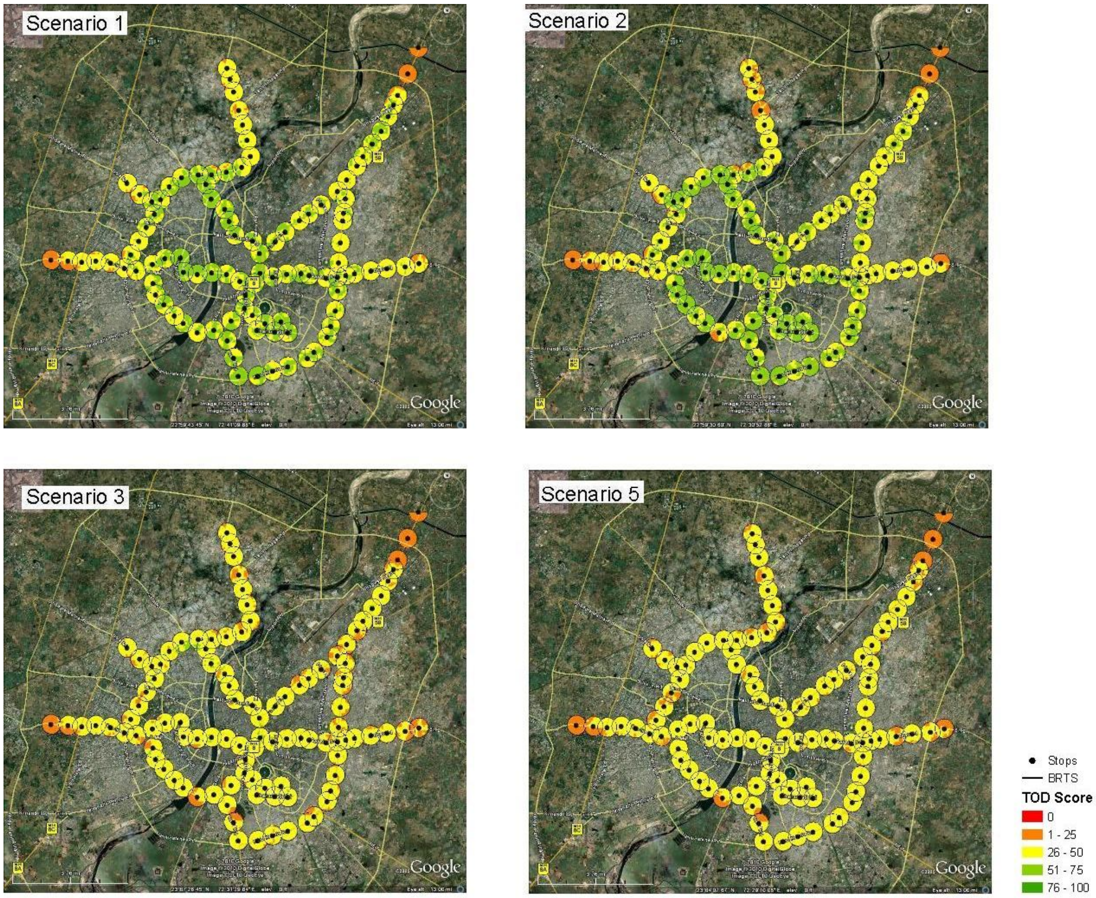

Of the five scenarios (in selecting the “best fit” model) we can ignore scenario 4 since it is a recommendation (very good walkability) based on the first scenario. The output maps for the other four scenarios are shown in Figure 33. On comparing the four maps, we can visually see that regions that are in green in scenario 1 and 2 are yellow or orange in the other two scenarios. The differences are explained by the different weights of the indicators. In 3, all indicators are weighed equally. If we consider this model to be the best fit, we are assuming that density is as important to TOD-ness as parks and open spaces, or pavements, or high quality transit. By definition, TOD requires frequent, high quality transit to function effectively which means that transit factors carry greater weight in the model. Similarly from an economic perspective high density is essential to achieve higher transit ridership. Thus, there are some criteria which are more important than others. Based on this argument, 3 is not the ideal model for analysis in the current research.

In scenario 5 on the other hand, transit indicators carry the highest weight, followed by density and then design criteria. So, in a way this is the ideal model. But the BRT in the current scenario has only been in operation for 3 months and the data available for analysis is low. Due to this only few transit indicators have been chosen for the study such as frequency, safety and reliability. But these are basic supply side elements and transit ridership or demand is more important in judging the success of the transit service. Due to a lack of demand data, the model cannot be selected for the analysis.

Scenarios 1 and 2 use the same ranking of indicators; 1 arranges the indicators in groups whereas scenario 2 does not. These two models produce almost identical maps. The difference in the descriptive statistics' of the two models is due to the fact that some of the indicators are input multiple times in different groups in model 1. At first glance it might seem that model 1 is wrong, we increase the importance of some of the indicators. For example, dissimilarity index is part of the society as well as environment groups. Dissimilarity index is important in a societal view, in that it improves the chances of people meeting others during the trip to the other activities, and it is important in an environmental sense that, shorter trips generate more non-motorized trips. Thus the extra importance placed on these indicators is justified. In view of this, model 1 is chosen as the best fit for analysis and to answer the research questions. While it is true that selecting a model that depends on the views of only 6 persons is not a very good option, limitations in terms of time and resources force the choice. This is a limitation of the current study.

The above analysis has been done for the entire corridor. By definition TOD can be either at station area or along transit corridor. Would the above conclusions change if the analysis was conducted for station areas only? In Figure 34 the same four scenarios are modelled by selecting a 500m influence zone around each station. It can be seen that the two figures (Figure 33 and Figure 34) are more or less the same. This is due to the fact that the BRT stops are close to each other (within a km) and on selecting a 500m zone, almost the entire corridor is selected.

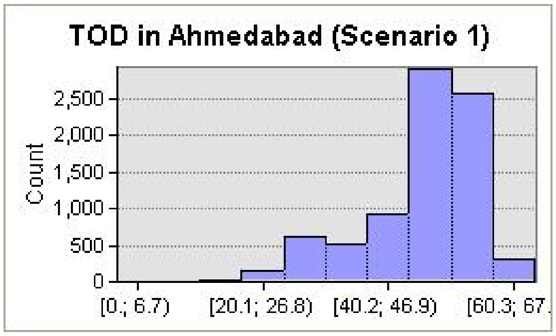
Figure 34: Station area analysis




## 5.5. Is Ahmedabad a TOD?

In the previous section a sensitivity analysis based on changing weights was used to determine the best fit model for the project. Based on the model and the output generated (Figure 32), we could conclude that there are some regions in Ahmedabad that are more TOD and some that are less TOD (green and non green). The descriptive statistics for the output is shown in Table 18 (column 1) and in the histogram in Figure 35. It can be seen that the mean value of the map is 47.7. If we consider 100 (or 1) as total TOD, then the region is close to 50% TOD. Also from the same table, 40% of the region is greater than 50% TOD. From these values we might be able to deduce that the region is already on the way to being a TOD and with some changes, total TOD-ness can be achieved.

Figure 35: Histogram of model 1




The inner city in Ahmedabad has very high density and diversity in land uses. Thus in traditional definitions, it is already a TOD. Figure 36 shows a zoomed in view of one particular station area in the inner city. It can be seen that on one side (left) of the bus stop there is very high density development with smaller building sizes whereas on the other size there are bigger buildings and more open spaces. The mean population density around this bus stop (500 m zone) is 205 persons/acre and the mean job density 121 jobs/acre. These values are higher than the average values in the study area. The area also has good distribution in terms of land use types, with many residential, commercial and green spaces. In terms of the economic criteria included in the analysis, this region is already a TOD. This is also seen by the TOD map shown in the same figure. Most of the region is already green. The yellow regions on the right are regions of transport links, which cannot be used for other purposes.

Figure 36: Station area

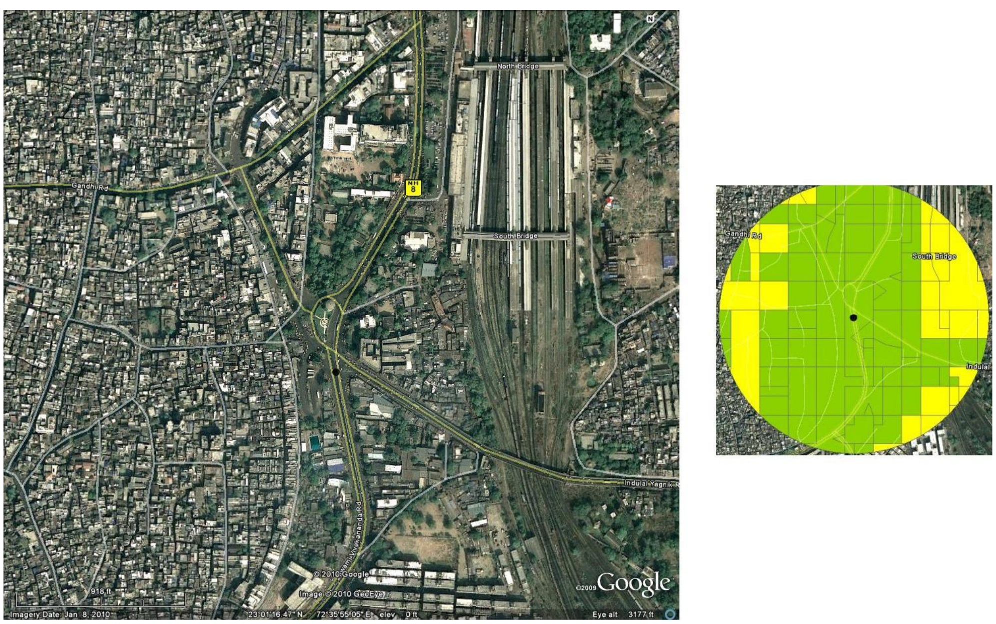



Figure 37 shows a station area in the outskirts of the city. Visually it can be seen that this area is on the other end of the spectrum. It is characterized by low density, grid type of development with lots of open green spaces. In terms of quality of living and design, this region ranks very high. This type of development is not satisfactory for TOD. This region also ranks very low on the TOD score. The average score is 35 with 45 the highest value. The value of 35 is due to good design factors. On improving density and diversity in this region, a more TOD type of development can be achieved. Also there is scope to improvement in these regions due to the large quantities of open spaces.

From these two examples, we can conclude that there are regions which are very close to being TOD and improving their score might not be entirely beneficial when there are other regions with greater scope for improvement.

Figure 37: Station area (example 2)

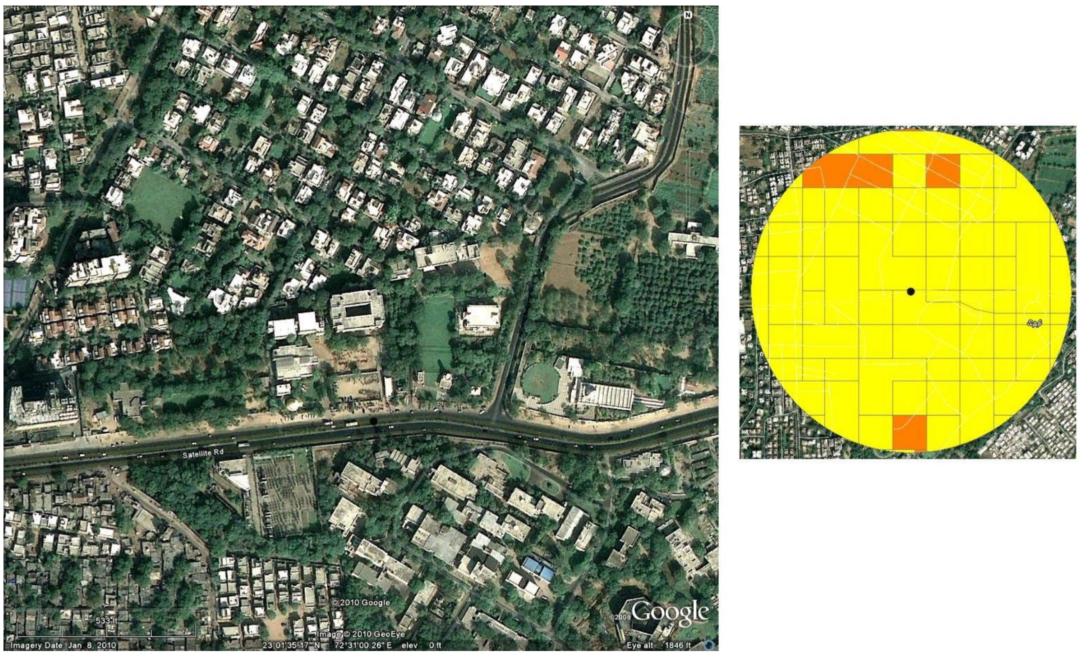
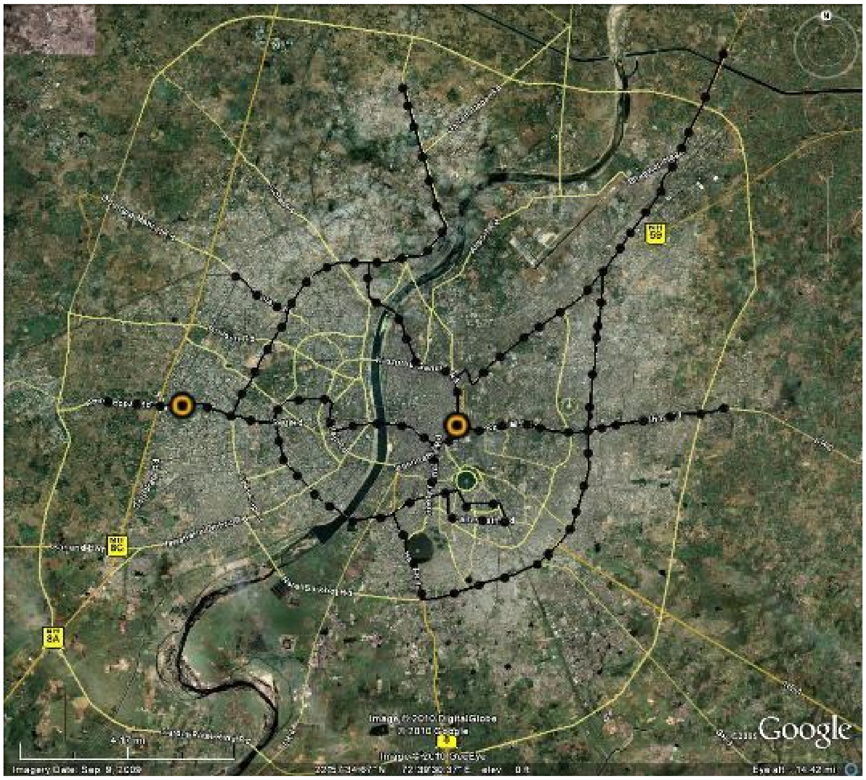


Figure 38: Location of selected bus stops in the corridor




The above conclusions have been based on the basic assumption that the western definitions of TOD hold true in an Indian context as well, i.e. urban form characteristics such as density, diversity and design promote the use of public transport. Figure 39 shows a map with bus trips generated in the study area. The data used for generating this map comes from a study that was done on the AMC bus trips. Since the current BRT has been in operation for 3 months only and the land use has not changed a lot during this time, the same data is used for analysis. We can see in the figure that the inner city generates very few bus trips whereas the outskirts generate more. This is due to the fact that the inner city has very high density and diversity. Most people living there work in the near vicinity of their residences and either walk or bike to work. This is demonstrated in Figure 40 which shows the percentage of non motorized trips (bike and walk). This figure shows that the entire region generates a good amount of walk and bike trips. This figure could lead us to conclude that the region is sustainable in terms of transportation. One of the arguments in traditional TOD definitions is that good urban form and design is essential to promote pedestrian accessibility. The study area ranks poor in terms of walkability (Figure 28, Figure 29 and Figure 30) which would mean that walk/bike trips should be at a minimum; Figure 40 shows otherwise. Thus western definitions of TOD and mixed use development cannot be directly adopted in the Indian context; rather they need to be adapted to the local situation.

Figure 39: Bus trips in study area (AMT system)

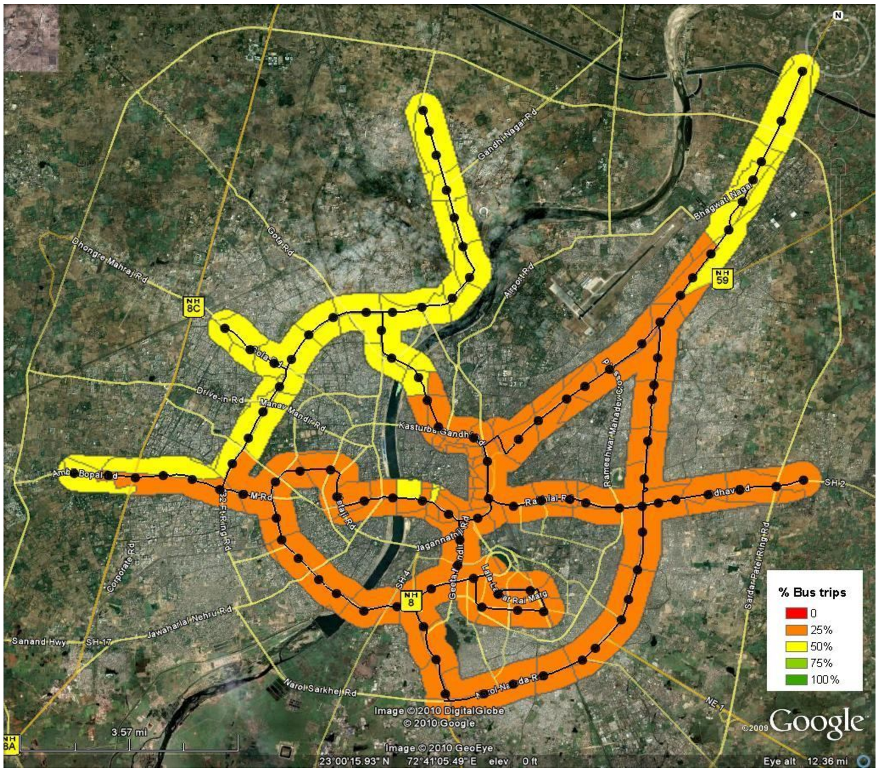
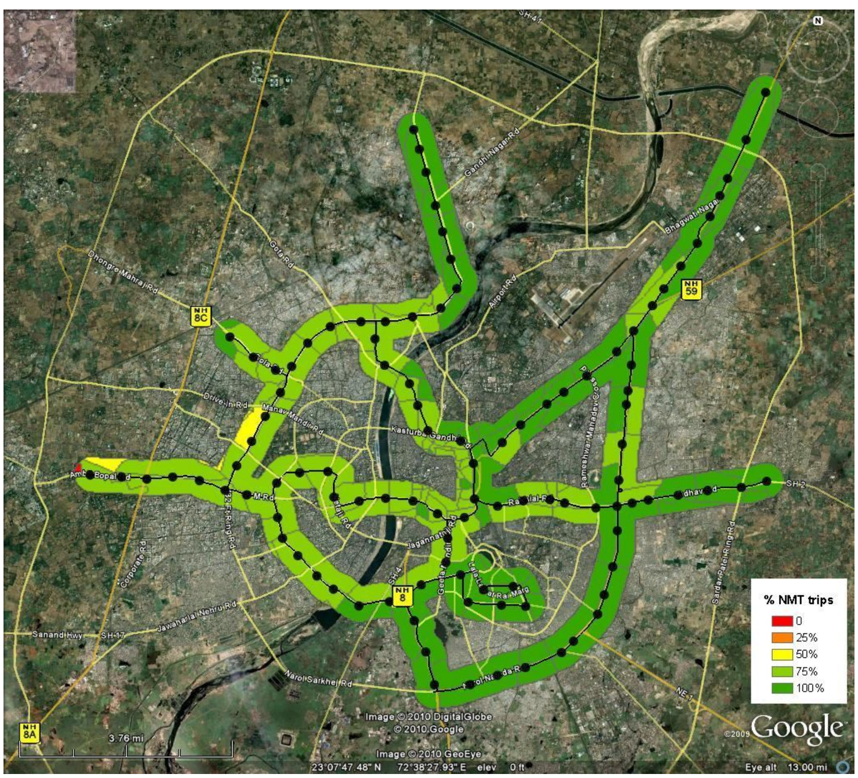



Figure 40: Percentage of NMT trips



## 5.6. Improvements for degree of TOD-ness

In order to determine possible parameters for improvements in the study area, the successful elements of the two case studies in the literature review chapter (Chapter 3) was used as input. In Curitiba, improved access to pedestrians, affordable housing, zonal policies were some of the success elements. Zonal policies help improve the mixture of activities and also improve development density. As determined by the dissimilarity index, the study area already has a good distribution of activities. But there is scope for improvement in terms of residential and job density (population density indicator and job density indicator). Hence pedestrian accessibility, affordable housing, and density are considered as the three parameters for improvement.

Considering figure 33 and 34, it can also be argued that walkability is not a necessary improvement, since the region already has a good amount of NMT trips. Also density and diversity in the inner city is quite high and development might not be entirely possible. Thus another type of intervention would be to focus on the line ends of the BRT corridors and improving the density, diversity and social dispersion in those regions.

Thus there are two possible scenarios for improvement, which are discussed in the following paragraphs:

1. Improve walkability, density, social dispersion all along the corridor.
2. Development of density, diversity and dispersion at the line ends

### 5.6.1. Scenario 1

In the second model, on replacing walkability indicators (pavements and street network), with a constant value of 1 (or very good walkability), the map (Figure 41) is obtained. It can be seen that almost the entire map (other than one pixel) is above a value of 26 and the major portion is between 51 and 75. Thus improving walkability values can improve the TOD type of development. Also of the two indicators, pavements rank the highest and have a higher weight. Thus completely providing pavements in the study area can play a major role in improving TOD-ness. Figure 42 shows a comparison of the existing scenario (without improved walkability) and the improved walkability. It can be visually seen from the two figures that on improving the walkability indicators, most of the region becomes green (TOD score between 51-76). Thus walkability can play a crucial role in improving the degree of TOD ness. On the other hand the regions that are already green do not get a better TOD score. Thus there is a limitation to the degree of increase in TOD score. Considering the TOD score as a reference, it can be concluded that it would be worthwhile to improve the regions with low walkability and not the entire region.

Figure 41: Improving walkability

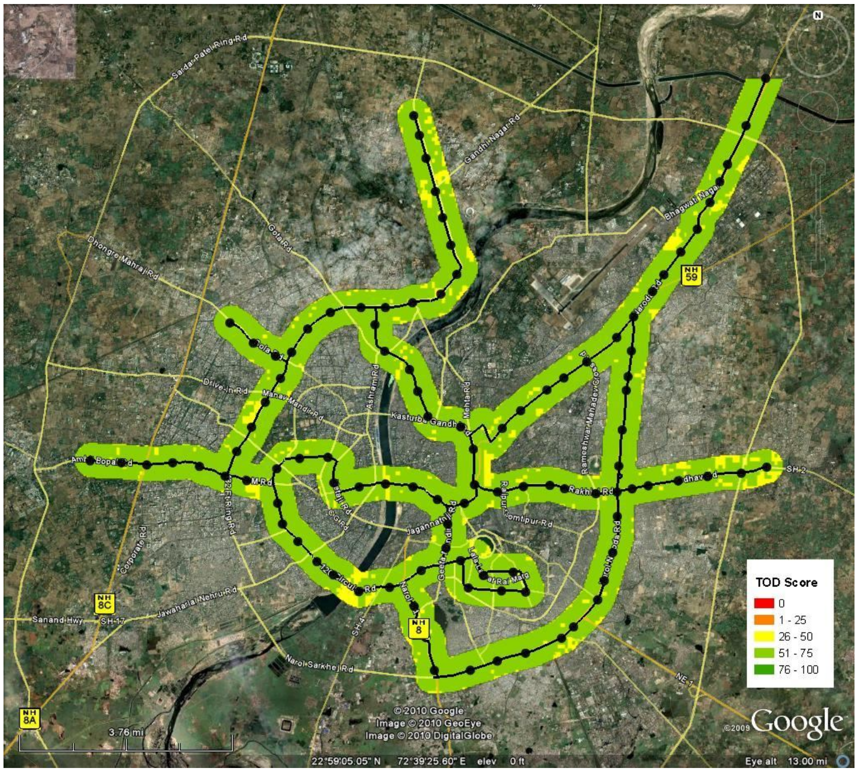
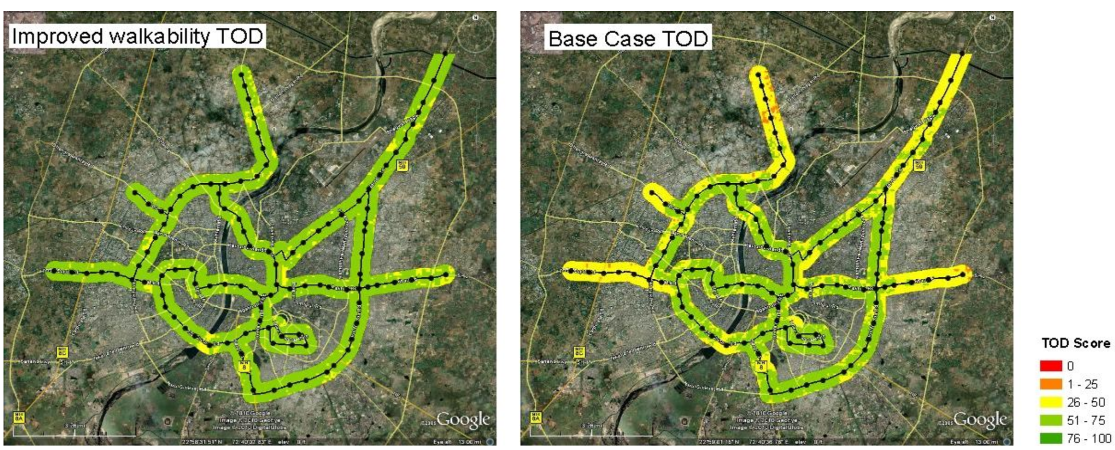



Figure 42: Comparison Base case scenario (model 1)




Good distribution of people along the corridor is essential not only for social equity (everyone has the same opportunity to access transit services) but also helps in improving the job-housing balance. Many people from the EWS work as domestic help in India; having a good ratio of people from all classes in the neighbourhood helps these people to work within the neighbourhood, thus improving their job opportunities and also reducing transport costs. Figure 36 shows the map generated on having a social dispersion indicator value as 0 (or equal distribution). Visually it can be seen that there is not much improvement in the overall TOD score (Figure 44).

Figure 43: Improved social dispersion

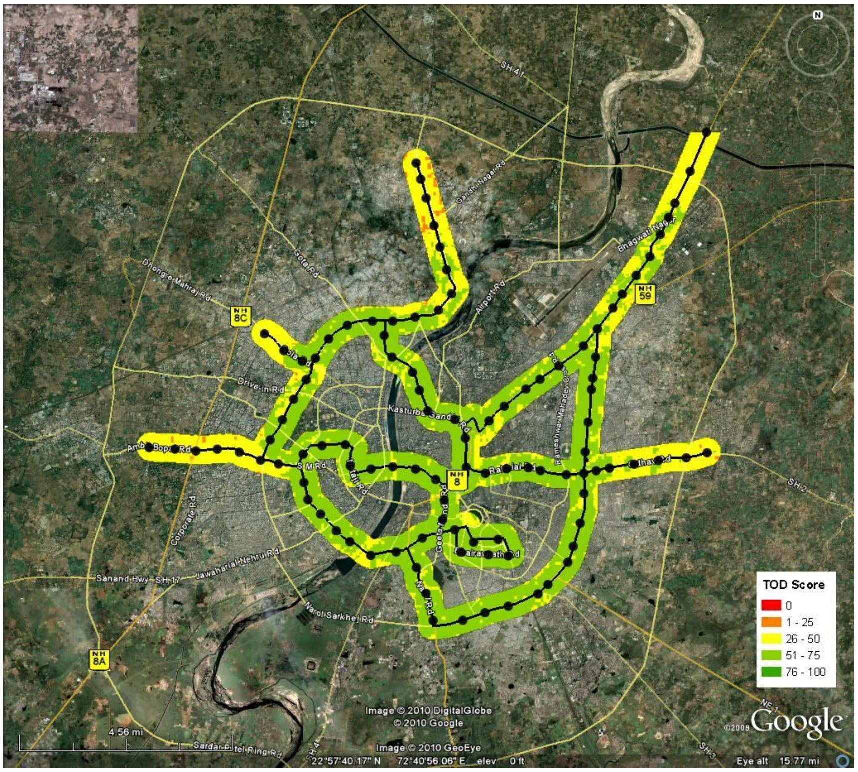



Figure 44: Improved social dispersion (after vs. before)

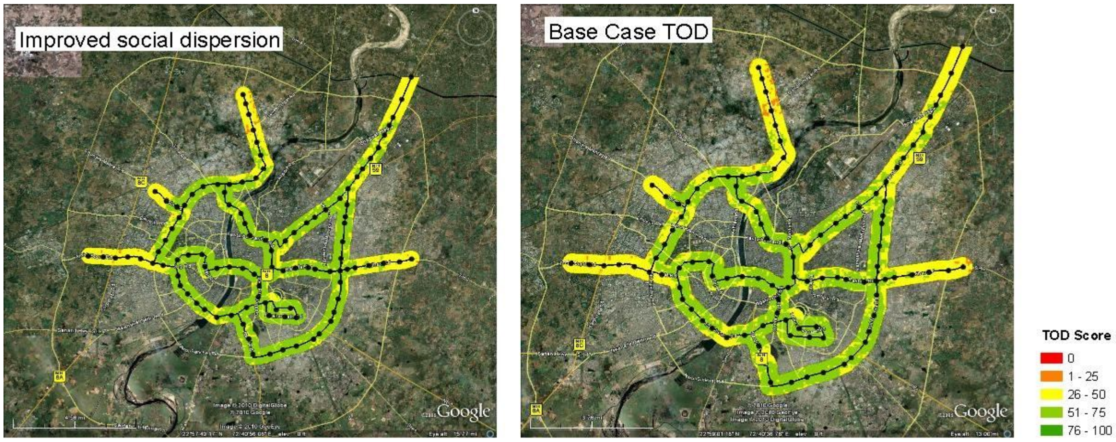


Figure 45: Histogram: Improved dispersion vs. Base model

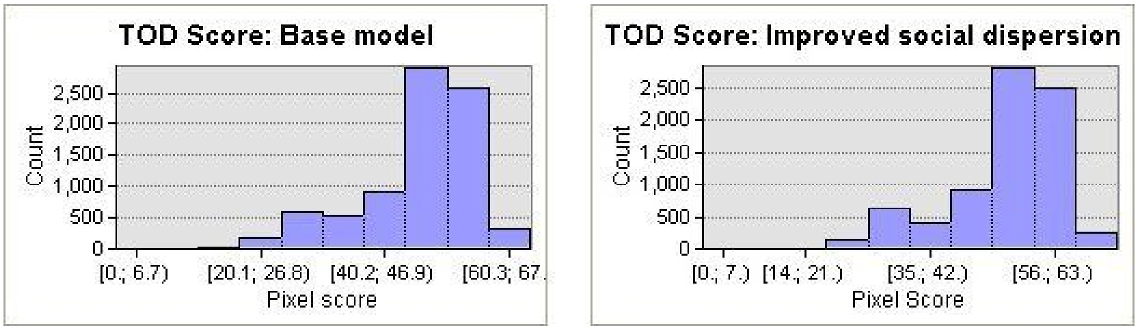



Figure 45 shows the histogram comparison between the two models. It can be seen that the overall distribution does not change by much, but the score is increased by a small amount. This occurs more in the inner city regions. Using the TOD score as the guiding factor we can conclude that improving social dispersion alone is not a satisfactory measure.

TOD is characterized by high density, high diversity and good connectivity. Higher densities can be either higher residential density or higher job density. In the previous section it has been presented that the FDOT recommended residential density for urban areas is 135 persons/acre and the minimum density for success of rapid transit is 48. In order to test if the increase in density helps improve TOD-ness, the regions of low residential density are increased to 48 and 135 is taken as the upper cut-off. This means that any value higher than 135 is not entirely desirable. For job density on the other hand the lower cut-off is 25 jobs/acre and there is no upper cut-off. According to FDOT, the job density can exceed 1000jobs/acre. Using this recommendation, no upper cut-off is specified for job density. Figure 47 shows the map output. This measure too does not provide a very significant improvement (Figure 46). Where this measure succeeds is that very low density regions (which also have low TOD scores) improve their TOD scores. Since a certain density is essential for TOD type of development, these regions of very low densities might benefit from this measure.

Figure 46: Histogram: Improved density vs. Base model

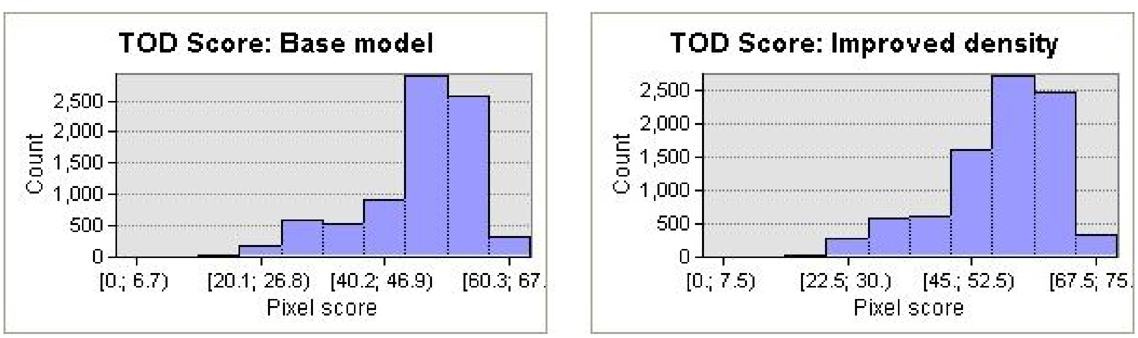


Figure 47: Improved density

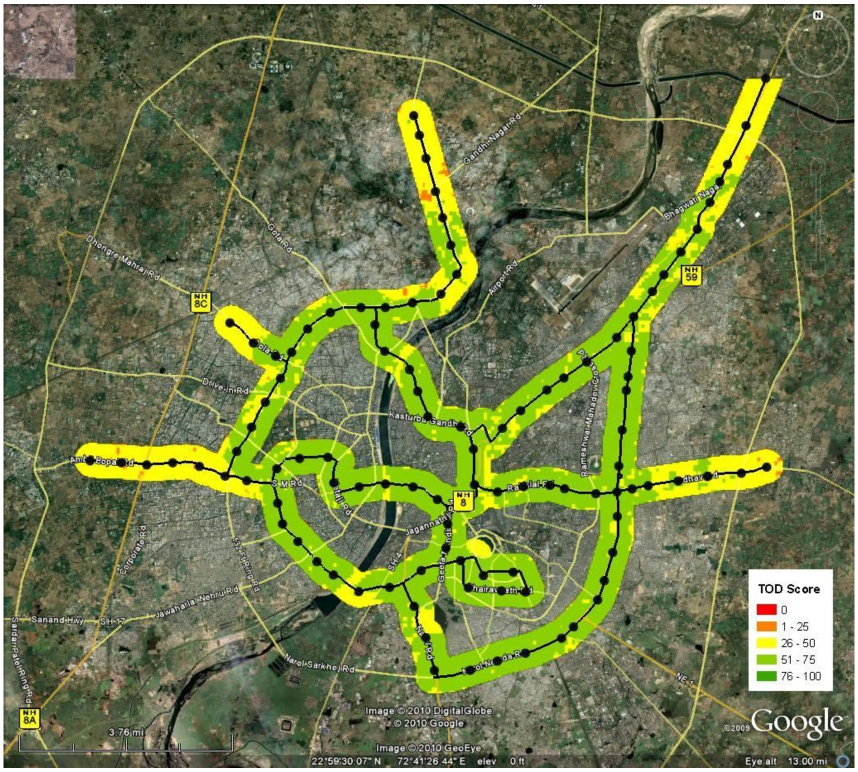
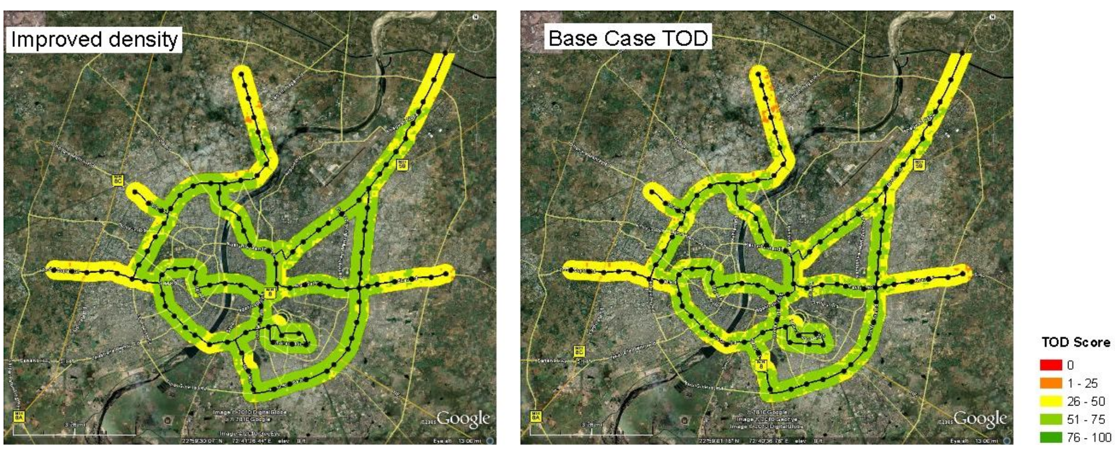
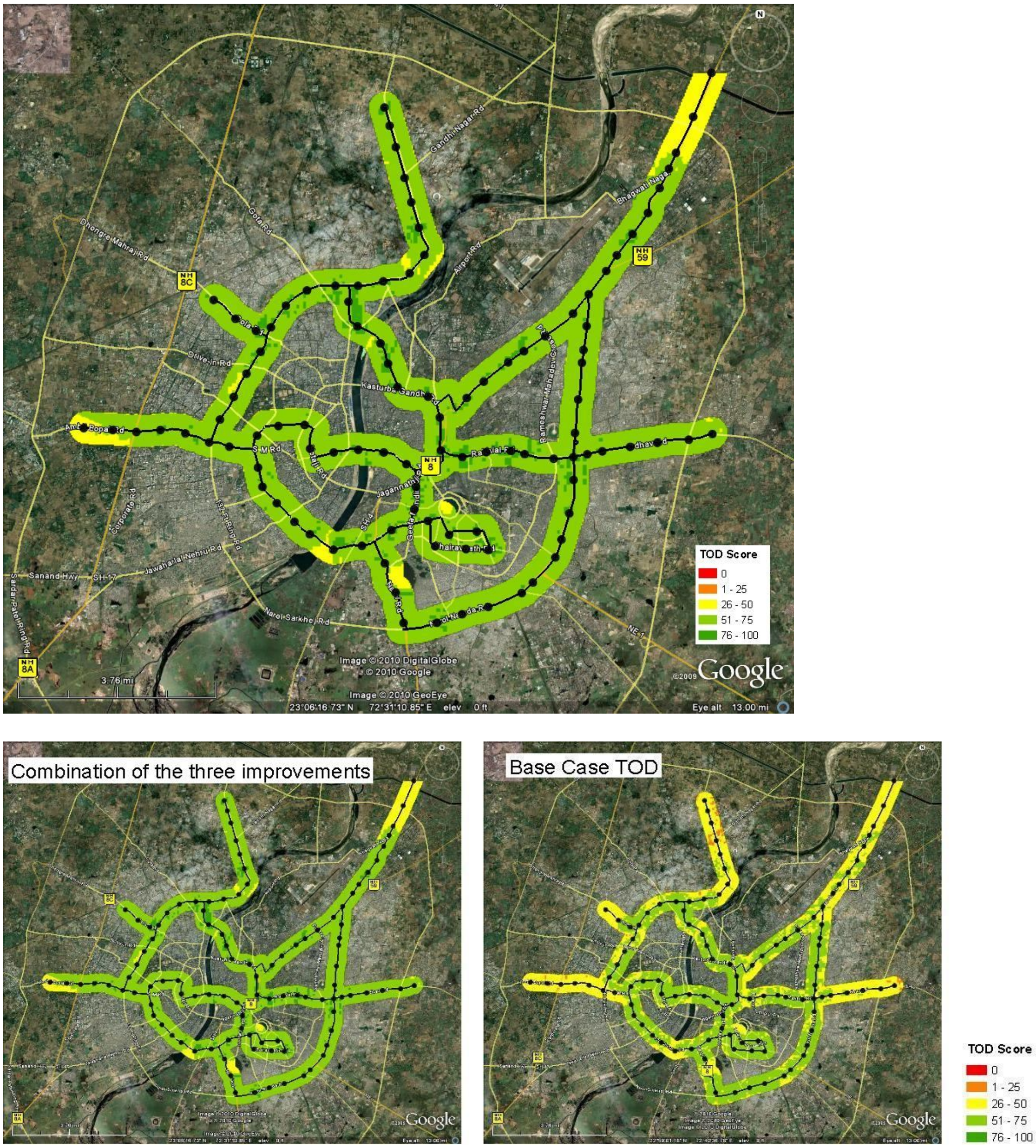



Figure 48: Improved density (after vs before)




Combining the three maps, the output in Figure 49 is obtained. It can be seen that the inner city region has good TOD score (green) whereas some pockets in the outskirts are still rank low. It has already been established that the inner city already has a compact development with good amount of NMT and bus trips. Thus the region is already close to being a TOD (based on the TOD score and trip patterns). The improvement in Figure 49 thus might not be entirely suitable since some of the outer regions remain low TOD score regions. Thus instead of considering the entire region for improvement, the outer corridor regions which have a low TOD score would be a more suitable option for improvement.

Figure 49: Improvement map (scenario 1)




## 5.6.2. Scenario 2

In the third case, development is limited to the transit corridors outside the inner city (regions with orange in Figure 32). Figure 50 shows the map of density, diversity and social dispersion indicators in the outer corridors. In the figure we can see that the region has low population density and low job density. The dissimilarity index on the other hand is varied; two corridors have very good diversity and two others have poor diversity at the ends. The social dispersion on the other hand is more or less green. The mean GINI index value is 0.32 which is equal to the mean value in the entire corridor. Also 56% of the region has a GINI value better than or equal to the mean.

Since the inner city is already a high density, mixed use type of development, improvements along the corridor can help the region become a complete TOD. Most of the trips from these regions are towards the inner city since the jobs are concentrated there. Hence a residential/commercial type of development might be viable in these regions so that people can use the BRT work trips and shop within the region. Based on these, the main improvements for the region are –

- Improving residential density: the mean res. density in this region is 43 and 66% of the region is below 43. As an initial measure, the density in regions with a value below 43 is first increased to 43. The value 43 is not close to the mean value of the entire corridor (93.5), but it is close to the minimum specified density value for urban regions (48; as specified by FDOT [55])

- Improved dissimilarity index: the mean value of DI (dissimilarity index) in the outer corridors is 0.40, which is greater than the mean value of the entire corridor (0.37). But, over 52% of the region has a poorer value than the mean. As such there is need for much improvement. Again, the dissimilarity values higher than the mean are improved to the mean (for DI, the goal is 0; higher values indicate homogeneity).

**Figure 50: Outer corridor indicator values**

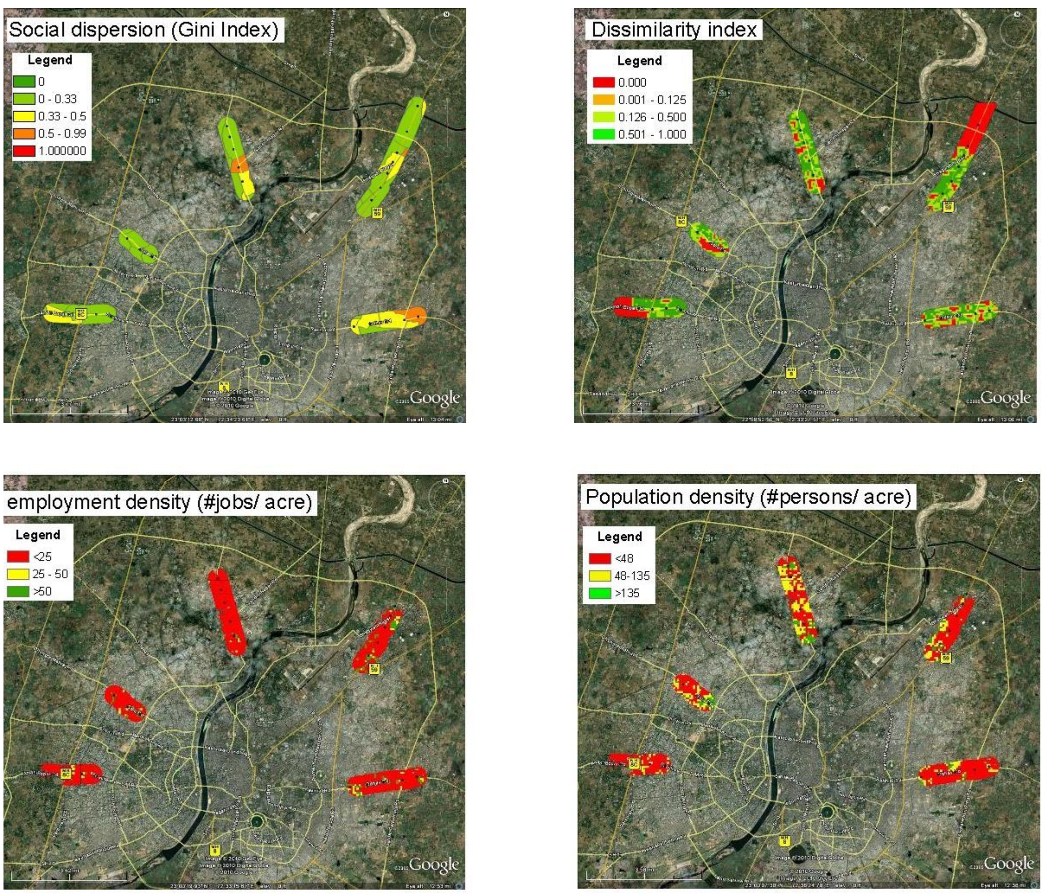
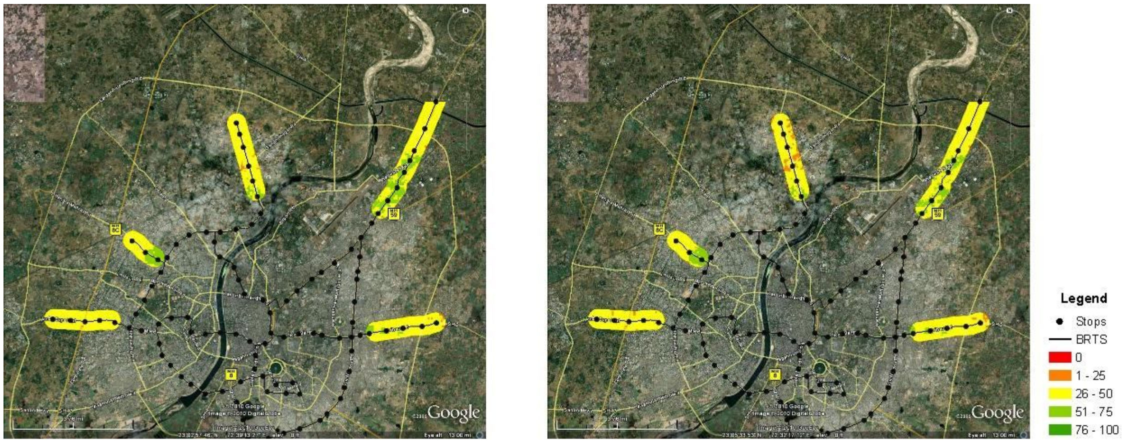


**Figure 51: Comparison outer corridor improvement (before and after)**




Outer corridor after improvement Outer corridor before improvement

On performing the above improvements, the output is show in Figure 51. In the figure, a comparison is also made with the situation before improvement. At first glance it might visually seem that there is no improvement in the corridor even after improving the population and diversity values. The histograms for the before and after situation are shown in Figure 52. It can be seen that the minimum value in the corridor increases and so too does the distribution. For example before improvement there are 200 blocks with values close to 28.3. After improvement the values change to 32.5. Thus there is an improvement but not a very large improvement. In this example we are considering the mean population density of the corridor as the threshold. But this value is just half of the mean density of the entire corridor. On changing the threshold to that of the mean density, the TOD map of Figure 53 is obtained. Again not much improvement is observed. The reason is due to the standardization of population density. According to the model, the maximum population density is considered as the best case scenario. The maximum value in the map is 852 persons/acre. After standardization, 93.5 persons/acre is equal to 0.109 (i.e. 93.5/852). In the previous step 43.5 was considered as the value which is equal to 0.05 units, which means population density has been improved by 0.05 units. After applying weights, the value becomes even smaller. Thus for the selected model, population density values must be much higher than 94 persons/acre to really affect the TOD score.

**Figure 52: Histogram comparison (outer corridor)**

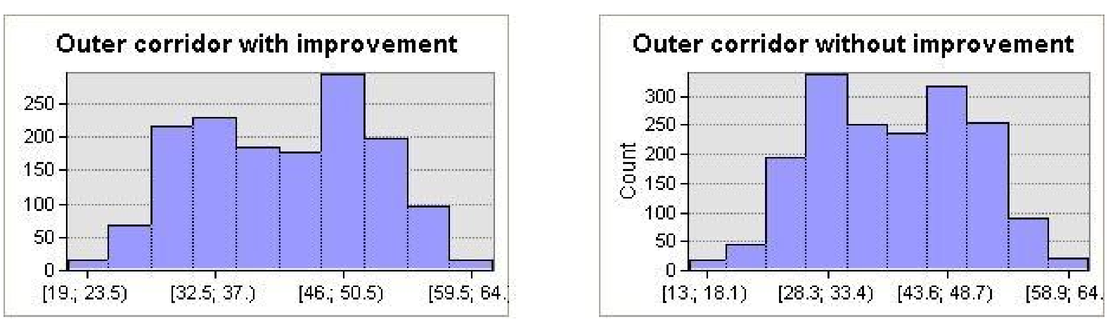
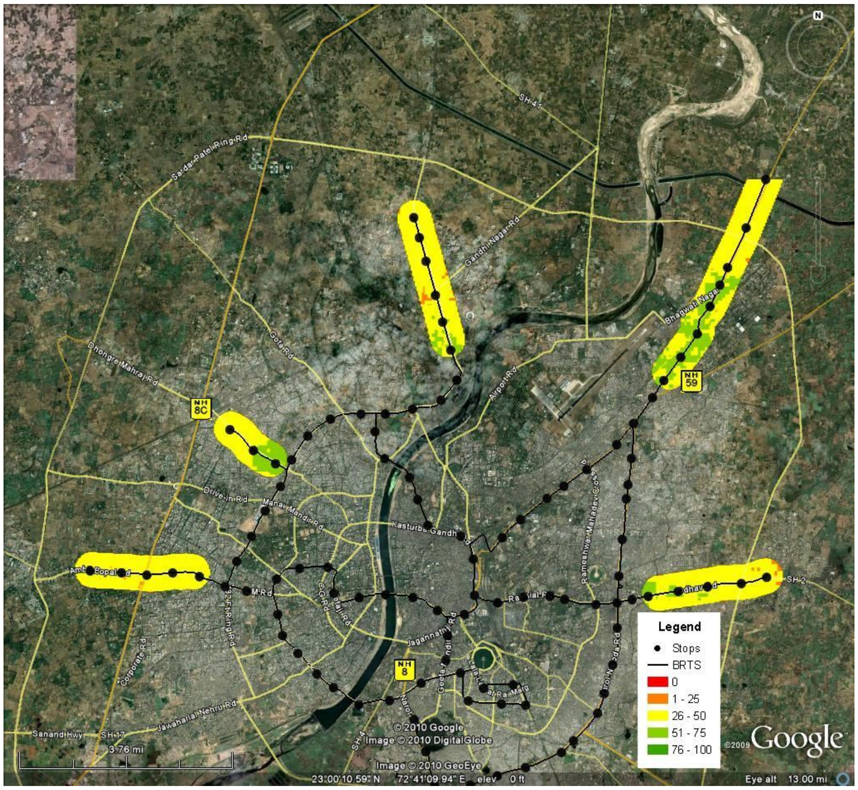


Figure 53: Outer corridor with improved population density




The histogram of population density in the entire corridor is shown in Figure 54. The first two blocks in the histogram account for 83% of the total blocks in the area. In the data set there are extreme values such as 872. These are obvious outliers and hence might not be a good choice for standardization. Instead of choosing 872 as the maximum value, if we choose 174 as the threshold for standardization (174 is the maximum value in the first two blocks), the output of Figure 55 is obtained.

Figure 54: Histogram of population density

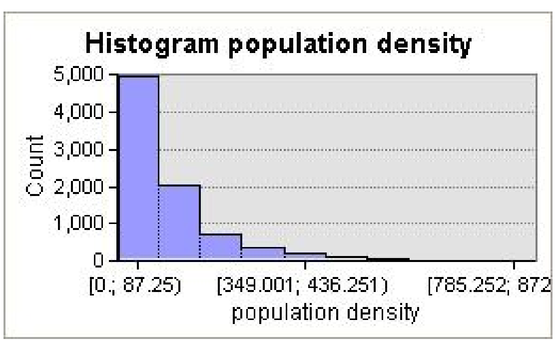
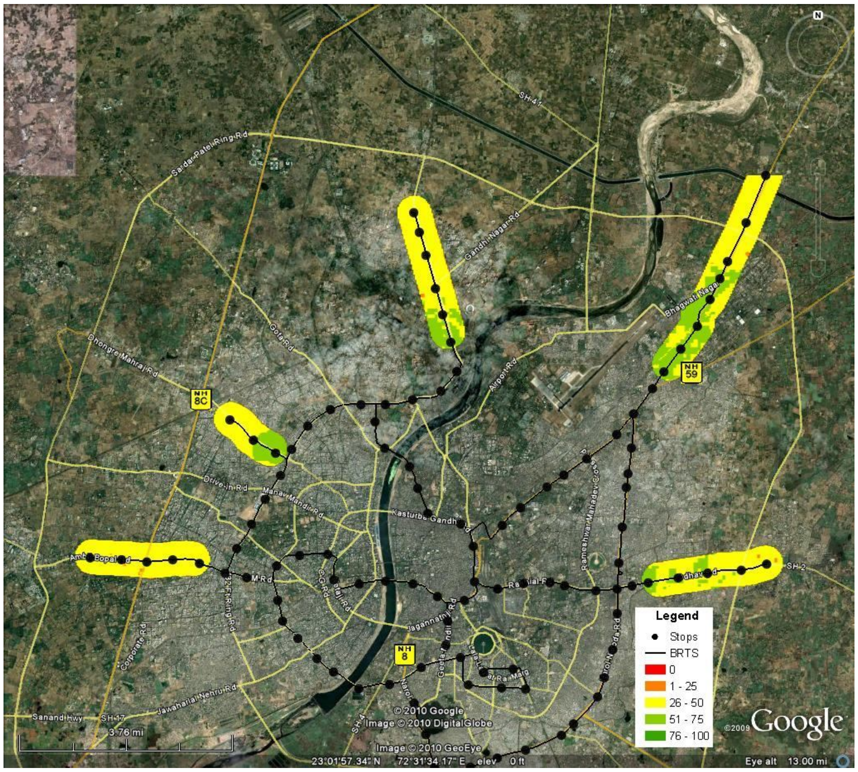


Figure 55: TOD in outer corridors on changing standardization threshold




The map has more green regions and also the mean value of the area is 44.5 which is more than the mean value of outer corridor without the improvement (39). But only changing population density and diversity does not create a 100% TOD region, which is logical considering the importance of other indicators as well. Since these outer regions are still in the early stages of development, it might be a worthwhile investment to try and increase the population density and diversity.

> Note: It is clear from the analysis that standardization plays a crucial role in the analysis. For example by definition TOD requires high population density. The term, high is very subjective. One way of defining high could be to consider the maximum density in the region as the standard. This would mean trying to increase the other regions to this high value. Another definition of high would be to consider a particular value such as the FDOT recommendation (135) as the high value. This would mean any value above this has no advantage. Thus regions with densities above 135 which might potentially produce more trips have the same value as the region with density of 135. By changing the standardization cut offs, and hence the methods, different outputs can be produced. The selection of the standardization method is thus a crucial element of the evaluation procedure.

## 5.7.Barriers to improvements

According to Cervero et al. barriers to TOD include common barriers of transit station development and specific TOD barriers [20]. In the report they present the following barriers –

- Fiscal barriers: construction costs, elevator and lobby requirements, and risk in high rise buildings put off potential developers
- Political barriers: transit based housing and infill development is equated with more traffic demand, longer lines at grocery shops etc.
- Organizational barriers: difficulty in coordinating between different stakeholders
- Congestion: high density development can lead to spot congestion in traffic (people or automobiles). While in a longer term, regional traffic can reduce, the short term congestion is a big impediment to local residents.
- Parking management: parking dilemmas relating to surface parking and parking limitation for residents are difficult to resolve.
- Mixed use development: getting the correct amount of mixed use is often near to impossible.

In addition to these barriers, Caltrans in their report on state wide transit oriented development [63] identified a lack of expertise on TOD as another barrier. But these are barriers identified in an American context. In order to determine if similar barriers exist in an Indian context, and to identify other barriers that might exist, an interview was conducted with academics[5] of Ahmedabad.

Accordingly, the barriers in Ahmedabad can be arranged into three macro levels –

- Financial
- Organizational
- Land use and zoning

**Land use and zoning**

One of the recommendations that have come out through the research is an increase in density and diversity in the outskirts of the BRT corridor. An increase in density has to be brought about by increasing the height of buildings and hence the FSI. Currently the FSI specified in the influence zone is 1.8, whereas the consumed FSI is 0.8 [64]. The outskirt regions have a lower consumed FSI. The reason for the lower consumption is by choice; people have paid a higher price to live in these regions. Increasing FSI in these regions can only be done by acquiring the land owned by these people. At present there is no mechanism in Gujarat to acquire land and pay compensation; the town planning mechanism in use is a land pooling and readjustment method. In this method a group of owners are invited together and a new plan is discussed, the pooled land is then restructured such that the state takes a share of the land for public use (roads, pavements etc.) and the remaining land is returned to the owners. The plot that is returned to each owner is in proportion to the original size.

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[5] Prof. Talat Munshi and Sejal Patel of the School of Planning, CEPT University, Ahmedabad were interviewed in order to gain an understanding to the planning process in Ahmedabad.

The other problem is with respect to parking management. At present surface parking is allowed just beside the BRT corridor to allow for Park and Ride. This indicates that the target of the BRT is people who own private cars as well. If a parking limitation is implemented within the influence zone, the catchment of the BRT reduces and the people using the BRT will be the captives.

Mixed use development is not really a barrier in Ahmedabad. The influence zone is characterized as a R1 zone, where any type of commercial/retail development is allowed.

Another problem with existing land management policies is the question of providing affordable housing. At present there is no mechanism which allows for affordable housing. Developers can acquire the rights to develop areas, and the state or the development authority has no mechanism with which to determine the share of affordable housing in those areas. One way to overcome this can be to provide additional FSI to developers who would be willing to set aside a share of the land for affordable housing. This type of mechanism is in use in the state of Maharashtra.

**Organizational**

Urban planning in Gujarat is a two step process – creation of a development plan (DP) for the area, creation of town planning schemes (TPS) for smaller portions of the area. The DP is the strategic document for the area, which needs to be approved by the state government. The TPS is a micro level document which involves a series of public participation and negotiations between the development authority and land owners.

The TPS preparation can take a maximum of four years and one month but usually takes longer [65]. The TPS usually has to pass through the Land Records Department which is understaffed and hence take a long time for clearance. The other time consuming phase in the town planning scheme is the negotiation between the development authority and the land owners for compensation and betterment charges. Finally, the TPS also needs to pass through the state government for approval. Thus the entire process is very centralized and approval from the state government (local assembly) is required at many stages.

**Financial**

In order to finance TOD type of development, developers must be willing to invest in construction of high density multi story buildings. The costs for these buildings will be much higher due to the requirement of steel frames, elevators etc. In Ahmedabad, if the FSI is increased, developers will be interested. Thus the market is ready, if such a plan is approved. But the costs and tax in the influence zone would mean that the houses can be purchased only by the richer people. And these people would want commercial complexes, multiplexes, multiple car parking options etc. Policies that restrict provisions for these such as parking policies, zoning policies etc. will drive the customers away and hence the developers too. There is a clear dichotomy in Ahmedabad with respect to private cars and transit users.

The other barrier is with respect to providing affordable housing. At present there is no mechanism to provide incentives to developers to build affordable housing. One solution to this would be to provide developers additional FSI, on the condition that they provide social housing.

# 6. Conclusions

This chapter concludes on the research objectives raised in chapter 2. Further, limitations and recommendations for future research are also discussed.

**Objective 1: To define sustainable urban development and transit oriented development (TOD) and investigate the potential of TOD for achieving sustainable urban development**

The current study was conducted under the hypothesis that TOD is a strategy for sustainable development. In the background literature chapter (Chapter 3), research conducted by Deakin [28] and Lai and Li [29] has been used as a reference to prove this hypothesis (Section 3.2). TOD has been defined using the 3 D's (density, diversity and design) of Kockelman and Cervero [18]. The indicators to measure these 3D's have been linked to the three goals of sustainability (economy, social and environment). The definition of TOD is generic in that it promotes sustainable development by developing compact communities. Achieving these goals is done by different combinations of the 3 D's, which is specific to each case. For example, in America where most of the TOD research is conducted, density and diversity play a key role, whereas in India which traditionally has compact development, other factors might be more important. Thus TOD as a concept can be applied anywhere, but after adaptations.

TOD is also a spatial decision; given a location we try to find the activities that can take place there. TOD is also a multi-disciplinary decision; planning, policies and design are just three of the disciplines necessary. Thus TOD is a multi-disciplinary spatial decision. Hence for the research, spatial multi-criteria analysis has been chosen as the research method (Chapter 3, section 3.4.1).

**Objective 2: To determine whether the current urban form and transport development on and around the BRT corridor in Ahmedabad can be characterized as a TOD type of development**

In order to assess the existing urban form, an assessment framework had to be established. Using a Delphi interview to rank the assessment criteria, an SMCE model was developed. The first conclusion based on this model was that the inner city region of Ahmedabad is already close to a TOD type of development. This conclusion holds merit when considering the type of development that exists in most Indian cities (i.e. high density and high diversity). If only density and diversity were considered, the study area would rank higher. In the design criteria it scores low. Due to data limitations only a few of the design indicators were chosen in the current research. Of the three that were chosen, Ahmedabad ranked low on two of them (pavements and street network). On choosing more indicators it is possible that the study area returns a lower TOD score. Thus improvements in design values especially, can leverage the existing development into a more TOD type of development.

At the same time the outer corridors of the study area have very low scores. This implies that while the core is very compact, the outer corridors have a more suburban type of development. Thus one way of creating a complete TOD type of development is to use the Copenhagen style of development; a compact core and TOD on the outskirts connected by transit radials.

**Objective 3: To investigate the changes that need to be made to make the current development a TOD or a more successful TOD.**

As concluded in the previous objective, the study area has a compact core and a suburban development elsewhere. When considering improvements, the whole study area can be improved, particularly the regions which have a very low score can be improved (Chapter 5, section 5.6); in the core region, the design values can be improved to improve the TOD score. For the outer corridors not just the design, but density and diversity values need to be improved as well to increase the TOD score.

**Objective 4: To investigate the policy and planning barriers that need to be overcome in order to implement the changes**

The development plan and town planning scheme (DP-TPS) used in Ahmedabad has its merits and demerits (Chapter 5, section 5.7). While it is democratic, the bureaucratic procedures involved mean that it takes a long time to be accepted by the government. Also, there exists a dichotomy between cars and buses in Ahmedabad which cannot be broken using only policy measures (e.g. parking management). This dichotomy means that finding investors for constructing parking free apartments or business complexes in these regions would be very difficult. Finally, there exists no policy mechanism to provide social housing currently. One way of providing social housing is through the use of an incentive mechanism to builders (more floor space index if they provide social housing). This method has been used successfully in the state of Maharashtra, India.

Policies measures such as parking management, social housing etc are used along with planning measures in order to improve the accessibility of transit stations (by increasing impedance to car use, reducing bike/walk impedances, etc.). Thus it is important to overcome the barriers identified in the fourth objective.

In conclusion, the inner city of Ahmedabad has a relatively high TOD as compared to the outer corridors. This is not to say that TOD already exists but only shows that a form of TOD exists in Ahmedabad but improvements are necessary in order to achieve complete TOD. The model used for the analysis can be improved by including more indicators. Indicators for measuring the design criteria are especially important; the study area scores low on two of the three indicators chosen for analysis, more indicators can change the score and hence improve the output.

These limitations and possible recommendations for improvement are discussed in detail in the next sections of the chapter.

## 6.1.Limitations

The SMCE method has been used as the framework for analysis in the project. One of the advantages of the method is that it allows for stakeholders opinion in selecting the criteria for analysis. In this project, the criteria for TOD analysis has been determined from a literature survey and administrators, academics and NGO's have been interviewed for determining the ranks for these criteria. The group consisted of 6 people, which is a very small dataset. Also the group is not representative of the entire list of stakeholders and not all of them are from the city of Ahmadabad. The other limitation was in terms of the data used in the project. Secondary data has been used in the project for analysis; the method in which these data have been collected is not entirely clear in all the cases. For example, the number of jobs field in the dataset has decimal values. This indicates that the data has not been collected in the field but has been calculated based on some mathematical operation. The meta data for the dataset was not available .

Other limitations were related to the validation of results. The concept of TOD is an Anglo-American concept which is apparent with respect to the definitions. Indian cities are traditionally compact with high density and diversity, in such a case the same definitions of TOD might not hold well. Thus a value of 135 persons/ acre, which is considered a high density type of development in Florida, USA might not be high density in Ahmedabad. Thus in the Indian context a different standard needs to be applied. Since TOD has not been extensively researched in India, these definitions (or cut-offs) need to be defined by a field visit and interviewing experts in the study area. Due to a budgeting limitation, this was not possible. Changing these definitions would change the standardization method in the SMCE model, which would in turn change the output. Thus the standardization used in the analysis of the study area is based on Anglo-American definitions and hence a potential area of improvement.

Finally, not all indicators from the traditional definition of TOD could be included in the research. Indicators for criteria such as parking management, transit ridership, public safety, climate etc. were not selected due to a limitation in the availability of data.

## 6.2.Recommendations

There are two parts to improvements that has been apparent through the current project. One part is to improve the SMCE model and the analysis framework, and the second is to improve the study area based on conclusions.

As mentioned in the previous section, the SMCE model has been developed based on a literature survey to identify the indicators and a group interview to rank these indicators. The combined opinion of stakeholders was used in designing the model, whereas in Keshkamat et al [66] stakeholders opinions were obtained for their interest areas. This is a possible improvement for the current study and can improve the quality of the model. Also the current study relies almost exclusively on spatial data whereas non spatial data such as ridership information, property values etc can also play a crucial role in TOD type of development. Thus, including these indicators can improve the quality of the output.

The quality and availability of data is another limitation that can be improved in future research. Since the data used in the research is entirely secondary in nature, the underlying operations and methods of data collection are not entirely apparent. One way of improving this is to conduct a field survey to validate the data available as well as correct them if needed. The field survey can also help in collecting data for indicators that are not currently available (such as demand patterns). This can improve the completeness of the SMCE framework.

The standardization of indicators in the SMCE model is a crucial part of the conclusions. Currently the standardization is based on an Anglo-American definition. The cut-offs selected might not be suitable in an Indian context. Since TOD is an integrated land use and transport approach to planning, a study of existing travel behaviour might be suitable in order to identify the cut-offs for a local situation.

One of the main conclusions from the research is that the region ranks very low on the indicators chosen to measure walkability. Quite a large portion of the study area is also unpaved, which offers scope for improvement. Since the funding for improved pavements can be availed from the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), it might be a worthwhile investment. The other conclusion is that some of the regions, especially in the outer sections of the BRT corridor have low density and homogenous land use. These are potential regions for improvement. Instead of improving the entire region, the density and diversity in these regions can be improved.

Finally, indicators for pollution, standard of living (availability of sanitation, water supply, electricity etc.) have not been selected in the SMCE model. Some of these such as availability of basic amenities such as sanitation etc. are not included in traditional definitions of TOD. In the case of a developing country such as India, these indicators are more important (many of the slums do not have good sanitation, electricity or water supply). Considering that Ahmedabad has a good compact development (inner city), focus on these areas might be a more worthwhile investment.

# 7. Summary

### Research setting

Urbanization – the concentration of people and activities in cities – is a rapidly growing phenomenon in the twentieth century. The global percentage of people in cities has grown from 13 in 1900 to 49 in 2005. Urbanization is mostly a desirable phenomenon; it brings about social and economic growth. Cities provide people more opportunities to work, educate themselves, experience new cultures etc. But, urbanization has its price too. Overcrowding, traffic congestion, pollution, urban poverty etc. are some of the ill effects of rapid urbanization. Thus, there is a need to bring about a more effective urbanization or in more scientific terms a strategy for sustainable development.

Transit oriented development (TOD) – defined as high density, mixed use type of development in the near vicinity of transit services –is one such sustainable strategy. TOD has received a lot of focus in the Anglo-American part of the world, where it has been extensively studied. But would the same definitions hold good in other situations as well? In America for example, the suburban culture is predominant; in such a case TOD and other compact development strategies might be very beneficial. Indian cities on the other hand are traditionally compact with mixed type of development. On comparing with the traditional definition of TOD, we could already conclude that these cities are TOD.

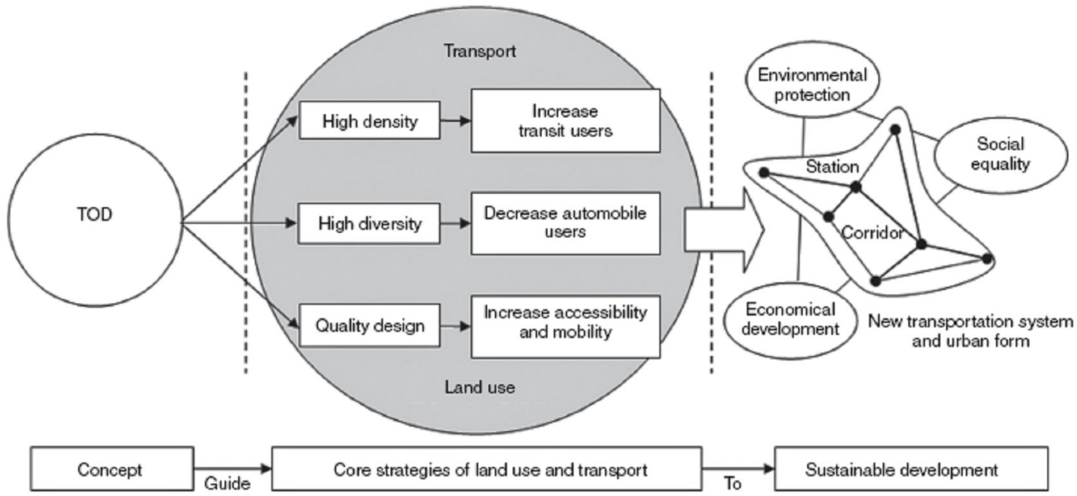
Thus the overall goal of the research is to investigate transit oriented development as a strategy for sustainable development in Indian cities. The study has been limited to one Indian city – Ahmedabad. Ahmedabad has been chosen for two reasons; firstly, the city has recently invested in a Bus rapid transit system (BRT) and secondly, due to a lack of funding a field visit was not possible and hence data could not be collect at the site. Secondary data for the study area was available at the faculty of geo-information science and earth observation (ITC).

TOD is by definition development in *close vicinity* of transit services. Hence a 500 meter area on either side of the BRT corridor is considered as the influence zone for the study. This leads us to the main objective of the study, which is to investigate (or analyse) the influence zone around the BRT corridor in Ahmedabad as a TOD type of development.

### Research design

One of the first assumptions in the study is that TOD is a strategy for sustainable development. Before proceeding with the analysis, this hypothesis needs to be validated. Sustainable development, according to Newman and Kenworthy [1] is any development that has social, economic and environmental benefits. TOD concentrates activities around transit services and within walking distances from these services. The TOD communities are also designed in order to promote the use of non motorized transport within the communities and to use transit to travel larger distances. Thus TOD reduces the use of private automobile and promotes the use of sustainable transport. The objective of TOD is also to provide opportunities to work and live in these communities for all types of people. Thus it helps in creating a social environment. Also the objective of TOD is to increase the accessibility to work and other activities, so that people have more choices and can benefit economically. Thus considering the above definition of sustainable development, we can conclude that TOD is a planning strategy aimed at achieving sustainable development. This is made clearer in the figure below.

Figure 56: TOD and sustainability



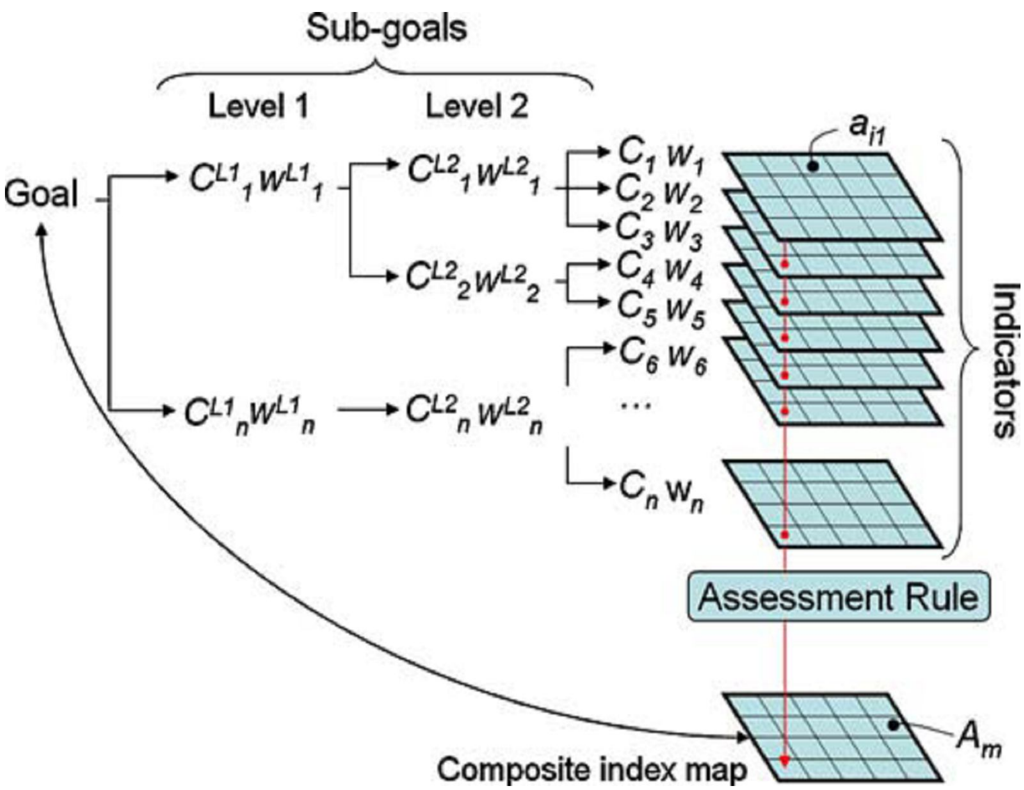

Source: [29]

TOD is an integrated approach to transport and land use planning; it is an integration of planning, traffic management, policies, and urban design. TOD is thus a complex multidisciplinary decision making process. Multi criteria evaluation (MCE) is a method which simplifies complex decisions which involve multiple stakeholders and is an ideal framework for analysing TOD type of development. TOD is also a spatial decision in that given a location (influence zone) we are looking at the type of activities that take place there. Spatial multi criteria evaluation (SMCE) which is a branch of MCE uses the MCE framework with GIS data and methods for spatial analysis. Thus for the answering the research objective, SMCE is used as the analysis method.

### SMCE model and analysis

The figure below shows the stages in spatial multi criteria analysis. The main objective of the study is divided into sub objectives which are further divided into criteria and indicators that measure these criteria. Finally weights are identified for each of these indicators and based on these weights and indicators values, a final composite value is determined which is used to analyse the goal.

Figure 57: SMCE framework




Source: [44]

TOD, according to Cervero and Kockelman [18] has three dimensions criteria – density, diversity and design. Based on these three criteria and through a literature survey, a set of indicators were identified. Sustainable development has three sub goals social benefits, economic benefits and environmental benefits. Since TOD is a sustainable development strategy, it is considered to have these three sub goals as well. Hence as a first step in developing the framework for analysis, the indicators were arranged into these three sub goals. Next, to identify the weights for each of the indicators, a Delphi interview with a group of experts including people from different disciplines was conducted. The output of the interview and the SMCE framework is shown in the following table.

Table 19: Assessment model for current project

| Goal | Theme (weight) | Indicator | Rank |
|---|---|---|---|
| Sustainable development | Social (1/3) | Social dispersion | 2 |
| | | pavements | 1 |
| | | green/open spaces | 4 |
| | | Dissimilar index | 3 |
| | Economical (1/3) | Job density | 3 |
| | | Residential density | 1 |
| | | Accessibility index | 2 |
| | | Commercial index<br>• Residential<br>• Bus stop | 4 (individual indicators get equal weights) |

| Goal | Theme (weight) | Indicator | Rank |
|---|---|---|---|
| | Environmental (1/3) | Street network<br>• Access density<br>• Intersection density<br>• Grid pattern | 5 (individual indicators get equal weights) |
| | | Commercial index | 3 |
| | | green/open spaces | 4 |
| | | pavements | 1 |
| | | Dissimilar index | 2 |

In order to develop a composite value (or map), all the indicators need to be converted to the same units. This procedure is termed as standardization. Standardization uses mathematical functions to reduce the indicators to dimensionless numbers (in the case of the ILWS tool used in this project, to a value between 0 and 1). Indicators can either be standardized as a benefit or as a cost; benefit indicators contribute positively to the output whereas cost indicators contribute negatively. The choice of standardization method and the weight of the indicators are very subjective and changing them can alter the output substantially. A scenario based sensitivity analysis was used to test the validity of the model shown in the above table. For the analysis five scenarios were selected:

- Scenario 1: same as model in table
- Scenario 2: Same as model in table 1, but without arranging them into sub goals (single tree of indicators)
- Scenario 3: Same as scenario 2, but with equally weighted indicators.
- Scenario 4: A model based on the "TOD index" developed by Evans et al. [32].

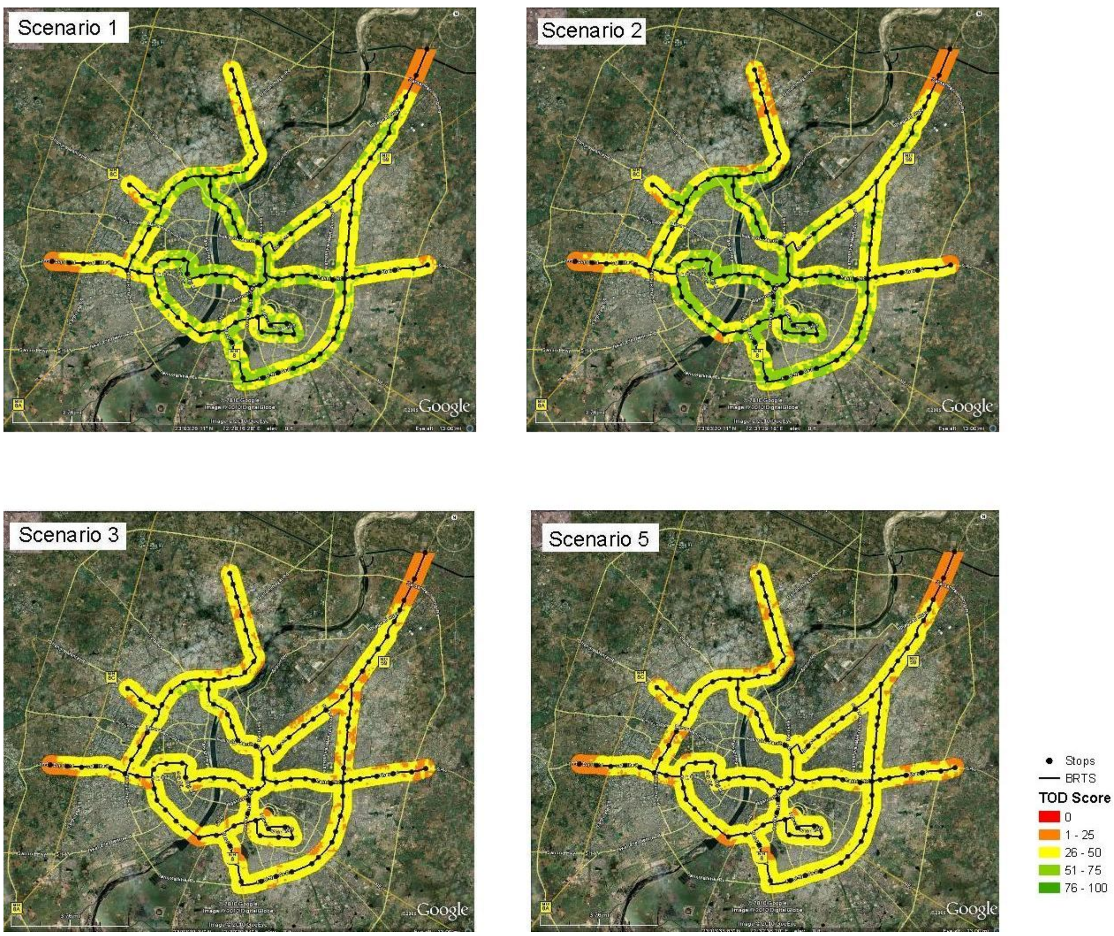
These five scenarios and their criteria tree are shown in the table below.

**Table 20: Sensitivity analysis scenarios**

| Scenario 1 (Rank) | Scenario 2 (Rank) | Scenario 3 (Rank) | Scenario 5 (Rank) |
|---|---|---|---|
| **Social (1)** | Pavements (1) | Pavements (1) | Reliability (1) |
| Pavements (1) | Social dispersion (2) | Social dispersion (1) | Frequency (1) |
| Social dispersion (2) | Residential density (3) | Residential density (1) | Safety (1) |
| Dissimilarity index (3) | Access index (4) | Access index (1) | Population density (2) |
| Green spaces (4) | Job density (5) | Job density (1) | Job density (3) |
| **Economy (1)** | Job housing balance (6) | Job housing balance (1) | Street network (4) |
| Residential density (1) | Commercial index (7) | Commercial index (1) | Pavements (4) |
| Job density (2) | Street network (8) | Street network (1) | Green/open spaces (4) |
| Accessibility index (3) | Green open spaces (9) | Green open spaces (1) | Access index (4) |
| Job housing balance (4) | Dissimilarity index (10) | Dissimilarity index (1) | Social dispersion (5) |
| Commercial index (5) | Reliability (11) | Reliability (1) | Dissimilarity index (5) |

| Scenario 1 (Rank) | Scenario 2 (Rank) | Scenario 3 (Rank) | Scenario 5 (Rank) |
|---|---|---|---|
| **Environment (1)** | Safety (11) | Safety (1) | Job-housing balance (5) |
| Pavements (1) | Frequency (11) | Frequency (1) | Commercial index (6) |
| Dissimilarity index (2) | | | |
| Commercial index (3) | | | |
| Green spaces (4) | | | |
| Street network (5) | | | |
| **Transport (1)** | | | |
| Reliability (1) | | | |
| Safety (1) | | | |
| Frequency (1) | | | |

Figure 58: Sensitivity analysis, 4 scenarios

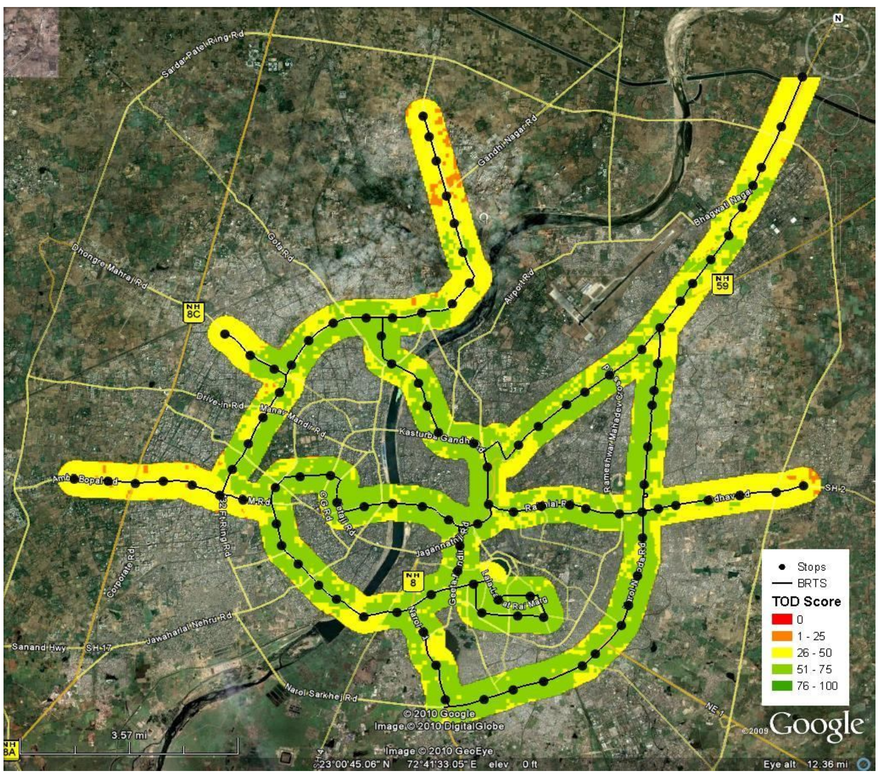



The output of these four scenarios is shown in the above figure. The outputs of scenarios 1 and 2 are very similar, while that of the other two are completely different from these two. The inner city portions of the city are very dense and have high diversity in terms of land uses. They also have a lot of NMT and bus trips. This should imply that this region must rank high on a TOD scale. According to model 3 and 4, this is not the case. The 4th model is based on an American and hence needs to be altered before use in an Indian context. The 3rd model assumes that each indicator has equal influence on the outcome of TOD, i.e. density is as important as the presence of parks for example. This is not an ideal case either and hence is not suitable for use in the project. Finally, the 1st scenario is chosen as the framework for analysis since it recognizes that sustainability has three dimensions and that each of them is important for achieving full sustainability.

### Conclusions and recommendations

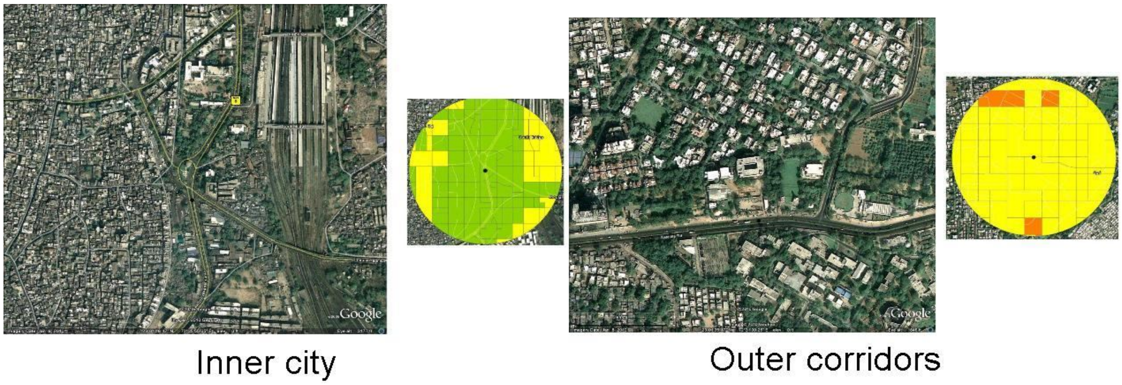
On applying the selected model to the study area, the following output map is obtained. From the map, it is obvious that the inner city region ranks very high on the TOD score and the outer corridors of the BRT does not. This is made even more apparent when we compare the existing development and the TOD map by selecting specific sections in these regions

**Figure 59: TOD in Ahmedabad**



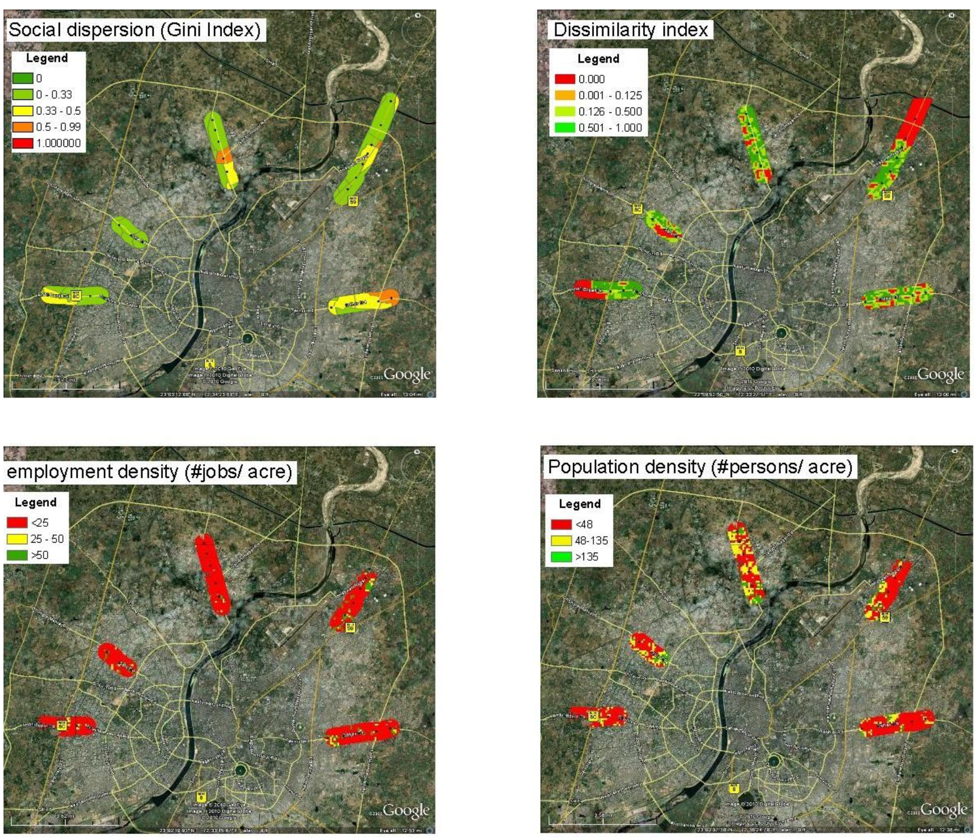

The inner city is very densly populated, compact type of development and is a high score TOD, whereas the outer corridors are sparsely populated suburban type of development and hence have a low TOD score.

Figure 60: TOD analysis (selected locations)




From this we can conclude that rather than looking to improve the TOD score in the entire region, specific sections can be targeted for improvement. The figure below shows the different scores of the individual indicators in these outer corridors, it is quite obvious that values for employment density, population density and dissimilarity index are quite low. Thus there is a possibility of improving these.

Figure 61: Outer corridor indicator values



The region is already classified as an R1 zone (residential with any commercial/retail type of development), hence mixed use development is an immediate possibility. Increasing density is possible by increasing the floor space index (FSI) in these regions. But these regions have an allowed FSI of 1.8 whereas the consumed FSI is only 0.8. Thus the first priority should be to improve the density by utilizing the whole of the allowed FSI.

Town planning and development venture in Ahmedabad has two stages, preparation of a development plan (DP) and then a town planning scheme (TPS). There is no provision of land acquisition. These two stages DP and TPS are very centralized in that they have to be approved by the state government before implementation. Also a lot of bureaucratic procedures are involved with the preparation of the TPS. Thus in general a lot of time is involved in preparing and getting the approval for any proposal. One way of overcoming this is to transfer the responsibility to the local development authority and remove the dependency on the state government for each stage of town planning.

Finally, there is no policy to provide for affordable housing to the poor in any of the new development areas. This needs to be addressed. The state of Maharashtra uses a policy where extra FSI is provided to developers who are willing to set aside a share of the land for affordable housing. This policy measure can be used in Ahmedabad as well.

# 8. Appendix 1: Questionnaire

**Please rank the following indicators on a scale of 1 to 10, 1 being least important and 10 being most important.**

**The influence area (TOD zone) for the study is taken as 500 meters around the transit infrastructure (stations or transit lines). The indicators below are considered for this zone.**

1. Availability of on street parking (On street parking indicates that people can travel to these areas and park their private vehicles for free, which does not really help promote transit) ........

2. Number of transit boarding's within a walking radius (500m) (Ideally people would not want to walk too far to board transit services.) ........

3. Number of houses around transit stations or close to transit corridor (transit zone) (More homes close to transit services encourage people to use transit) ........

4. Number of jobs in transit zone ........

5. Number of connecting services to rapid transit (using the rapid transit line as the economic development zone means that other regions in city should be able to easily access these facilities) ........

6. Distribution of people (the concept of TOD encourages transit use to reduce automobile dependency. Hence there is a need for affordable housing whereby people of all walks of life should be able to live in these communities) ........

7. Number of intersections (more intersections imply slower speeds for vehicles and hence are a deterrent to owners of private cars as well as being safer for pedestrians and bikers) ........

8. Number of access points (more access means better connectivity) ........

9. Public lighting for pedestrians and at transit stations (safer environment) ........

10. Availability of sidewalks (encourages walking) ........

11. Bike lanes (encourages biking) ........

12. Diversity of land use (diverse land uses with different activity opportunities promote trip chaining and use of sustainable modes of transport to conduct these activities) ……..

13. Open spaces/parks (creates a more aesthetic and green community) ……..

**Are there any indicators that you feel are important and not listed above? If so please list them (with rank) below.**

………………………………………………………………………………………………………………………………………………

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**Would it be alright to contact you in case of further clarifications? If so, please indicate your name and email address below.**

Name: ……………………………………………………………………………………

Email: ……………………………………………………………………………………

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