URBAN CYCLING AND LAND-USE INTEGRATION IN PUNE, INDIA

EXAMINING THE USE OF A SPATIALLY-CONSTRAINED ACCESSIBILITY MEASURE

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March, 2011

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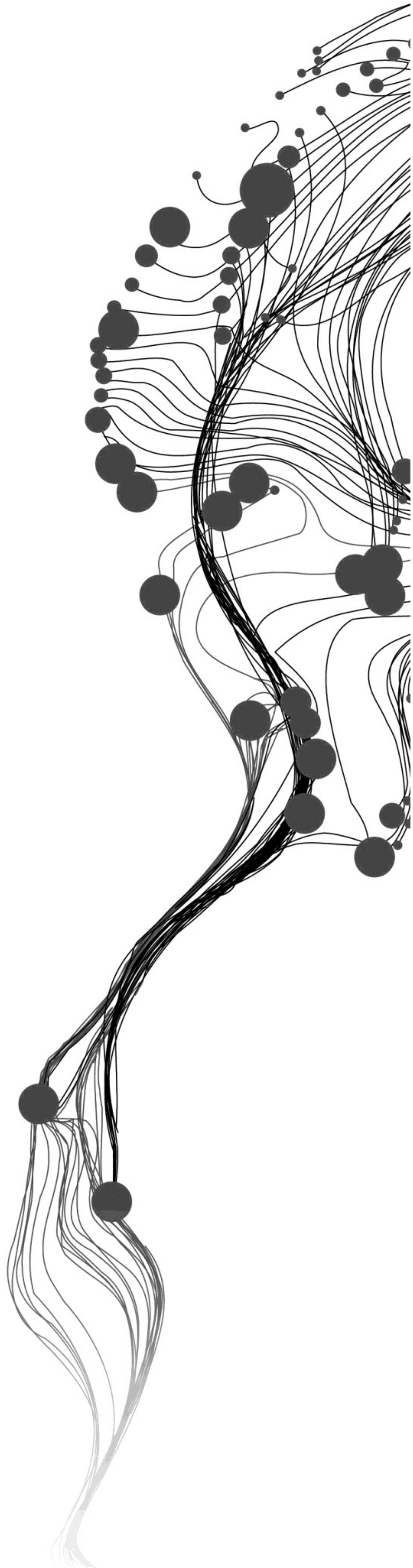

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ALANDO, Walter
Enschede, The Netherlands, March, 2011

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'The real voyage of discovery consists not in seeking new lands but seeing with new eyes'

Marcel Proust (1871 – 1922)

To my late grandmother, Silvia who taught me the value of humility

ABSTRACT

Urban cycling can contribute to ameliorating the current urban transport challenges facing developing cities if it is well integrated into urban transport and land-use system. Unfortunately, it is scarcely ever taken into account in most developing cities in general and Pune in particular. No previous study seems to have explicitly investigated the effects of physical barriers caused by land-use and transport planning on urban cycling in developing cities in order to inform its integration into the urban system.

The current study examines the use of a spatially-constrained accessibility measure in integrating urban cycling and land-use in the context of Pune city, India. This is important in order to find out its usefulness in supporting decisions on urban cycling and land-use integration. The main objective of the study is to develop and test a spatially constrained accessibility measure for integrating urban cycling and land-use. Four specific objectives are addressed: i) To analyse the existing urban transport and land-use situation in Indian cities in general and Pune in particular; ii) To analyse the cycling patterns and behaviours in Pune; iii) To analyse the spatial configuration of Pune; and iv) To develop and implement a spatially-constrained accessibility measure for urban cycling-land-use integration in Pune. The findings of the study are relevant to urban planning practitioners, scholars and all persons interested in urban cycling-land-use integration.

Socio-economic, road network and land-use data from secondary sources are analysed to address the study objectives. To this end, a three-stage approach is followed to analyse the data and to interpret their meaning in the context of the current study i) literature is reviewed to get the current state of knowledge with regard to urban cycling and land-use; ii) statistical analysis is carried out on socio-economic data to understand the cycling behaviours and patterns in Pune. Parallel to this is a spatial analysis that aims to find out the possible implications that land-use patterns have on the revealed cycling behaviours and patterns; and iv) accessibility modelling whose aim is to understand how the land-use patterns and cycling infrastructure provision has impacted on urban cycling in Pune.

The key findings of the study are that i) urban cycling is influenced by both land-use patterns on the one hand and the provision for cycling on the roads on the other hand. The latter influences distances between trip origins and opportunities while the former influences the perception regarding safety among cyclists. These determine whether or not people will cycle; ii) current theories of urban transport and land-use are inadequate in explaining cycling behaviour and patterns with respect to urban land-use in the developing cities; and iii) The use of a spatially-constrained accessibility measure can enable the levels of accessibility in different parts of a city to be studied under different scenarios and to further relate them to land-use patterns and the provision for cycling infrastructure.

In view of the findings, the study concludes that the spatially-constrained accessibility measure offers a useful tool for urban cycling and land-use integration. The measure can enable an analysis of the impacts of land-use plans as well as transport plans on cycling and provoke urban planners to influence land-use patterns and infrastructure that are sensitive to cycling needs. These can make it a useful decision support tool for integrating urban cycling and land-use.

The study recommends the development of theories to explain the relationship between cycling and land-use in the context of developing cities and data collection for validation of its findings. A more targeted investigation of the urban form factors that influence cycling in developing cities would also be useful in enabling a more succinct definition of the barriers to cycling.

Key words: Accessibility, urban cycling, urban form, Pune, spatially-constrained accessibility measure

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Walter Alando
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1. INTRODUCTION

1.1. Study background

The contemporary urban transport challenges characterised by increase in air pollution, traffic congestion and unsustainable fuel energy consumption among other concerns call for a different approach to addressing urban transport needs. Recent studies (Forman, 2008; Muñiz & Galindo, 2005; Zhao, 2010) have raised concerns regarding the threatened urban environmental sustainability due to car pollution and dwindling world oil supply thanks to the continued dependence on fossil fuel. The authors have also attributed the increasing urban inequality with respect to accessing transport infrastructure and services to the contemporary urban transport situation that is mainly car-dependent. This state of affairs begs for an urgent attention in order to sustain the current cities.

These concerns are no longer the preserve of the cities of the developed world alone but equally of those of the developing countries (da Silva, da Silva Costa, & Macedo, 2008; Huang, Lu, & Sellers, 2007; Ooi, 2009). In India in particular, road congestion, noise and air pollution, traffic fatalities, injuries and inequity among other urban transport challenges have been identified as key concerns (Pucher, Korattyswaropam, Mittal, & Ittyerah, 2005; The World Bank, 2002a, 2002b). This state of affairs has been attributed to deficiencies in the country's urban transport service and infrastructure provision (Pucher et al., 2005; The World Bank, 2002a, 2002b).

The situation with regard to urban cycling has not been any better albeit for different reasons. Unresponsive manner in which land-use and streets of these cities are patterned is in part thought to account for this situation (Tiwari, 2002). While non-motorised transport at large accounts for over 2/3 of urban trips in small and medium cities like Pune, it remains weakly addressed in both land-use planning and designing the space dedicated for roads (Pucher et al., 2005; The World Bank, 2002a, 2002b). This has particularly rendered the poor who comprise the majority of cyclists to work, school and other short distance destinations exposed to traffic fatalities as most roads do not accommodate them (Mohan, 2004; Pucher et al., 2005). Pucher et al. (2005) for instance observe that cycling is currently the most dangerous mode of transport in India.

The foregoing situation is complicated by a rapidly burgeoning urban population which has precipitated further urban sprawl without commensurate transport infrastructure, not least for the cyclists. Chakrabarti (2001) notes that India's urban population has grown by nearly five times over the last 50 years and projects that it will have the largest concentration of mega cities in the world by the year 2021. Similar urban transport challenges have been documented in cities of China (Zhao, 2010), Brazil (da Silva et al., 2008) and Tanzania (Olvera, Plat, & Pochet, 2003) among other fast-growing cities of the developing countries. The urban transport situation is even more worrying in small and medium cities of the developing countries due to their invisibility from policy and decision makers (Dimitriou, 2006). In Asian cities alone, the author observes that policies and investments have been skewed against the medium and small cities in spite of the urban transport challenges they face.

Efforts to address these concerns have witnessed a renewed call for an urban planning approach that integrates urban land-use and transport planning. These can lend important lessons for integrating urban cycling and land-use. The basis for this is the mutual interdependence that has been recognised between transport and land-use by Zhang and Guindon (2006), Zhao (2010), Geurs and van Wee (2004) and

Srinivasan and Rogers (2005) among other authors. These authors have demonstrated a cyclic relationship in which the development of transport infrastructure spurs land-use change which in turn stimulates the development of transport infrastructure. This new thinking can lend important lessons for integrating urban cycling and land-use in developing cities. Chen, Jia and Lau (2008), Forman (2008), Frank, Greenwald, Winkelman, Chapman and Kavage (2010), Hankey and Marshall (2009), Hasse (2007) and Ooi (2009) have drawn parallels between rapid urban growth and the contemporary urban transport concerns. They not only attribute rapid urban growth and its attendant changes in urban form to rapid economic and socio-spatial transformation but also observe that these processes have in part given impetus to the contemporary urban transport concerns as they alter travel patterns. Against this backdrop, there is an emerging consensus that urban transport challenges cannot be addressed in isolation of the underlying urban form framework that influences travel behaviour (Bertolini, le Clercq, & Kapoen, 2005; da Silva et al., 2008; Frank et al., 2010).

Emerging trends towards the turn of the last century witnessed a major departure from the traditional urban transport planning. Iacono, Krizek and El-Geneidy (2010) and da Silva et al. (2008) note that this approach narrowly focuses on mere promotion of vehicular mobility rather than accessibility as the strategy for addressing urban transport challenges. The authors' reasoning seem to suggest that urban land-use and transport planning have fallen short in addressing the reason why people travel; rather, they have been more reactive through provision of infrastructure to enable people to move. It is in this context that new approaches underscore the need for integrated social, economic and environmental view to urban transport planning and firmly put land-use planning at the core of sustainable transport (da Silva et al., 2008; Iacono et al., 2010). Consequently, emphasis is placed on promoting accessibility alongside mobility without losing sight of environmental, social and economic sustainability concerns. This has brought to fore the need to encourage non-motorised transport. Particular focus is now placed on cycling and other means of non-motorised transport that are seen to be affordable, efficient and environmentally clean (Bertolini et al., 2005; Iacono et al., 2010; Muñiz & Galindo, 2005).

It has been noted that a well-defined concept of accessibility can offer a useful framework for integrating transport and land-use planning (Bertolini et al., 2005). The authors point out that the concept can directly be related to the quality of transport and land use systems on the one hand and social, economic and environmental goals on the other hand. While there is no best approach to assessing the usefulness of accessibility measures in integrating urban land-use and transport, Handy and Niemeier (1997) have identified theoretical soundness, interpretability and usability as some broad criteria against which this can be achieved. On the other hand, Geurs and van Wee (2004) broadly classify accessibility measures into four groups comprising of infrastructure-based, location-based, person-based and utility-based measures.

Despite the improvements in accessibility measures, Iacono et al. (2010) note that the measures remain predominantly car-based and limited to studying access to employment destinations. Accessibility measures that explicitly take into account the urban land-use patterns and spatial barriers occasioned by the design of the road space in developing cities seem to remain largely scarce. There is hence a need for a detailed enquiry into accessibility for cycling in the context of developing cities and to find out its utility in supporting land-use and cycling integration.

1.2. Justification

A number of current studies relating to the integration of urban land-use and transport seem to largely remain restricted to motorised modes of transport (Bertolini et al., 2005; Iacono et al., 2010). Similarly, it has been observed by authors like Iacono et al. (2010) that many calculations of measures of accessibility have largely been concerned with only a few destination activities that are accessible to motorised transport. Interestingly, there seems to be little attention so far accorded to the rapidly developing cities like Pune despite their unique urban land-use patterns, modes of transport and levels of transport infrastructure development which have been found to impose barriers to cycling in these cities. The current study sought to bridge this current gap by developing and testing a spatially constrained accessibility measure that takes cognizance of the unique interplay between urban cycling in developing cities and their underlying land-use patterns and road design.

The significance of the study is that it demonstrates the usefulness of the spatially-constrained accessibility measure in aiding decisions on urban cycling and land-use integration in a rapidly developing city like Pune. The study hopes that its findings with regard to the relationship between urban form and cycling will inform urban planning policies that encourage accessibility for cycling. Similarly, it is hoped that these findings will be useful to urban planning authorities in developing scenarios for assessing the influences that changes in urban form impart on cycling. This is important in order to not only redress the current urban land-use planning policies that promote automobile dependency but also to address the rapidly widening inequality gap with respect to access to urban transport infrastructure and services. The findings of the study also lead to an improved theoretical understanding of sustainable urban accessibility in the context of the developing cities.

It is hoped that the findings of the study will be relevant to urban planning authorities, academia and persons interested in the interchange between urban form and cycling in general. The findings of the study remain particularly important to Pune's urban planning authority, more so within the context of the current India's National Urban Transport Policy which targets to move people rather than vehicles. Nonetheless, the findings are equally useful to other urban planning authorities that are facing identical urban transport concerns as Pune.

1.3. Statement of the problem

The need for sustainable urban transport strategies in developing cities like Pune cannot be overemphasised considering their rapid socio-economic and spatial expansion. The realities of urban environmental degeneration on the one hand and the growing inequality with regard to accessing transport infrastructure and services on the other hand are a growing concern. These emanate in part from the current urban land-use and transport planning systems that are largely skewed in favour of motorised transport. In Indian cities in particular, traffic congestion, environmental deterioration and traffic fatalities affecting mostly the captive cyclists have been reported as a growing concern (Mohan, 2001, 2004).

It has been suggested that a deliberate focus on promoting cycling can help in ameliorating this worrying trend by availing options that are not only affordable but also clean, efficient and healthy (Frank et al., 2010; The World Bank, 2002a, 2002b). Despite this, the current land-use and transport planning set-up in India, like in many other developing countries, remains largely insensitive to cycling despite the fact that it commands a significant share of urban trips (Pucher et al., 2005; The World Bank, 2002a, 2002b). There is hence a need for a systematic investigation to understand the prevailing urban planning regime and the nature of spatial constraint it presents to cycling.

Furthermore, it has been argued that urban land-use planning must dovetail with transport planning in order to achieve the desired sustainability in urban transport (Iacono et al., 2010). In this regard, there is currently a consensus among authors and practitioners that the concept of accessibility offers a useful framework for integrating the two (Bertolini et al., 2005; Geurs & van Wee, 2004; Iacono et al., 2010). Many accessibility measures that have been developed to integrate them have however fallen short of expectation (Iacono et al., 2010). The author argues that these measures have so far not been able to aid decisions on transport and land-use integration. Against this backdrop, the ability of accessibility concept to provide a framework for integrating urban land-use and cycling remains unclear, more so in the context of developing cities like Pune. Moreover, that most of the current researches have focused on developed cities also raises concerns with regards to the spatial transferability of their findings to the developing cities. The need to develop accessibility measures that are sensitive to the situations of developing cities cannot therefore be overemphasised given these realities.

Against the foregoing background, the study documented herein sought to develop and test an accessibility measure that would be useful in integrating land-use and cycling in the context of Pune city and by extension other developing cities facing similar urban transport challenges.

1.4. Research objectives

The main objective of the study was to develop and implement a spatially-constrained accessibility measure for integrating urban cycling and land-use planning in Pune city. The study raises the hypothesis that accessibility for cycling in the city is constrained by physical barriers that result from urban planning processes and therefore largely confined to the zones defined by these barriers.

The specific objectives include the following:

i.) To analyse the existing urban transport and land-use situation in Indian cities in general and Pune city in particular;
ii.) To analyse the cycling patterns and behaviours in Pune city;
iii.) To analyse the spatial configuration of Pune;
iv.) To develop and implement a spatially constrained accessibility measure for urban cycling in Pune.

1.5. Research questions

The study raises the following questions in order to address objectives:

1.5.1. To analyse the existing urban land-use and transport situation in India in general and Pune city in particular

- *What are the salient urban land-use and transport policy issues and aspirations of India in general and Pune city in particular?*
- *What is the nature and social, economic and environmental implications of the foregoing situation?*
- *How has cycling as a means of urban transport in Pune been affected by the current land-use and transport policies and situation in India?*

1.5.2. To analyse the cycling patterns and behaviours in Pune city

- *What are the striking cycling patterns and behaviours in Pune city?*
- *What land-use and road network factors influence these patterns and behaviours?*

1.5.3. To analyse the spatial configuration of Pune

- *What urban form indicators can be used to determine cycleable zones of Pune?*
- *How can these indicators be operationalised in GIS to describe the urban form of Pune?*
- *How can the spatial configurations and characteristics of the zones be analysed using these indicators?*
- *How does the urban form relate to cycling patterns?*

1.5.4. To develop and implement a spatially constrained accessibility measure for cycling in Pune

- *What are the various accessibility measures in literature?*
- *Which of these measures can be adapted to enable an assessment of the interaction between land-use and transport?*
- *How can these measures be used to assess the cycleability of the city?*

- *How does the urban form that results from the implementation of the accessibility measure developed impact on cycling patterns in the city?*
- *How useful is the measure developed in enabling the integration of urban cycling and land-use planning?*

1.6. Research design and thesis structure

The study documented in this thesis is based in Pune city, India. The researcher assumes that the conditions of the study area are identical to those of other developing cities of its rank and that the findings from the current study can lend important lessons for integrating urban cycling and land-use in these cities too.

The study sets off by literature review, which informs its appreciation of the real world urban transport challenges evidenced by their social, economic and environmental impacts. The literature review then delves into the Indian context with a view to finding out how the current urban transport and land-use situation have impacted on urban cycling in the country in general and in Pune in particular. This enables the study to formulate the research problem. Literature review is further carried out to bring to the fore the current state of knowledge with regard to urban cycling and land-use integration. This informs the theoretical basis of the study besides enabling a better understanding of concepts like urban form and accessibility. It is recognised that while the theories are motor-based, the underlying human behaviour that they explain remain similar to an extent even in the case of cycling.

With the above knowledge, the study then proceeds to formulate its research objectives and questions. These are used to guide data search from secondary sources to enable the study to realise its objectives. Data analysis integrates literature-based analysis, statistical and spatial analyses, network analysis and accessibility modelling based on the revealed cycling patterns and behaviours obtained from statistical analysis. This enables the study to draw conclusions and to make recommendations that it hopes can lead to better modelling of accessibility measure for cycling and by extension better integration of urban cycling and land-use. Figure 1-1 below summarises the study design.

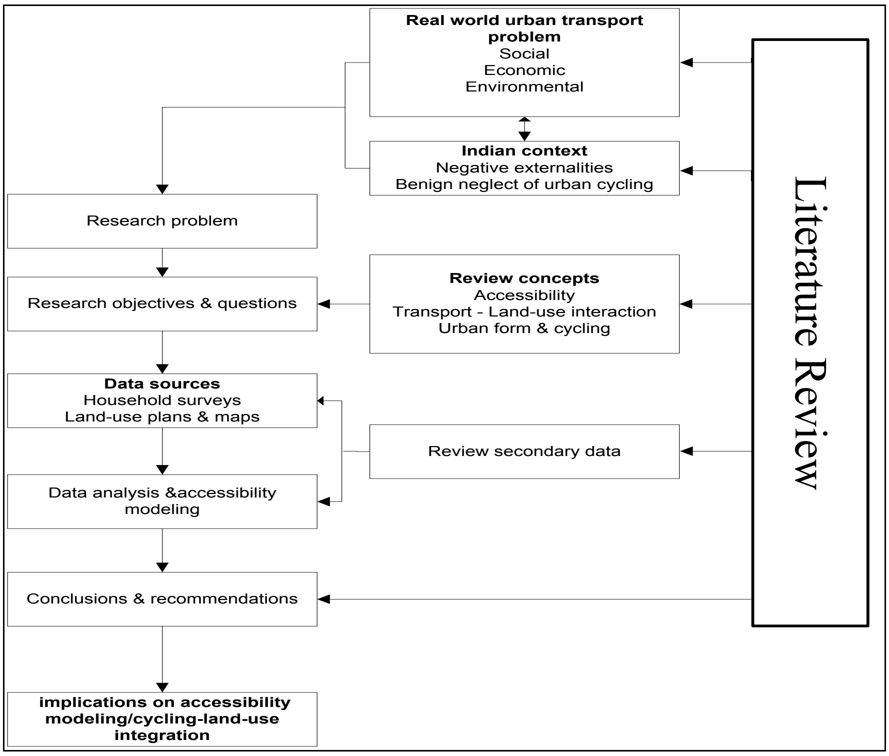

Figure 1-1: Research design

The study is organised in seven chapters. The first chapter sets the background of the study and gives a justification for undertaking it. The problem statement, research objectives and research questions are also detailed in this first chapter. The chapter concludes with a research design which offers a step by step account of the strategies that were adopted in order to realise the objectives of the study.

The literature review in the second chapter puts the concepts of urban form, urban transport and accessibility into perspective. A theoretical grounding of the interaction between urban transport and land-use is then presented in the chapter, consequently enabling the study to establish the place of accessibility in integrating the two. This is followed by a review of the current state of knowledge with regard to the concept of accessibility. A conceptual framework that presents how the study has been idealised concludes the chapter.

The third chapter discusses the data used in the study and the methods that were adopted in order to address the study objectives. The chapter also details the data sources, preparation and analysis. The chapter concludes by highlighting the key limitations of the study.

Chapter four introduces the study area in an effort to put it into the context of the current investigation. The basis for selecting the study area is as well given in the chapter.

In chapter five, the actual data analysis and results are presented. Accessibility for cycling is also carried out in the chapter while chapter six discusses the results of the analysis and modelling with a focus on linking these results to the study objectives. A summary of the findings and their implications on urban cycling and land-use integration are presented in chapter seven. The chapter also contains the conclusions and recommendations of the study.

2. URBAN FORM, URBAN TRANSPORT AND ACCESSIBILITY IN PERSPECTIVE

The previous chapter has introduced the study by detailing its general background, the research problem and objectives and its justification. The present chapter reviews the current state of knowledge with regard to urban form, accessibility and urban transport. The general interdependence between urban form and transport is introduced in section 2.1 followed by a theoretical account of this interaction in section 2.2. The concepts of urban form and accessibility are discussed in section 2.3. The section also gives a working definition of these concepts that is relevant to urban land-use planning and cycling integration. The literature review then takes a closer look at the interdependence between urban form and cycling in section 2.4. The chapter culminates in a conceptual framework that highlights how the entire study was idealised.

2.1. Introduction

The mutual interdependence between urban transport and urban land-use is not a recent recognition. Theories developed from as early as the times of Von Thunen (1783-1850) sought to account for this interdependence by looking at the location behaviour of firms and individuals under different transport conditions. Recently, researchers like Hansen (1959) and Zhao (2010) have looked at this interdependence from land-use perspective while others like Srinivasan and Rogers (2005) and Williams (1989) have looked at it from transport perspective. These researchers have come to the conclusion that neither urban transport planning nor urban land-use planning can on its own lead to sustainable cities. Despite this, dovetailing the two remains an elusive goal to the contemporary urban planner (Curtis & Scheurer, 2010; Tennøy, 2010). Tennøy (2010) for instance points out that conflict in framing urban transport problems among land-use and transport planners poses a great drawback in integrating the two.

Understanding the influence of land-use policies on urban transport on the one hand and the impacts of urban transport policies on urban land-use on the other hand has featured prominently in recent years (Banister, 2008; Bertolini et al., 2005; Cao, Mokhtarian, & Handy, 2007; Curtis & Scheurer, 2010; da Silva et al., 2008; Dimitriou, 2006; Wegener & Furst, 1999). At the same time, it has been argued that a well-defined concept of accessibility avails a useful platform for integrating urban land-use and transport (Bertolini et al., 2005).

There seems to be a consistent consensus among authors like Hansen (1959), Wegener and Furst (1999), Cao et al. (2007) and Zhao (2010) that urban land-use policies impact on key urban transport indicators like trip length, trip frequency and mode choice. It is apparent from their argument that urban land – use planning shapes urban form through the location, distribution and densities of opportunities thereby influencing people's travel patterns. Wegener and Furst (1999) for instance positively correlate higher densities of employment to average trip lengths while Cao et al. (2007) point out that high density residential development only leads to shorter average trip lengths if the travel cost is increased. On the other hand, attractive neighbourhood facilities are suggested to reduce trip lengths while a mix of workplaces and residential land-uses with shorter trips are seen to have a positive impact on physical transport modes like cycling and walking.

On the flip side of the foregoing are studies that have looked at the relationship between urban land-use and transport from urban transport policies point of view. These studies have found out that transport policies influence urban land-use patterns by altering accessibility at locations. Bertolini et al. (2005) and Wegener and Furst (1999) for instance note that higher accessibility increases the attractiveness of a location for all types of land-uses, consequently influencing the patterns of new urban development. According to this reasoning, locations with better accessibility to opportunities like employment, shops, schools and leisure facilities are likely to attract a lot of traffic.

The urban road networks and their functional design have also been found to influence travel costs, travel time, safety on the roads and accessibility. These in turn impact differently on the choice of modes and routes. According to Srinivasan and Rogers (2005), Wegener and Furst (1999) and Williams (1989) locations with good accessibility to many destinations are likely to produce longer trips of higher frequencies. In terms of modal choice, locations with good accessibility by a particular mode of transport have been found to produce more trips of that mode (Wegener & Furst, 1999).

2.2. Theoretical context

The first section of this chapter has introduced the interaction between urban form and transport. The current section now establishes the theoretical foundation of the relationship explained in the first section. While these theories are car-based in origin, the current study nonetheless recognises that the human behaviour that underpins them does not significantly change in the case of cycling which is the concern of the study.

The interrelation between urban land-use and transport finds its initial account from the work of early theorists who sought to explain the urban structures and land-use patterns of their times. Among them are Von Thunen (1783 – 1850), Burgess (1886 – 1966) and Alonso (1933 – 1999). They theorised that the distribution of land-uses like residential, industrial and commercial over space patterned the location of human activities like shopping, leisure, living and working which in turn created a need for spatial interaction through transport systems (Ayeni, 1979). This explains the current argument that the demand for travel is derived from the need to take part in activities that are spatially separated (e.g. Banister (2008)) It is evident in the models of these early theorists that minimising the cost of overcoming the spatial separation between opportunities and trip origins was central in shaping the urban land-use pattern. As can be seen in figure 2-1 below, trip makers' desire to locate near opportunities is constrained by competition for space near these opportunities. Consequently, land-use activities (e.g. commercial) that are more profitable locate closest to the opportunities than those that were less profitable (e.g. residential).

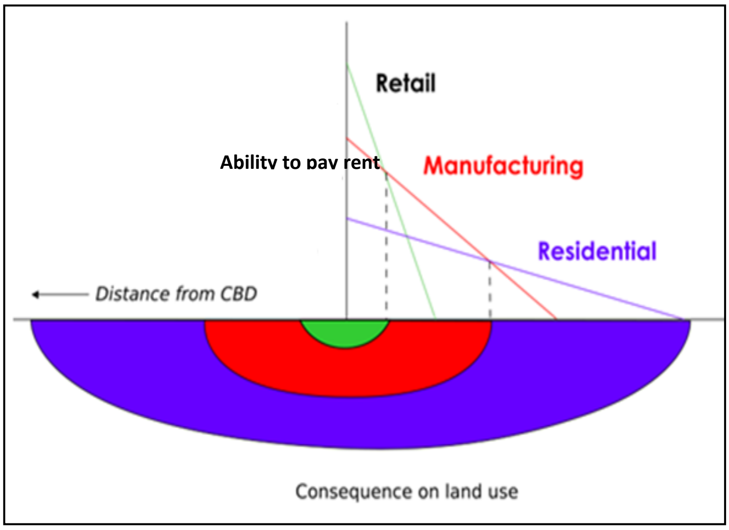

Figure 2-1: Locational behaviour

(Source: www.citilabs.com – based on Alonso's bid rent theory)

The foregoing raises important points that are of relevance in the current study: i) urban land-use planning patterns the distribution and densities of opportunities. It consequently spurs travelling as trip makers seek to take part in activities that are spatially disjointed; ii) urban land-use planning also results in distances between urban land-use activities by separating them through such strategies as the zoning plans. The distances so created are not only an impedance to travelling but can also be barriers to some modes of transport like cycling once it is no longer economically viable to travel beyond particular distances; iii) the location of urban land-use activities is the product of both urban planning as well as lack of it. Both of them impact on the travel patterns. Consequently, urban sprawl will continue for as long as rents at the inner city remain high and as long as the planning system keeps lagging behind urban development. Quite often such developments have tended to be of residential type and they will keep generating new demand for travel as long as the opportunities keep concentrating in one part of a city.

Three broad categories of theory, namely technical, economic and social theories have since been advanced in an effort to account for the interaction between urban transport and land-use.

The technical theories, founded on the spatial interaction paradigms, explain the relationship between transport and the urban development using the concept of accessibility. Hansen (1959) in his study of Washington DC for instance demonstrated that locations with good accessibility had a higher chance of being developed, and at higher densities than remote locations. The technical theories recognise that travel patterns and location decisions co-determine each other and that land-use and transport planning must as such be coordinated. According to the technical theories, the frequency of interaction between different locations is directly proportional to their population sizes and inversely proportional to the distance separating them (Grigg, 1977; Ravenstein, 1885). The theories' assumption that there exists equal ease of access to all locations and that the transport conditions are also similar have been their main source of criticism (Wegener & Furst, 1999). Similarly, their inability to account for economic behaviour that influences trip making and location choices have also been questioned (Wegener & Furst, 1999). Nonetheless, they remain relevant in this current study in as far as they are capable of explaining the influence of opportunities and impedance factor imposed by distance in shaping trip makers' travel patterns.

Part of the shortcomings of the technical theories is addressed by the economic theories. These theories postulate that establishing economic equilibrium between location choices and transport cost is the driving force that shapes urban form (Alonso, 1964). Accordingly, firms and individuals agglomerate in particular locations in order to minimise the cost of transport and to benefit from economies of scale (Alonso, 1964; Krugman, 1996). At a micro-scale, Alonso (1964) points out that firms and households locate where their bid rent equals the asking rent so that the land market is always in equilibrium. A location away from the equilibrium leads to higher transport cost but lower rents. Individuals and firms therefore have to weigh such location decisions against the bid rent and the cost of transport.

Economic theories have for instance been used by Wegener and Furst (1999) to explain the spatial polarisation and continued urban sprawl observed within urban regions. The authors employ economic theories to account for the location of manufacturing firms in low density sites as well as the location of retail facilities in the suburbs near customers. Tacit from these observations is the role that good accessibility plays in influencing location behaviours and by extension urban form. The relevance of this theory in the context of the current study is that it raises curiosity to establish how cyclists behave in terms of their location *vis a vis* the land-use opportunities and the impedance imposed by the cycling conditions of the roads.

The social theories have on their part considered urban form as a fundamental dimension of human existence. Perhaps the most instructive theory under this set of theories is that developed by (Zahavi, 1974). Contrary to the expected behaviour, this theory argues that individuals in their daily mobility decisions do not minimise travel time or travel cost but instead maximise activities or opportunities that can be reached within their travel time and money budget. Wegener and Furst (1999) invoke this theory to explain why households use the gains in travel speed occasioned by road infrastructure expansion to make longer trips rather than to save time as always intended by such projects. Similarly, the authors have applied the same theory to explain why there has not been a reduction of automobile travel and travel expenditure in European countries despite the decline in petrol prices by more than half in real terms over the past forty years.

While the first two theories can directly be related to cycling, the social theories on the other hand seem to reinforce the thinking in the current study that a deliberate effort has to be made outside of car-based solutions to address the current urban transport challenges facing the developing cities. In line with the reasoning under the social theories, it is apparent that the continued expansion of infrastructure alone cannot address these challenges. In spite of the differences in approach among the theories discussed above, it is interesting to note the central influence that ease of accessing destinations has in all these theories. This concept of accessibility is discussed in detail in the proceeding part together with the concept of urban form.

2.3. Concepts

2.3.1. Accessibility concept

The concept of accessibility in transport planning was first defined by Hansen (1959) as the ease of reaching the desired destinations. Anchored on the theory that space constrains the number of opportunities available to travellers, accessibility concept has enabled an account of the travel behaviour such as trip frequency, destination choice, mode choice and trip complexity (Hanson & Schwab, 1987; Williams, 1989). Despite its recognition in enabling urban land-use and transport integration however, the concept remains largely misunderstood, poorly defined and poorly measured (Geurs & van Wee, 2004). This probably explains why it is currently neglected in mobility and land-use dynamics in spite of being recognised as an important precondition for sustainable urban development (Iacono et al., 2010; Priemus, Nijkamp, & Banister, 2001; Wegener & Furst, 1999). Nonetheless, authors like Bertolini et al. (2005) and van Wee, Hagoort and Annema (2001) have suggested that the concept can not only enable qualities of urban transport to be related to land-use systems but that it can also facilitate the integration of economic, social and environmental goals. It is worth noting that these are the very foundation upon which the current quest for sustainable urban transport is anchored.

Studies relating to the concept of accessibility in land-use-transport integration have documented the current state of knowledge with regard to the concept, posed challenges to it and opened up gray areas for deeper enquiries. Probably the works of Daniels and Warnes (1980), Breheny (1992) and Priemus et al. (2001) offer a better starting point in this review. These authors have recognised the mutual influence between mobility and spatial dynamics on the one hand and their environmental implications on the other hand. Priemus et al. (2001) for instance draw parallels between European compact cities and their greater use of public transport and low fuel energy consumption unlike American cities which are largely characterised by urban sprawl. It is however interesting to note that while these authors seem to be against suburbanisation processes of urban spatial dynamics, other authors hold different opinions about the issue. Gordon and Richardson (1995) for instance argue that suburbanisation of both living and work may indeed result in a reduction of both commuting distances and commuting time. This argument is reinforced by the observation that the compact city planning can engender an increase in car kilometre (Priemus et al., 2001).

Perhaps the foregoing is a challenge to urban land-use planners to focus more on influencing travel patterns through functional land-use mix as opposed to their current preoccupation with compact development within a clearly desegregated land-use setup. It is not surprising that Priemus et al. (2001) have observed that compact city planning can after all promote an increase in car traffic if the underlying reasons for trip generation and attraction are not addressed. In the Netherlands, Bertolini et al. (2005) single out an emerging development pattern characterised by redistribution of non-daily services like shopping and public facilities, which have traditionally occupied the urban core from the old city centres to new centres. This approach supports accessibility concerns not only in the Netherlands and other developed cities but also the developing cities where similar urban development patterns have been reported by Chakrabarti (2001), da Silva et al. (2008), Ooi (2009) and Zhao (2010) among others.

An appreciation of the underlying human behaviour has similarly been brought to fore in an attempt to define accessibility (Bertolini et al., 2005). In an observation that seems to be guided by the social theory of human behaviour, the authors point out that the definition of accessibility is not complete until it takes into account *"the amount and diversity of places of activity that can be reached within a given travel time and/ or cost"* (p. 209). The challenge posed to urban cycling and land-use integration is therefore how to make conditions for shorter travel times as well as how to modify the competitive positions of cycling in order to improve its attractiveness. Closely related to this line of thinking is the observation by Iacono et al. (2010), Krizek (2005) and Handy and Clifton (2001) that accessibility measures and practice have so far been auto-based and limited to only access to employment. The authors' proposal for a broadened scope of accessibility to include multiple destinations and multiple modes is therefore relevant in the context of the current study.

The work of Levine (2006) on the other hand raises important questions with regard to the relevance of accessibility in integrating cycling and land-use in the absence of a detailed, reliable, objective and robust metric for measuring it. Similar concerns are echoed by Iacono et al. (2010) who note that accessibility can only be useful in ensuring sound decisions with respect to integrating non-motorised transport and land-use if it has sound metrics for measuring it. Some of these measures are discussed below.

2.3.1.1. Accessibility measures

In an evaluation of accessibility measures, Geurs and van Wee (2004) conclude that a good accessibility measure should be theoretically sound, easy to operationalise and to use in social and economic evaluation. Equally underscored is the importance of the ease of interpreting and communicating the measures if they are to be anything useful. At the same time, accessibility measures need to be understandable to and consistent with the uses and perceptions of stakeholders involved in the planning process (Bertolini et al., 2005).

In view of the foregoing, the current study attempted to strike a balance among these criteria in order to remain not only scientifically sound but also useful in informing sustainable urban accessibility policies that are useful in integrating urban cycling and land-use.

Four notable accessibility measures have currently been identified on the basis of the components that they take into account to calculate accessibility (Geurs & van Wee, 2004). These include infrastructure-based, location-based, person-based and utility-based measures.

Infrastructure – based measures

Infrastructure-based measures describe accessibility in terms of the functioning of a transport system. Measures like congestion, operating speed on transport network and travel times are considered in this case. While these measures are recognised for their ease of operationalization and communication, their inability to account for land-use present a major drawback in their use in linking cycling and land-use. Geurs and van Wee (2004), point out that the measures fall short when it comes to handling temporal constraints and individual characteristics of trip makers. These theoretical weaknesses of infrastructure-based measures can lead to wrong conclusions regarding accessibility. This drawback is exemplified by the work of Linneker and Spence (1992) in the city of London. Contrary to the expectation under the infrastructure-based measures, the authors found out that the city of London had the highest level of potential accessibility to jobs despite having the highest access costs in the United Kingdom.

Person-based accessibility measures

Based on the time-space geography of Hägerstrand (1970), the person-based measures look at the individuals' and/ or households' travel patterns in space and time given a time constraint. Accessibility is calculated in terms of the number of opportunities that can be reached given the constraints. Despite their theoretical soundness, the measures fall short when it comes to accounting for competition effects. Geurs and van Wee (2004) observe that the measures are demand-oriented and as such fail to account for potential capacity constraints of supplied opportunities. Moreover, the measures have been found to be difficult to operationalise and communicate in part due to computational intensity and lack of feasible operational algorithms (Kwan, 1998). These therefore inhibit their use in integrating cycling and urban land-use planning.

Utility-based accessibility measures

Accessibility in this context is measured in terms of travel choices that people make in order to reach the opportunities that satisfy their demands. Like it is the case with the preceding measures, a major set-back of utility-based measures is their difficulty of interpretation and communication (Geurs & van Wee, 2004).

Location-based accessibility measures

Location-based measures seem to have the most opportunity for integrating urban cycling and land-use. The measures can be broadly classified into two sub-groups, namely the distance and gravity-based measures. The former sub-group comprises of distance and contour measures which focus on the straight line distance between points on the same surface. The distance measures are applicable where there are only two points involved while the contour measures are used where there are more than two points. In this latter case, the contour measures count the number of opportunities that can be reached given a time, distance or cost impedance. Like in the case of infrastructure-based measures, the distance/ contour measures are also strong on operationalability, interpretability and communicability but fall short when evaluated against the theoretical criteria identified by Geurs and van Wee (2004). This inhibits their use in integrating urban cycling and land-use. Geurs and van Wee (2004) observe that even though the measures take account of transport and land-use, they neither evaluate their combined effects nor take cognizance of the effects of competition among different opportunities. The assumption of the measures that all opportunities are equally desirable regardless of their type and impedance one has to overcome to access them has also been questioned (Ben-Akiva & Lerman, 1979; Geurs & Ritsema van Eck, 2001).

The gravity-based measures on the other hand estimate accessibility of opportunities in one zone to several possible zones; smaller and/ or more distant opportunities provide diminishing influences (Hansen, 1959). The general form of the measure is given in equation 2-1 on the next page:

$$A_{i=} \sum_{j=1}^{n} D_j \, e^{-\beta C_{ij}}$$

Equation 2-1

- Where A_i is a measure of accessibility in zone i to all opportunities D in zone j;
- C_{ij} is the cost of travel between i and j, and
- β is a cost sensitive parameter of distance decay.

The function Cij represents the cost of moving between a trip origin and the opportunities accessible to it. It can be considered as the distance between the two points, the monetary cost or time it takes to overcome the spatial separation between the two points (Iacono et al., 2010). In line with the postulations of the economic theories that explain the interaction between places, it is expected that higher Cij would lead to less travel between two points. On the other hand, it is expected that the presence of barriers between two points would lead to a complete lack of interaction between two points. In this case, urban cycling is seen not to be possible beyond distances that trip makers view to be economically acceptable. The β on the other hand is the distance decay parameter; it is the factor by which quantifies the frictional effect of the cost of moving from one point to another. It has been noted that the cost sensitivity function used has a significant influence on the accessibility measure and that the function should be estimated using recent empirical travel behaviour data in order to obtain credible results (Geurs & van Wee, 2004). According to Krizek, El-Geneidy and Thompson (2007), the function can be estimated by either a survey of the number of users of a mode of transport and determining how this percentage varies with distance from an access point or by estimating how far users of a transport mode are willing to travel if the distance is increased.

One of the strengths of the gravity-based measures is their ability to overcome the theoretical shortcomings that are inherent in the infrastructure-based and distance measures of accessibility (Geurs & van Wee, 2004). This is achieved through their capability to evaluate the combined effect of land-use and transport elements and to incorporate travel behaviour theory through the use of the distance decay function.

2.3.2. Urban form

While it is generally agreed that urban form impacts on the urban transport (Chen et al., 2008; Jabareen, 2006; Ooi, 2009), there seems to be no universally accepted definition of the concept in literature. Different authors attach different meanings to it depending on the contexts of their studies (Frenkel & Ashkenazi, 2008; Huang et al., 2007; Lynch, 1981; Schwarz, 2010). What comes out clear however is that the specific character of a city that a study is interested in is of more relevance in aiding an understanding of the concept than a strict definition. The definition given by Lynch (1981) is particularly relevant in the context of the current study. According to the author, urban form is the *'spatial pattern of the large, inert, permanent physical objects in a city that include buildings and streets'* (p. 47). On the strength of this definition, urban form is operationalised in the current study to mean the layout of the built-up areas and streets together with the characteristics that enable their relationship on space to be described. The characteristics are measured through the use of indicators. This can be quantified by analysing the density, clustering or sprawl of socio-economic variables like population and employment. Similarly, network indicators can also be used to quantify urban form from the context of the road networks. The bicycle path to network density, beta index and network coherency ratio identified by Zuidgeest, Rouwette and Kager (2009) are particularly relevant in the context of the current study.

2.4. Urban form and cycling

Literature on the interaction between urban form and cycling in developing cities seems rather scanty. Nonetheless, interesting findings have been realised from studies based in the developed cities which can lend valuable lessons to the developing cities on how to integrate urban form and cycling. Current researches have focused on infrastructure design issues; explaining why people choose cycling over other modes; and the role of urban form in influencing cycling patterns and behaviours (Pucher, Komanoff, & Schimek, 1999; Rietveld & Daniel, 2004). Rietveld and Daniel (2004) has for instance demonstrated that elements of urban form like the city size, densities of development and the general spatial structures of cities can impede or encourage urban cycling. The authors also point out that the design of roads determines the number of detours, the waiting time at crossings and can similarly promote or discourage cycling. Other factors that have been found to be at play include the functional design of roads which influences competition for road space (Hunt & Abraham, 2007; Pucher et al., 1999; Rietveld & Daniel, 2004). Roads that have separate cycling paths or that allow lower car speed are perceived to be safer and therefore more cycled compared to those that are perceived to expose cyclists to accidents (Hunt & Abraham, 2007; Pucher et al., 1999; Rietveld & Daniel, 2004).

The work of Rietveld and Daniel (2004) at the same time challenges the wisdom that the provision of cycling infrastructure alone is enough to promote cycling. According to the authors, provision of cycling infrastructure must be coupled with supportive urban land-use planning policies in order to encourage cycling. This argument is echoed by other authors like Pucher et al. (1999) who have underscored the need higher density developments of mixed users in order to encourage cycling. It is implicit from these authors that reasonable distances are necessary to promote urban cycling.

In spite of many researches which have investigated barriers to cycling, Raford, Chiaradia and Jorge (2007) note that there is still lack of a rigorous analysis of the transport network factors and urban land-use planning factors that determine the numbers of cyclists. The authors conclude that route accessibility plays an important role in cyclists' route choices. An important contribution of this study is that cyclists tend to choose fastest routes rather than just the shortest routes as often assumed. While this is so, Parkin, Wardman and Page (2007) have identified lack of bicycle lanes as well as motor traffic speed and volumes as some of the key determinants of cycling patterns and behaviour that shape route choice. Handy (1996), defines travel patterns as the aggregate-level characteristics of travel, which help in quantifying the potential impact of urban form on travel and travel behaviour as the individual choices, which enable an understanding of how and why urban form is linked to travel. Parkin et al. (2007) have pointed out that cycling behaviour and patterns are the results of the perceived safety among cyclist and that these are central in determining whether they will cycle on given routes. In view of this, it is evident that urban form that is focused on achieving land-use mix alone cannot realize integration between urban cycling and land-use; additional efforts have to equally focus on removing the perceived barriers to cycling.

It is evident therefore that the meeting point between urban cycling and land-use lies in urban configurations that reduce cycling distances and the physical efforts while at the same time offering the safety that cyclists need to overcome the spatial separation between trip origins and the opportunities. In this regard therefore, urban form must be viewed not just as the relationship between trip origins and destinations but also as the conditions on the routes that link them. These must be taken into account when integrating cycling and urban land-use planning.

2.5. What makes cycling in developing cities unique?

Urban population growth, political history and economic strength have been identified as the key drivers that shape urban transport situation in both the developing as well as the developed cities (Gwilliam, 2003). Whereas population increase engenders competition on land for infrastructure development, the political history has accounted for the patterns of urban land-use which structure the cities. Economic growth on the other hand has been related to the levels of transport infrastructure development and also vehicle ownership and use (Gwilliam, 2003).

The foregoing processes identify with both the developed and developing cities. Interestingly though, the situation in the developing cities remains largely unique and difficult to account for using the current transport models that have been designed for the developed cities. Literature abounds that seems to offer possible explanations to this observation. To begin with, unlike in the developed cities, rapid and unchecked population growth in the developing cities has resulted in city growth that far outpaces transport infrastructure provision. Rapid population growth has been associated with rapid urban sprawl and a reduction in the amount of urban space that can be dedicated to urban transport (Gwilliam, 2003). This coupled with inadequate finances to develop urban transport infrastructure has led to inadequacy and poor state of urban transport infrastructure currently witnessed in these cities. At the same time, this pattern of urban development creates more demand for travelling, often based on the car. The situation with regard to cycling is even more saddening given that most developing cities do not even prioritise it in the first place (Gwilliam, 2003; Tiwari, 2002). In Indonesia for instance, the authorities have taken measures to eliminate cycling and other non-motorised transport altogether (Gwilliam, 2003).

In India, (Tiwari, 2002) notes that non-motorised mode of transport is badly served despite accounting for 25 – 50% of all trips in major Indian cities. Unlike in the developed cities, cycling in Indian cities is stifled by lack of a clear separation of road functions which has resulted in road-use conflict between cyclists and motorists (Mohan, 2001). Consequently, cyclists not only have to compete with motorists for the road space designed for vehicles but also the street vendors and shop premises that encroach on the roads. This is in addition to the cars packed on the same roads due to lack of alternative parking spaces. This state of affairs limits cycling to only roads that permit slower car speeds, at least for the captive cyclists (Mohan, 2001, 2004). There is a need to explicitly take these into account in integrating cycling and urban land-use planning in Pune.

Furthermore, most Indian cities and other developing cities are characterised by collapsed bus transport services and a consequent take-over by unorganised and scarcely regulated small vehicle paratransit operators (Gwilliam, 2003). These operators charge exorbitant and unpredictable fares which has given rise to a huge number of captive cyclists especially for short distance trips. This contrasts with cycling in the developed cities which is largely voluntary. Travel behaviours and patterns of cyclists in the developing cities must be understood explicitly in order to better integrate cycling into the mainstream urban land-use planning. However, urban land-use planning in these countries has also not been without its shortcomings. According to Gwilliam (2003) and Tiwari (2002), systematic urban land-use planning remains weak and guided mainly by the desire to achieve political expedience in most of the developing cities. The result has been multiple commercial centres and scattered land-use activities that are not in harmony with each other. This further gives rise to travel patterns that are different from those of the developed countries where most of the current transport models have been developed and tested.

Moreover, while studies by authors like Parkin et al. (2007) have found out that perceptions about safety of cyclists, location of opportunities, speed of cars form the barriers to cycling, the work of Moudon et al. (2005) seems to suggest that these do not constitute barriers in developed cities where cycling infrastructure is in most cases adequately provided for.

In view of the foregoing, it is apparent that shaping urban land-use and managing the space devoted to roads in order to make them favourable to cycling remains a central concern in integrating urban cycling land-use. These must be supported by a clear understanding of trip characteristics occasioned by the land-use patterns of these cities, travel patterns and behaviours of their cyclists as well as barriers imposed by land-use patterns and road networks.

2.6. Knowledge gaps

The preceding sections of this chapter have reviewed various literature on urban form, transport and accessibility. In this current section, the existing gaps with relation to the connection between urban form and transport are identified.

Various studies (Cao et al., 2007; Handy, 1996; Handy & Clifton, 2001) have investigated how urban form impinges on travel patterns. Four main approaches, namely simulation, aggregate analysis, disaggregate analysis, choice models and activity-based analyses have been adopted in these cases. While these studies show the role of urban form in influencing travellers' choice and by extension their travel patterns and behaviours, some gaps still remain that need further enquiry. The key ones that have shaped the current study include:

i.) It has not been clearly shown what aspects of urban form influences travel choices. Hence it is not clear whether these are street patterns, permitted car speed on the roads, width of the roads;
ii.) No known study has investigated the effects of barriers to cycling, more so in the context of developing cities;
iii.) It still remains unclear how to model several trip destinations as current studies have largely been concerned with single destination;
iv.) Given the foregoing, it still remains unclear how urban land-use planning and policies can be formulated to be responsive to cycling.

2.7. Conceptual framework

This section concludes the current chapter on literature review. It presents how the current study understands the relationship between urban cycling and land-use, the shortcomings of this relationship as it currently has been understood in the current study links the literature reviewed above with the study objectives by presenting how the study was conceptualised.

The current study is premised on the emerging evidence that the contemporary urban planning approaches in Pune, like in many other developing cities have concerned themselves more with facilitating motorised transport and less with cycling (Bertolini et al., 2005). Consequently, urban planning strategies have tended to promote mobility rather than addressing the very reasons that underpin trip making. Furthermore, deliberate spatial strategies aimed at influencing affordability, environmental friendliness and equity with regard to urban transport services and infrastructure seems to be largely lagging behind when compared to cities of the developed world. This state of affairs is believed to account for a range of negative externalities of environmental, social and economic dimensions (Mohan, 2001, 2004; Pucher et al., 2005). While the present study views cycling as one of the remedies to this shortfall, it similarly observes that the option has largely been neglected by urban planning authorities in Pune. Consequently, urban land-use has continued to be patterned without considering the cycling needs of the city. This situation not only locks out the cyclists from the roads but also aggravates car-dependence and its attendant negative externalities.

While the foregoing is the case, literature reviewed in previous sections demonstrates that accessibility concept enables the qualities of urban transport to be related to the land-use systems (Bertolini et al., 2005). The current study therefore develops an accessibility measure that is sensitive to the cycling patterns and land-use situations in Pune city and that can be used to integrate these two. The need for this cannot be overemphasised given the renewed focus on accessibility as the centre-stage in the search for a solution to the current urban transport challenges (Iacono et al., 2010). The measure developed incorporates theory, usability and interpretability, which have been found to be sensitive to cyclists' travel behaviours besides being useful in informing land-use policies (Geurs & van Wee, 2004). The study assumes that this integration can reverse the current benign neglect of cycling as an urban transport option in Pune and also contribute to ameliorating negative externalities occasioned by its current urban transport situation. Figure 2-2 below presents the conceptual framework underlying the current study.

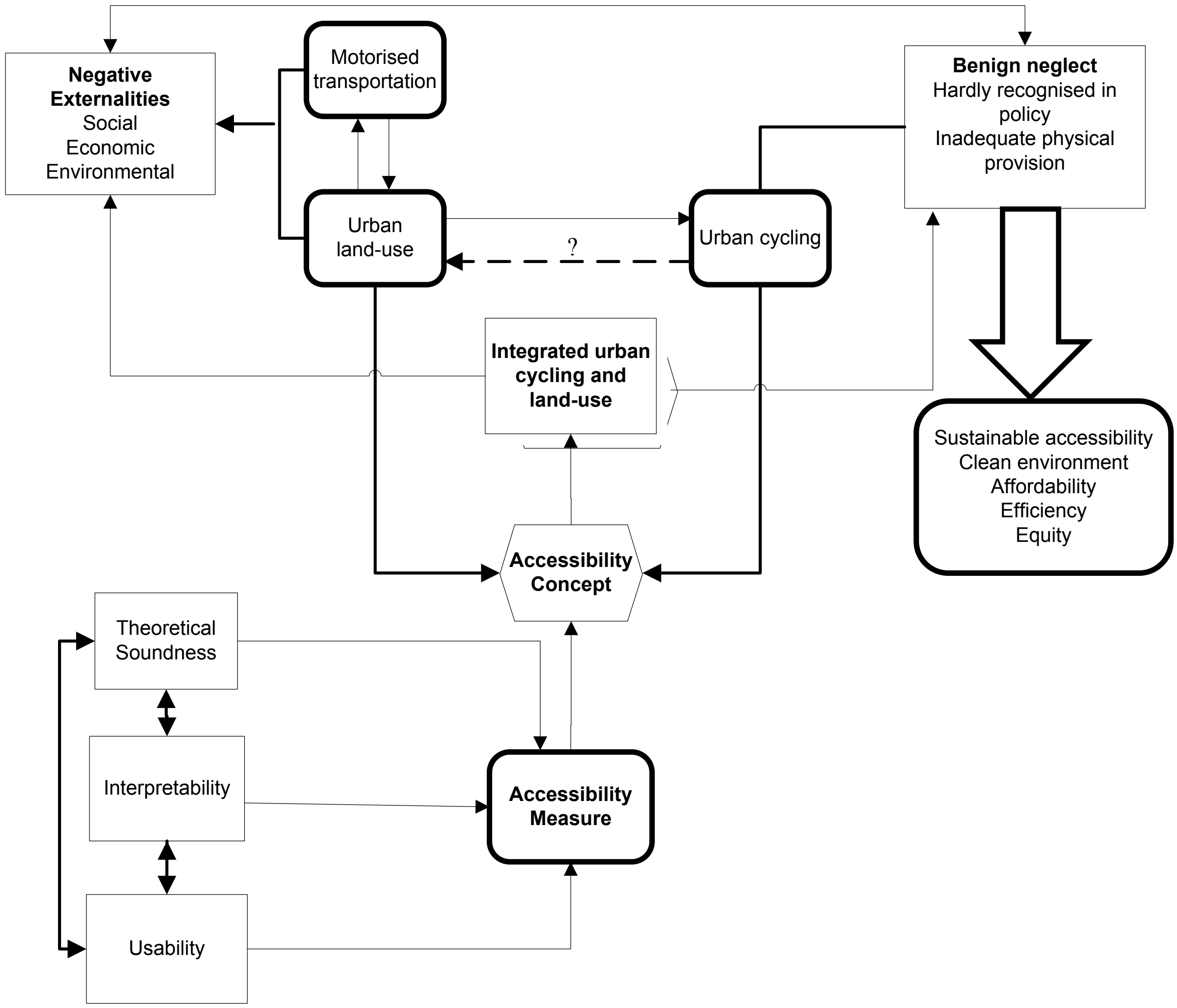

Figure 2-2: Conceptual framework for the study

3. DATA AND METHODS

This chapter presents the data and methods that were employed in order to achieve the study objectives and questions raised in the first chapter. These methods are anchored upon the theories and concepts reviewed in the second chapter. The chapter sets off by detailing the data used and their sources (Section 3.1). This is followed by an account of the data preparation strategies that were adopted to make the data ready for use in the current study (Section 3.2). The limitations of the study that arise out of the data gaps are presented at the end of the section. Section 3.3 on the other hand introduces the exact analyses that were carried out on the data in order to realise the objectives of the study. The chapter concludes by highlighting its key limitations in section 3.4.

3.1. Data used

The study used secondary data sourced from the Faculty of Geoinformation Science and Earth Observation (ITC) of the University of Twente and the Transportation Research and Injury Prevention Programme (TRIPP) of the Indian Institute of Technology. Five datasets, namely census tract data, road network data, household survey data and road network survey data and a land-use map of 2006 were used (Figure 3-1). The census tract data included both shapefile as well as the attribute data of 144 wards of Pune city. This data together with the road network data of the city were obtained from ITC while the household survey data and the road network survey shapefile were obtained from TRIPP. These surveys were conducted on the basis of the two maps obtained from ITC.

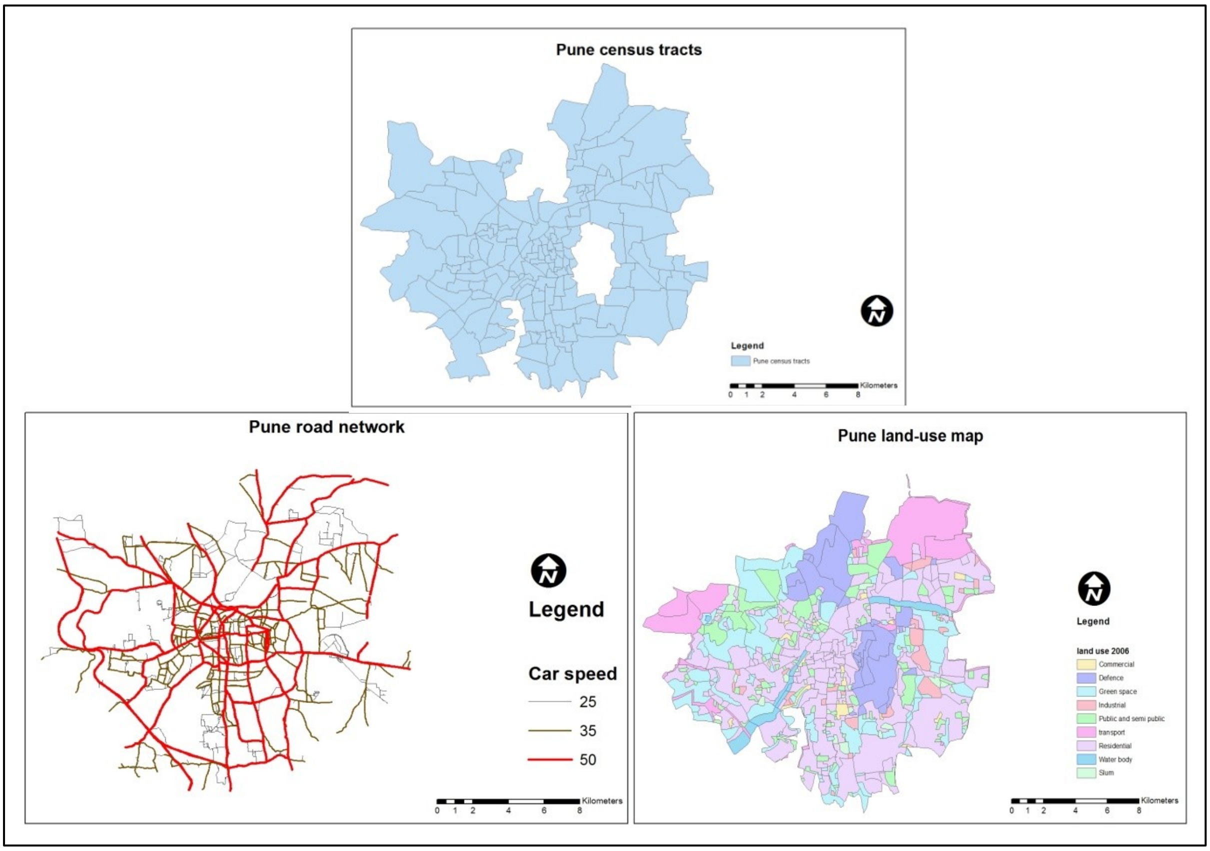

Figure 3-1: Spatial datasets used in the study

The census tract data contained the following attributes for all the zones including the military cantonments. These attributes were deemed relevant for the current study:

i.) Area (m^2)
ii.) Pune Municipal Corporation boundary
iii.) Population density (per m^2) based on 2007 population estimates
iv.) Capacity of school (per m^2) based on 2006 estimates
v.) Employment density (per m^2) based on 2006 estimates
vi.) Overall trip production density (per m^2) based on 2006 estimates
vii.) Overall trip attraction density (per m^2) based on 2006 estimates
viii.) Cycle trip production density (m^2) based on 2006 estimates
ix.) Cycle trip attraction density (m^2) based on 2006 estimates
x.) Land-use classification based on 2006 development plan for Pune

The road network data on the other hand contained the following relevant attributes for the study:

i.) Permitted car speed on the roads
ii.) Road classification (i.e. lanes, minor, major roads and national highways)
iii.) Length of roads (m)
iv.) Road widths

The household survey data related to the socio-economic aspects and travel patterns of Pune as well as the propensity to cycle. The questionnaire in *Annex i* details the subject matters dealt with in the household survey. This data was collected by TRIPP between February and March 2010 from 28 zones that were selected through stratified random sampling. According to Frankfort-Nachmias and Nachmias (1996), stratified sampling is appropriate when a researcher aims to ensure that different groups of a population are adequately represented in a sample so that accuracy levels are increased when estimating its population parameters. A total of 475 zones that satisfied the short trip distances of not more than 6km were created from the 144 census wards of the city. The centre of the city was identified by getting the centroid of the entire city from its boundary map. After this, 4, 12 and 12 zones were randomly selected from zones within 1, 3 and 8 km radius from the centre respectively. Annex ii gives the details of the sampled zones. These 28 zones formed the basis for the selection of the households and streets that participated in the household survey. The household survey involved a sample of 1407 captive and potential short-trip cyclists. Stratified random sampling strategy was adopted again. In this case, the survey selected every tenth household along the streets to participate in the survey. Annex iii gives a breakdown of the number of households selected from each zone.

On the strength of the argument advanced by Frankfort-Nachmias and Nachmias (1996), the current study concludes that the data obtained from the household survey was appropriate enough to use in addressing its objectives.

3.2. Data Preparation

This section details the strategies used to prepare the data described in the preceding section in order to make it useful for analysis in the context of the study.

3.2.1. Revealed and stated preference data

The household and road network survey data from TRIPP were checked for its appropriateness for use in the study before they were adopted for use in the study. The procedure of collecting the data was assessed as well as its representativeness of the situation in Pune. These are explained in section 3.1 above.

The survey data were then coded and input to Predictive Analytic Software (PASW) format to enable further analysis. Preliminary frequency analysis was done in PASW in order to assess for data entry errors and outliers that could be possible indications of errors. Cases that were found were corrected.[1] The data was then linked to the spatial database in ArcGIS using the zone_ID as the foreign key to allow for further analysis in ArcGIS and PASW.

3.2.2. Creation of new Traffic Analysis Zones

Traffic Analysis Zones (TAZs) are geographical units which divide a study area into relatively homogeneous land-uses that represent the trip origins and destinations. In network analysis, the node is then used to represent data such as amounts of employment, education opportunities and population that relate to these zones.

New TAZ were created based on the land-use map of 2006 and census tracts of the city in order to represent the spatial data in a way that could permit accessibility modelling. The aim was to create homogenous zones that could be used as the unit of analysis of the cycling patterns and other attributes of cycling in the city.

The following factors were then considered in creating the TAZs:

i.) Homogeneity was achieved by creating TAZs within only one land-use;
ii.) The TAZs were restricted to the ward boundary to enable attributes of the wards to be disaggregated to the TAZs level;
iii.) The TAZs were created in such a way not to overlap the rivers which constituted natural barriers to cycling across them. TAZs that overlapped these rivers could therefore not represent the traffic patterns in a realistic way. The TAZs were later revised not to overlap the roads where car speeds of up to 50kmh^{-1} were permitted. This was after the analysis of cycling patterns revealed that such roads prohibited cycling in the city.

3.2.3. Data disaggregation

The data obtained from the census tracts was at a higher geographical scale and therefore not suitable in the context of the current study. In order to make it useful, the data was disaggregated to the TAZ level. The density values highlighted in section 3.1 were used to disaggregate population, cycling trips and employment to the new traffic analysis zones. It was assumed that the distribution of these elements was uniform across each of the entire census tracts. The formula given by equation 3-1 below was used:

$$X = \frac{x_n}{A} \, x \, a^1 \qquad \textit{Equation 3-1}$$

Where: X = Disaggregated value of population, education opportunities, employment etc. in a TAZ;
x_n = Value of the element in a ward before redistribution;
A = Total census tract area (before creation of TAZ);
a^1 = Area of new TAZ;

Table 3-1 on the next page gives a breakdown of the actual operations on each of these elements in order to disaggregate their values from the origins census tracts to the new TAZs.

[1] After discussion with Ms. Deepthi Durgi who was involved in collecting the data.

Table 3-1: Data disaggregation

Element	Input variables	Method of disaggregation
Population	• Population density in census tract • Area occupied by population in census tract • Area of new TAZ	$\frac{\text{Area occupied by population in census tract}}{Area\ of\ census\ tract} x\ Area\ of\ new\ TAz$
Education opportunities	• Density of education opportunities • Area of new TAZ	$Density\ of\ education\ opportunities\ x\ Area\ of\ new\ TAZ$
Employment opportunities	• Density of employment opportunities • Area of new TAZ	$Density\ of\ employment\ opportunities\ x\ Area\ of\ new\ TAZ$
Cycling trips production	• Density of cycling trips production • Area of new TAZ	$Density\ of\ cycling\ trips\ production\ x\ Area\ of\ new\ TAZ$
Cycling trips attraction	• Density of cycling trips attraction • Area of new TAZ	$Density\ of\ cycling\ trips\ attraction\ x\ Area\ of\ new\ TAZ$

NB: It is assumed that the densities are uniforms across all the census tracts.

The resulting data from the above operation contained the land-use characteristics that were needed in subsequent modelling of accessibility.

3.2.4. Creating cycling networks

The networks were needed to represent the supply capacity for cycling in the study area. They were specifically used in the network analysis to calculating distances between the trip origins and destinations. The length of the segments in this case represented the distances cycled.

Cycling in the current study was assumed to take place on the same roads used by cars. This assumption was guided by the work of Mohan (2004) who has shown that a good amount of cycling in India takes place on some of these roads. However, the researcher's inability to obtain data at the level of cycle track in cases where these existed also contributed to this assumption.

Bicycle routes were created from the roads data in ArcCatalog 10 platform. Global turns were later incorporated after analysis of the statistical data to make the network reflect the delays at the junctions. The turns are discussed later in chapter 5.

A personal geodatabase was then created from the feature classes resulting from the land-use and transport data explained above in order to allow for their further handling.

3.3. Addressing the study objectives

The study followed a three-stage approach to address its objectives. It started with a literature review which sought to get the general interaction between urban transport and land-use in India. This was followed by statistical analysis to understand the cycling behaviours and patterns in the study area. Parallel to this was a spatial analysis which sought to find out the possible implications that land-use patterns had on the revealed cycling behaviours and patterns. The results from these analyses formed the foundation for accessibility modelling in the third stage of the study. A number of strategies were adopted in an effort to realise the objectives set forth. These are highlighted in the proceeding parts. The actual operationalization of these methods is done in chapter 5.

3.3.1. Urban land-use and transport situation in Pune

The investigations set off by a literature review that sought to put into perspective the interaction between India's urban land-use and transport in general and cycling in particular. This literature review also sought to enable the researcher to identify and evaluate various accessibility measures that could be used to integrate cycling and urban land-use. Part of this analysis is already presented under literature review in chapter 2.

Secondary data, including Pune City Development Plan and Indian National Urban Transport Policy, were analysed for their content in order to establish the existing urban transport situation in India in general and Pune in particular. The analysis also sought to identify how urban land-use patterns had influenced urban transport and cycling in the city. The data from these sources were corroborated by content analyses of the publications the World Bank and other reputable institutions that had conducted researches on urban transport in India.

3.3.2. Cycling patterns and behaviour and their relation to urban land-use patterns

The stated and revealed preference data was statistically analysed in order to obtain the prevailing cycling patterns and behaviours in Pune. In handling the stated preference data, the researcher deliberately focused on the responses given by the active cyclists since it was felt that they reflected the true rather than hypothetical cycling behaviours and patterns. However, the responses from the potential cyclists were also analysed in order to examine the effects of physical barriers on cycling in the city.

i.) Frequency analysis and percentages analyses were carried out to summarise the cyclists by their origins and destinations in order to find out the dominant trip sources and destinations.

ii.) Cross-tabulation analyses were then done to relate cyclists to the land-use at their trip origins. The aim here was to find out the characteristics of land-use at the trip origins such as the land-use activities.

iii.) Cluster analysis was done on employment, population and education to find out the spatial patterns of these land-use activities. The aim was to find out if there were spatial patterns that would have a bearing on the ability of cyclists to get to the opportunities.

iv.) Spatial regression was carried out to relate the density of cycling attracted at the zones and the density of opportunities. The aim in this was to find out if there was a clear correlation between amount of cycling attracted and the opportunities and thus to build a case for making such opportunities accessible.

v.) Polynomial regression was used to find out the effects of distance on the proportion of cycling and to fit a model for estimating the reaction of cyclists to increasing distances from their trip origins.

vi.) Correlation analysis was carried out to find out the relationship between cycling attracted at the zones and the zone area, population densities, employment densities and education densities. Further, the weighted least squares method was used to estimate the attractiveness of the zones on the basis of these opportunities.

vii.) Multiple regression analysis was done on the volume of cycling and factors such as car speed, volume of cars and buses on the roads and size of the carriageways among other factors in order to find out which urban form factors influenced the amount of cycling. The aim of this was to find out which characteristic of the roads could be used to determine the roads that constituted barriers to cycling.

Six key patterns were analysed to link the cycling patterns and behaviour to urban form. Table 3-2 on the next page details the focus of cycling patterns analysis, the statistical measures used to quantify them and the urban form they were compared with. The table also identifies the relevance of these patterns to accessibility model developed later in this thesis.

Table 3-2: Analysis of cycling patterns, behaviour and urban form of Pune

Cycling patterns and behaviour	**Statistical Measures**	**Question addressed** **(relevance to accessibility modelling)**	**Urban form indicator to enable comparison**
• How does the amount of cycling relate to increasing distance from home?	• Regression analysis	• *What is the distance decay factor?*	• *Cluster analysis*
• Where are the trip sources and ends?	• Frequency	• Where do cyclists come from and where do they go to? *(Where are the origins and destinations?)*	• *Density analysis of population vs. employment and education opportunities*
• How far are people willing to cycle from home?	• Mean • Mode	• Are opportunities close to where cyclists can reach them easily? / • *(What cut-off should be used in modelling accessibility?)*	• How far are the opportunities from places of residence? *(Cluster analysis)*
• What makes potential cyclists reluctant to cycle?	• Mode	• *What are the barriers to cycling?* • *What are the impedances to cycling?*	• *n/a*
• Trip frequency	• Mode	• What is the dominant trip purpose? • Is the land-use planned to allow trip destinations close to places of residence?	• Are residential areas clustered near opportunities? (*Cluster analysis)*
• Where do people cycle to?	• Frequency	• *What are the factors that contribute to attractiveness of zones?*	• What are the magnitudes of opportunities? (*Density geographically weighted regression)*

3.3.3. Developing and implementing a spatially constrained accessibility measure

The results from the analyses of cycling patterns and urban form described above were used to derive the distance decay factor, zone attractiveness and the cut-off point for the distance cycled. These were in part needed to model accessibility at the trip origins. In order to obtain the variables for the accessibility equation given on the next page, the following strategies were used. (Refer to section 2.3.1 for the meanings of the variables):

$$A_{i=} \sum_{j=1}^{n} D_j\, e^{-\beta C_{ij}}$$

i.) The opportunities at destinations, $_j$ (D_j) were obtained by regressing the size of each TAZ, the population size, amount of employment and amount of educational opportunities;
ii.) The value of distance decay function (β) was calculated in Microsoft Excel by relating the number of cyclists and the corresponding distance from origin, $_i$ to destination, $_j$. A scatterplot was prepared in MS Excel to relate the percentage of cycling and the distances cycled. Polynomial regression of order 5 was then used to fit the resulting curve that approximated the cyclists' reaction to increasing distances from trip origins
iii.) C_{ij} was taken as the distance from origin, $_i$ to each of the destinations, $_j$ that could be reached from that origin.

Bicycle routes that were created from the road networks data in ArcCatalog 10 platform were overlaid with TAZ layer to enable accessibility at different zones to be calculated. The study assumed that bicycle trips originated from and terminated at the centroids of the TAZs. Consequently, trip ends on the networks were assigned foreign keys that were identical with those of the TAZ centroid they corresponded to. This part was done in ArcMap 10 platform. An O-D cost matrix was then developed and solved in the Network Analyst extension of ArcMap 10 to calculate the paths cycled from trip sources to various trip destinations. The Network Analyst calculates the distances cycled between the trip origins and destinations on the basis of the segment lengths which represent the distance in this case. The resulting C_{ij} values were exported to Microsoft Excel where accessibility at the zones was calculated using the accessibility formula. Accessibility scores obtained were thereafter linked back to ArcGIS10 for visualisation. The researcher then analysed for bicycle compatibility of the zones by considering their score against different indicators explained in chapter 2. This enabled the researcher to make recommendations that touched on how to make the model more useful in making urban land-use planning more responsive to the emerging cycling needs in developing cities like Pune. Figure 3-2 below presents the methodological framework that guided the study in realising its objectives. Through data analysis and accessibility modelling, the figure shows how data highlighted in the research design in figure 1-1 has handled to arrive at the conclusions drawn at the end of the study.

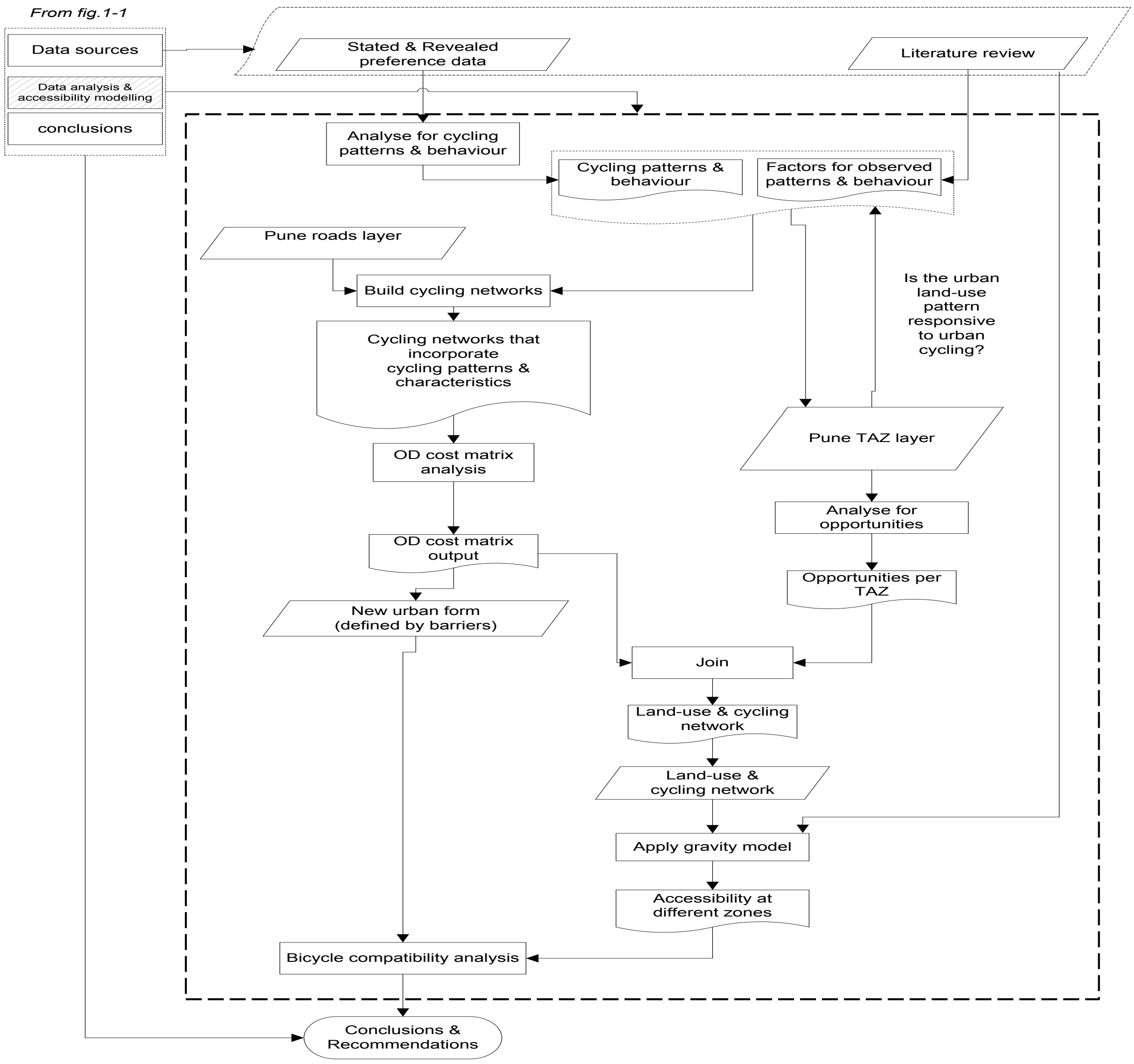

Figure 3-2: Methodological framework

3.4. Limitations of the study

The current study suffered two major limitations which have compromised the ability of the model developed to accurately reflect the actual situation the ground.

i.) Inability to link the road survey data to the road network data that was available. This limitation was however mitigated through non-spatial statistical analysis of aggregated road characteristics at TAZ level.
ii.) The model developed could not be validated due to lack of data for doing so. This has been identified as a recommendation for future research.
iii.) Lack of data on cycling across the roads. This would have made an interesting analysis on how barriers inhibit cycling across the road.
iv.) Reliance on data which was not explicitly collected for the study carried out in this thesis. This limitation was mitigated by correlating available data sets in order to find out which cycling characteristics and behaviour could still be related to the land-use patterns nonetheless.
v.) The researcher was unable to do fieldwork hence the entire study is based on the data that was available at ITC.

4. BACKGROUND TO THE CITY OF PUNE

This chapter introduces Pune city, the study area. It presents the reasons for choosing Pune as the study area and gives key background information about the city. The climax of the chapter is a review of the urban transport and land-use situation in India in general and Pune in particular in section 4.3. This section aims to bring forth the current gap between urban transport and land-use planning and to put into context its implications on urban cycling. A review is presented of the current efforts that have been made to bridge the urban cycling – land-use gap with a view to identifying their inherent shortfalls that need to be addressed through responsive urban land-use planning. Through this, the first objective raised by the study is also addressed. The section lays the foundation for the subsequent analyses besides providing a link between the study and policy.

4.1. Selection of study area

The study documented herein was based in Pune city. The choice of Pune was informed by scientific, social and practical reasoning.

To begin with, the city's sorry state of urban transport in general and bicycling in particular (Section 4.3) was deemed to be representative of the situation in other fast developing cities of its rank. The findings of the study could thus be generalised to identical cities that seek to integrate cycling as an urban transport option. Pune city was similarly selected as a suitable study area on account of the recently formulated Indian National Urban Transport Policy that endeavours to formalise cycling and other non-motorised urban transport options (National Institute of Urban Affairs, 2006). The findings from Pune with regard to identifying the barriers to cycling, their urban form causes and how they can be addressed would therefore lend a basis for responsive urban planning that encourages urban cycling not only in Pune city but also other fast developing cities.

The choice of Pune city was as well guided by considerations about data availability to enable the investigation to address the objectives it raised. According to Frankfort-Nachmias and Nachmias (1996), the cross-sectional study design is appropriate in situations where a study cannot manipulate the variables under investigation. In the case of the current study, neither urban form nor urban cycling behaviour and patterns could be amenable to manipulation in order to observe the changes in the other variable. Stated and revealed preference data obtained through the cross-sectional study design was therefore deemed to be suitable for analysing in order to find out the relationship between urban form and cycling. In addition, there was a readily available road network and land-use data at ITC which could be used for the study.

4.2. Study area background

Pune city is located in Maharashtra state on the western side of India. The major cities that neighbour it are Mumbai to the north, Bangalore to the south, Mulshi to the west and Solapur to the south east. The city is located at the confluence of the National Highway NH4 and the State Highway NH151 (Figure 4-1). It is estimated that the city covers an area of about 243 km^2 with a population of about 3 million people as of 2005 (Pune Municipal Corporation, 2006). Pune currently serves as an administrative, military, cultural and education centre of Maharashtra state.

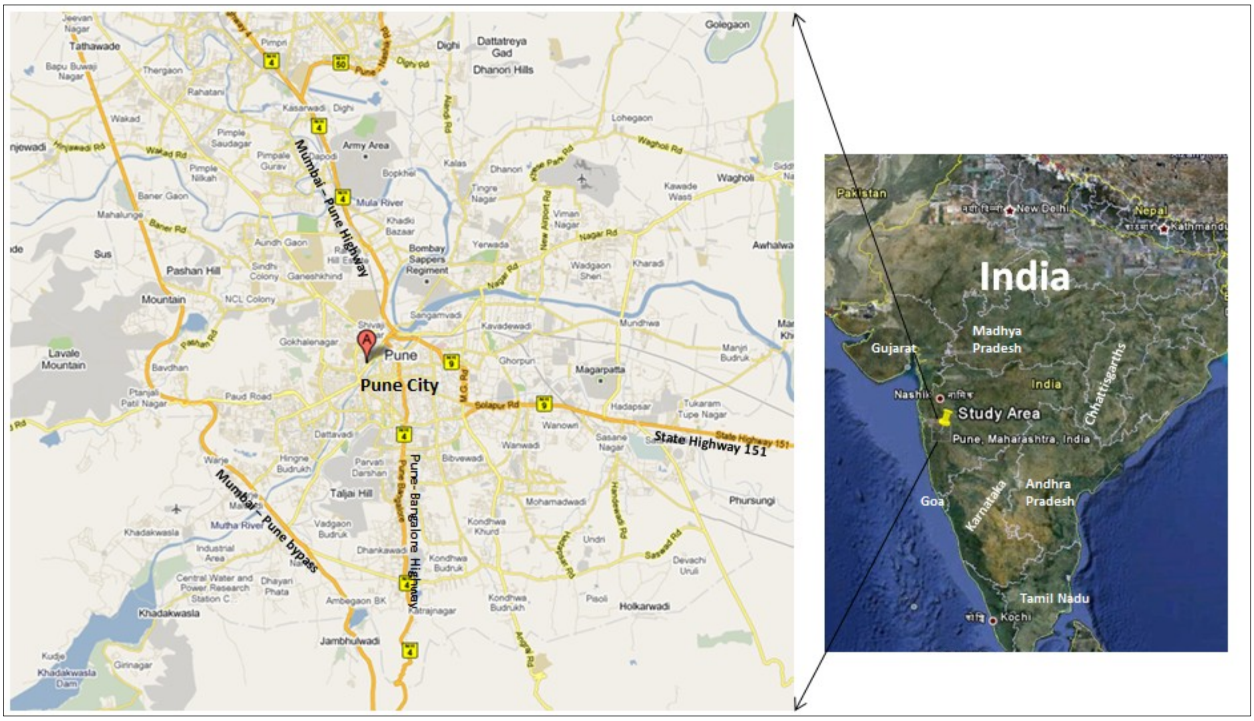

Figure 4-1: The study area

Source: Adapted from Google map, November 2010

4.2.1. Urban development and land-use pattern

The city's urban development pattern has in part been attributed to its location at the confluence of River Mutha and River Mula (Pune Municipal Corporation, 2006). These have divided the city into three broad zones with its core near the confluence of the rivers. In addition, the growth and development of the city has been driven by the presence of major national highways, state highways and by-passes (Pune Municipal Corporation, 2006). Rapid population increase that is mainly attributed to immigration of labourers has led to sprawl and ribbon development along these roads. For instance, Pune Municipal Corporation (2006) reports that a number of developments that have a direct bearing on Pune have sprung up along Pune-Mumbai road. It is also noted that the establishment of Pimpri-Chinchwad as an industrial satellite also led to additional urban sprawl of the city to its direction. By and large, the municipal authority seems to be overwhelmed by the planning challenges facing the city.

While the city remains densely developed at the centre near the confluence of River Mutha and Mula, its growth has in recent past been towards the south along Pune-Bangalore highway. Most of this development has been of residential type forming a ribbon type of development along the major roads. Indeed, residential development comprises more than 50% according to the current city development plan. Table 4-1 below gives a breakdown of the city's land-use by their percentage composition.

Table 4-1: Percentage distribution of land-use in Pune

Land-use	Distribution in percentage
Residential	42.52
Industrial	1.61
Commercial	4.05
Public and semi-public	6.83
Public utility	0.57

Table 4-1: Percentage distribution of land-use in Pune (Cont'd)

Land-use	Distribution in percentage
Reserved areas, forest and agricultural	11.91
Transport	13.04
Water bodies	5.95
Hills and hill slopes	5.11
Recreational	8.41
Total	**100**

Source: Pune city development plan (2006 – 2012)

The foregoing patterns of land-use and urban development have a significant bearing on urban transport and specifically urban cycling. Figure 4-2 shows the land-use map.

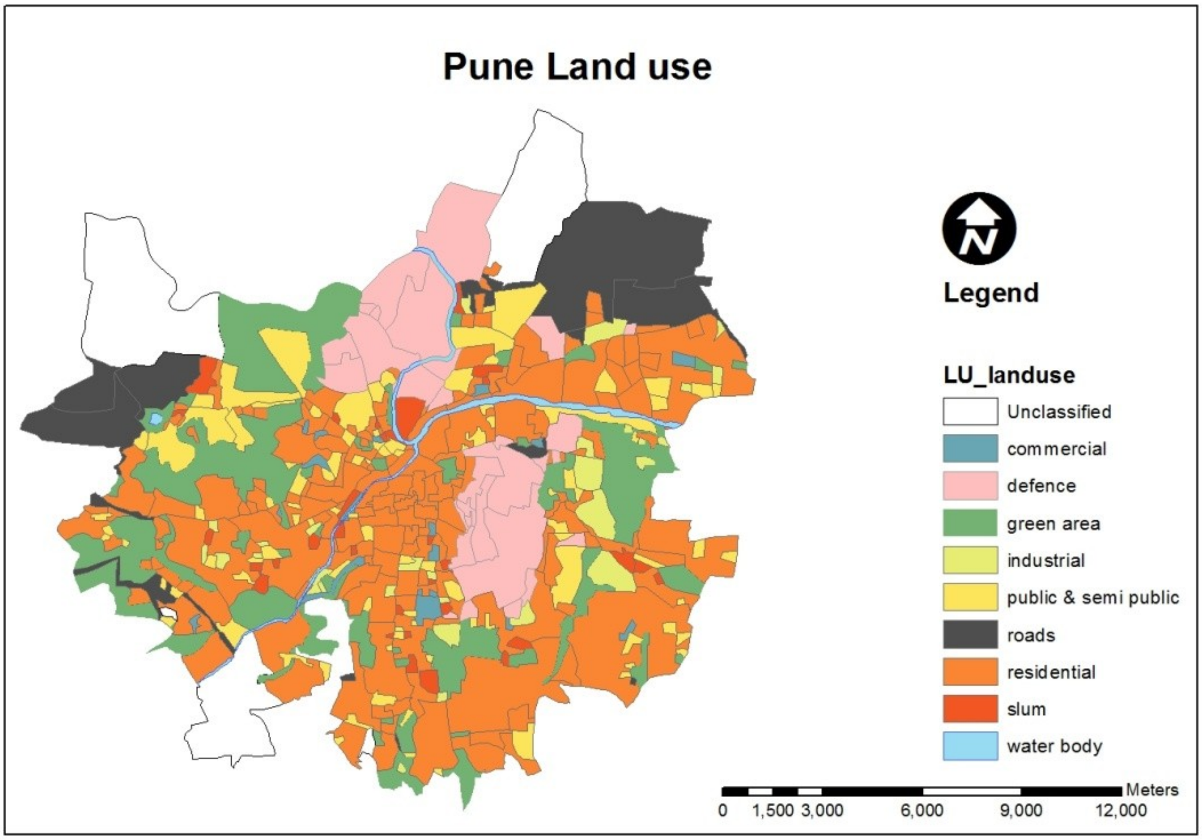

Figure 4-2: Pune land-use map

Source: Prepared from data based on Pune City Development Plan (2006 – 2012)

4.3. Urban land-use and transport situation in India in general and Pune in particular

Urban transport in Pune, like in many other Indian cities suggests a crisis state of affairs (Chakrabarti, 2001; Pucher et al., 2005). Not only does the city suffer from inadequate urban transport infrastructure; its transport service has been described as inadequate, unsafe and non-responsive to the needs of the poor majority comprising of cyclists and pedestrians (Chakrabarti, 2001; Mohan, 2001, 2004; Mousumi, 2009; Pucher et al., 2005). It is now suggested that rapid urban population growth against a backdrop of a warped urban transport and land-use planning system has been responsible for this situation (Pucher et al., 2005; The World Bank, 2002a, 2002b; Tiwari, 2002). These have engendered key concerns that are of urgent policy interest if the current situation is to be ameliorated.

To begin with, rapid urban population growth coupled with ineffective land-use planning and weak development control has fanned rapid urban sprawl in different directions of the city. This has led to increased travel demand on the one hand and longer trip lengths on the other hand. The situation disproportionately impacts negatively on the poor, most of whom can hardly afford the cost of motorised commutes (Pucher et al., 2005). The city's urban development policies do not seem to help this situation either. Pucher et al. (2005) for instance reports that policies aimed at decongesting inner city by limiting the building heights at the centre while permitting higher heights at its peripheries have led to more urban sprawl. What is more worrying is that such developments at the peripheries have been occurring without commensurate transport infrastructure to support them (Chakrabarti, 2001; Pucher et al., 2005; Tiwari, 2002). Cases of this have been reported in Pimpri-Chinchwad in Pune, Tidal Park in Chennai and Gurgaon in Delhi (Bertraud, 2002). The situation in Pimpri-Chinchwad in particular has a direct bearing transport in Pune.

The foregoing situation has witnessed an increased ownership and use of private car as the public transport system is almost non-functional, inefficient or non-existent in the sprawled areas (Pucher et al., 2005). This locks out the poor, who can only cycle or walk from urban transport not only because it is not affordable but also because it exposes them to accidents. Besides, it has been reported that this new trend in urban transport in India engenders congestion, air pollution and noise pollution (Gwilliam, 2003; Mohan, 2001; Pucher et al., 2005). Indeed, Indian cities are classified among the most polluted in Asia due to their current urban transport situation (Mohan, 2001; Pucher et al., 2005). At the same time, their roads can hardly be cycled due to the dangers they pose to cyclists (Mohan, 2001; Pucher et al., 2005). While this is the case, it is reported that majority would opt for other means of transport like cycling if the conditions were favourable (Mohan, 2004). Creating the favourable conditions for cycling therefore seems to be a challenge that can probably make a contribution to ameliorating this sorry state.

By and large, urban land-use planning system in India in general and Pune in particular has not been able facilitate the delivery of affordable housing near places of work. This further complicates its urban transport situation as majority are forced to live far from their places of work, consequently giving rise to longer commutes, increased pollution levels and higher chances of fatal accidents among cyclists (Pucher et al., 2005).

In view of the foregoing, the future sustainability of Pune city seems uncertain from social, economic and environmental fronts unless the foregoing situation is addressed. Interestingly however, the city's urban transport strategies seem notably skewed in favour of the car. Consequently, little deliberate and pro-active efforts seem to have been made to integrate urban land-use and transport planning and specifically to accommodate cycling on Pune roads. Perhaps the closest effort is the recently formulated National Urban Transport Policy which seeks to *inter alia* promote non-motorised urban transport among other key areas of sustainable urban transport (National Institute of Urban Affairs, 2006). However, from the manner of implementation of projects like the bus rapid transport, it seems there is still a disproportionate attention given to large-scale infrastructure projects for the cars, often at the expense of infrastructure for cycling and other non-motorised transport. Moreover, current literature gives no evidence that the policy has been domesticated in Pune city. Studies like the study on traffic and transport policies and strategies in urban areas in India (Wilbur Smith Associates, 2008) which are supposed to strengthen the policy also seem to remain largely diagnostic without any clear framework on how to integrate urban cycling and land-use.

Given this state of affairs with regard to urban transport in Pune, it is notable that policies aimed at improving urban transport will have to focus on reducing traffic injuries and fatalities, reducing road congestion and the accompanying environmental pollution and promoting equity in accessing urban transport infrastructure and services. These aspirations are in tandem with the current quest for smatter and just cities that promote better city life (UN-HABITAT, 2010). Rapid increase in car ownership and use can further be addressed through policy orientation that makes it safe for non-motorised transport options like cycling. These can be achieved through urban planning strategies that not only give attention to designing safe and functional roads but also pattern land-use activities on the urban space in a manner that promotes cycling. The proceeding chapter attempts a methodological account of how accessibility concept can be used to achieve this.

5. DATA ANALYSIS, RESULTS AND ACCESSIBILITY MODELLING

The preceding chapters 3 and 4 above identified the data and strategies used to realise the objectives of the current study together with an introduction to the study area. A review of the land-use and transport situation in the city has also been presented. In this current chapter, the study now uses the data presented to addresses the research objectives taking into account the urban transport and land-use situation of the city. Section 5.1 presents a statistical analysis aimed at finding out the cycling patterns and behaviours in Pune and their relationship with the underlying urban form. On the other hand, the urban form factors that inhibit cycling in the city are analysed in section 5.2. These two sections enable the study to identify the parameters to use in modelling accessibility at various trip origins. The model presented in section 5.4 marks the climax of the chapter. The parameters identified in the first two sections are implemented in this section in order to find out the accessibility situation in the city.

5.1. Cycling patterns and behaviour and their relation to urban land-use patterns

Handy (1996) defines travel patterns as the aggregate-level characteristics of travel, which help in quantifying the potential impact of urban form on travel and travel behaviour as the individual choices. The latter enables an understanding of how and why urban form is linked to travel. Accordingly, cycling patterns in this study were considered to comprise of trip purposes, the average distances cycled as well as the origins and destinations cycled. Cycling behaviour on the other hand was considered to include the reduction in the amount of cycling as distance increased; cyclists' reaction to barriers to cycling and the longest distances cycled. These were analysed to enable the study to assess how supportive Pune's urban land-use pattern was to cycling and to further enable the study to identify the urban form factors that constituted hindrances to cycling. Furthermore, analysis of the travel patterns enabled the researcher to obtain the magnitude of the opportunities that were cycled to. These formed the input in modelling accessibility in part 5.4. The specific analyses are presented in the proceeding parts.

5.1.1. Trip sources and destinations

These analyses were carried out to aid the selection of trip origins and destinations in the accessibility model. In order to find out the trip sources and their characteristics, the revealed preference data was analysed for the amount of cycling from each zone. The respondents were cross-tabulated with the zones from where they came to obtain their trip sources. The results are given in Annex iv. The resulting zones were then joined to the corresponding spatial data in ArcGIS in order to determine the land-use characteristics of the trip origins. Attention was paid to identifying the land-use category and the density of each of these land-uses. These were necessary to enable the study to understand the contribution of each of these land-use categories to cycling production and attraction. Figure 5-1 on the next page shows the percentage of cycling from the origins while figure 5-2 shows the density of land-use at each of the origin categories.

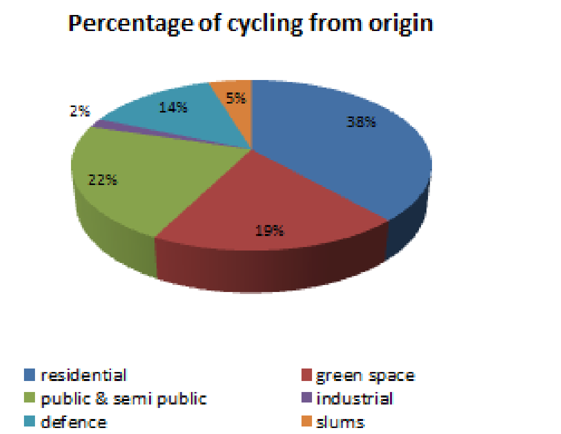

Figure 5-1: Percentage of cycling from origin

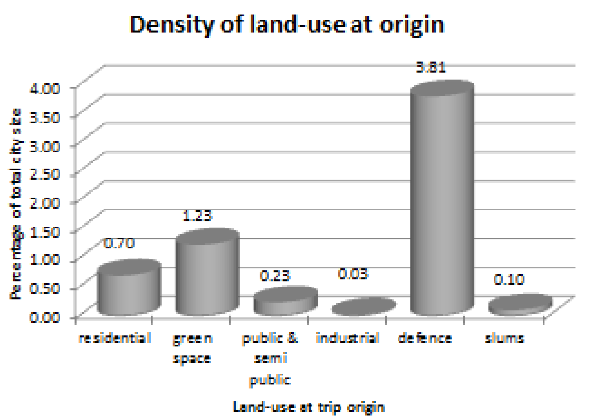

Figure 5-2: Density of land-use at origin

This analysis shows that majority of cyclists came from residential areas. Formally recognised residential areas together with slums produced about 43% of all cycling trips (Figure 5-1). Consequently, for accessibility modelling purposes, the study assumed that all trips originate from the residential areas. Trips produced from the other land-use categories were assumed to be return trips back to the residential places. In terms of the city's land-use organisation, it is interesting to note that while residential areas accounted for the majority of trip origins, the total density of residential areas where cyclists came from was only less than 1% of the city's total area. This suggests that only a few places in the city were safe for cycling. Alternatively, this could as well imply that cyclists came from particular residential places, probably slums and low income areas.

In order to determine the trip destinations on the other hand, the reported trip destinations from the revealed preference survey were identified. These were then summarised by frequency in order to determine how popular they were among cyclists. Table 5-1 below gives the results of this frequency count.

Table 5-1: Trip destinations

Trip destination	No. of cyclists	Percentage
Hawker/ vendor	3	1.1
Factory	9	3.3
Shop/ commercial	21	7.69
House	21	7.69
Office	28	10.26
Roadside/ informal	9	3.3
School/ college	*145*	*53.11**
Others	37	13.55
Total	**273**	**100**

* *Most cycled destination*

According to the results presented in Table 5-1 above, it is evident that most people cycled to school and work destinations of various types. Educational institutions comprised the destinations that were most cycled to, accounting for over 53%. This was followed by work destinations, which attracted about 26% of cycling. Internal cycling within the residential areas attracted only 8% as trip destinations while other destinations accounted for about 14%.

In order to assess how supportive the existing land-use pattern was to cycling between these origins and destinations, a cluster analysis of the densities of employment and education opportunities was done to find out how evenly they were distributed across the urban space. Dissart and Vollet (2011) have shown that the cluster analysis can be used to analyse for spatial patterns such as the relationship between landscape and employment. Figure 5-3 below shows the results of the cluster analysis of employment opportunities.

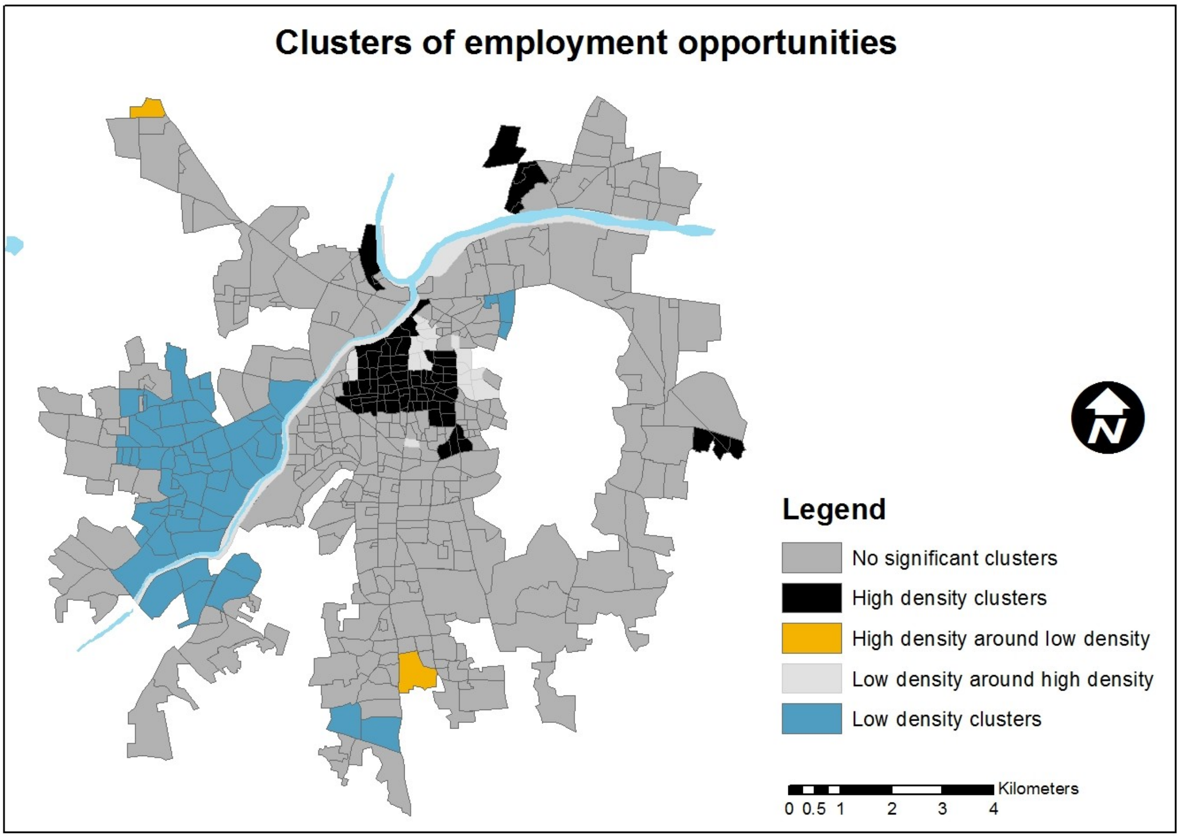

Figure 5-3: Clusters of employment opportunities

It is evident from the above figure that most employment opportunities were clustered at the centre of the city. There were also clusters of high density employment towards the north, just after the confluence of River Mulla and Mutha as well as to south eastern side of the city. These are shown in the figure above. The western side on the other hand did not have much employment as seen from the clusters of low density employment opportunities neighbour each other. A better part of the city however did not have any striking significant clusters of employment opportunities.

In terms of cycling therefore, this pattern of land-use organisation means that while cyclists who live near the areas of high cluster of employment could easily cycle to work, their counterparts from farther away had to cycle longer distances in order to access the same job opportunities. This provokes an interest to find out how then distance between origin zones and these opportunities influenced the ability of cyclists to partake in these opportunities. It is equally interesting to find out how barriers to cycling also impacted on the ability of cyclists to get to these opportunities that were clustered only at a few places in the city.

In order to check if there was any relationship between cycling and these opportunities, a spatial regression carried out on the density of cycling attracted at the zones and employment and education opportunities. According to Fotheringham Brunsdon and Charlton (2002), the geographical weighted regression could be used in such situations to predict variables by fitting a regression equation on every zone in the dataset. The geographical weighted regression achieves this by searching for explanatory variables that fall within the bandwidth of the dependent variable. In this case, density of cycling attracted to a zone was taken as the dependent variable while education and employment opportunities were the explanatory variables. The default bandwidth of 2021 neighbours was adopted to determine the number of neighbours for the estimation. The advantage of this is that it allowed the density of cycling in all parts of the city to be related to the explanatory variables. Figure 5-4 below shows the result of this analysis.

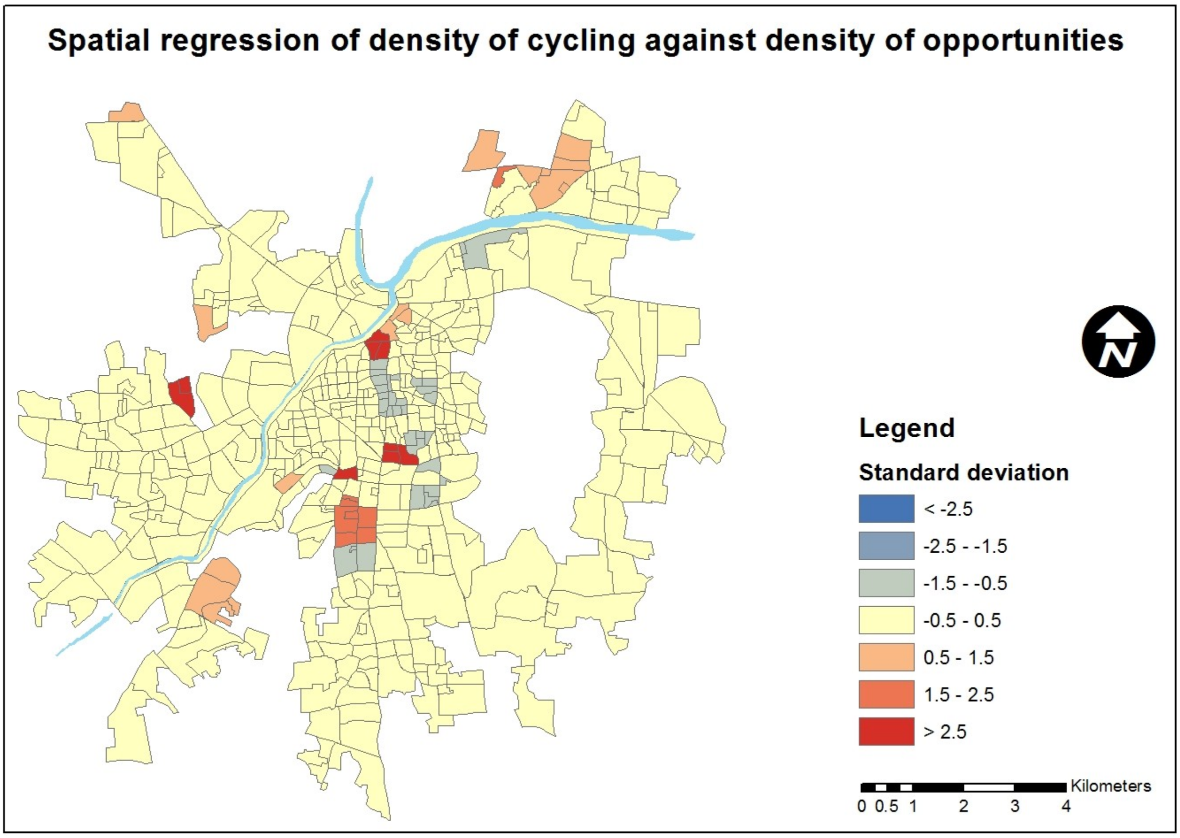

Figure 5-4: Assessing the relationship between cycling and opportunities

The results reveal a positive correlation between the density of cycling attracted to the zones and the opportunities available in those zones. An R^2 value of .88 was obtained indicating that density of cycling attracted could be well explained by the amount of opportunities at a zone. The dominance of zones with a standard deviation ranging between -0.5 to 0.5 shows that changes in the densities of opportunities went hand in hand with changes in the amount of cycling attracted in the zones. There were however a few zones that showed clusters with large standard deviation, greater than 2.5 or lower than -2.5. This is however acceptable since these zones were just a few. Furthermore, the opportunities could only account for 88% of the changes in cycling densities attracted.

Given the findings presented above, it was interesting then to find out the pattern of distribution of people on the other hand in order to relate this to their ability to access these opportunities. A cluster analysis was done to achieve this. Figure 5-5 shows the results of this analysis. Unlike the distribution of employment opportunities, it is striking that the distribution of population was in this case spread out in various parts of the city. This is seen from the yellow zones where low population sizes neighboured high population sizes.

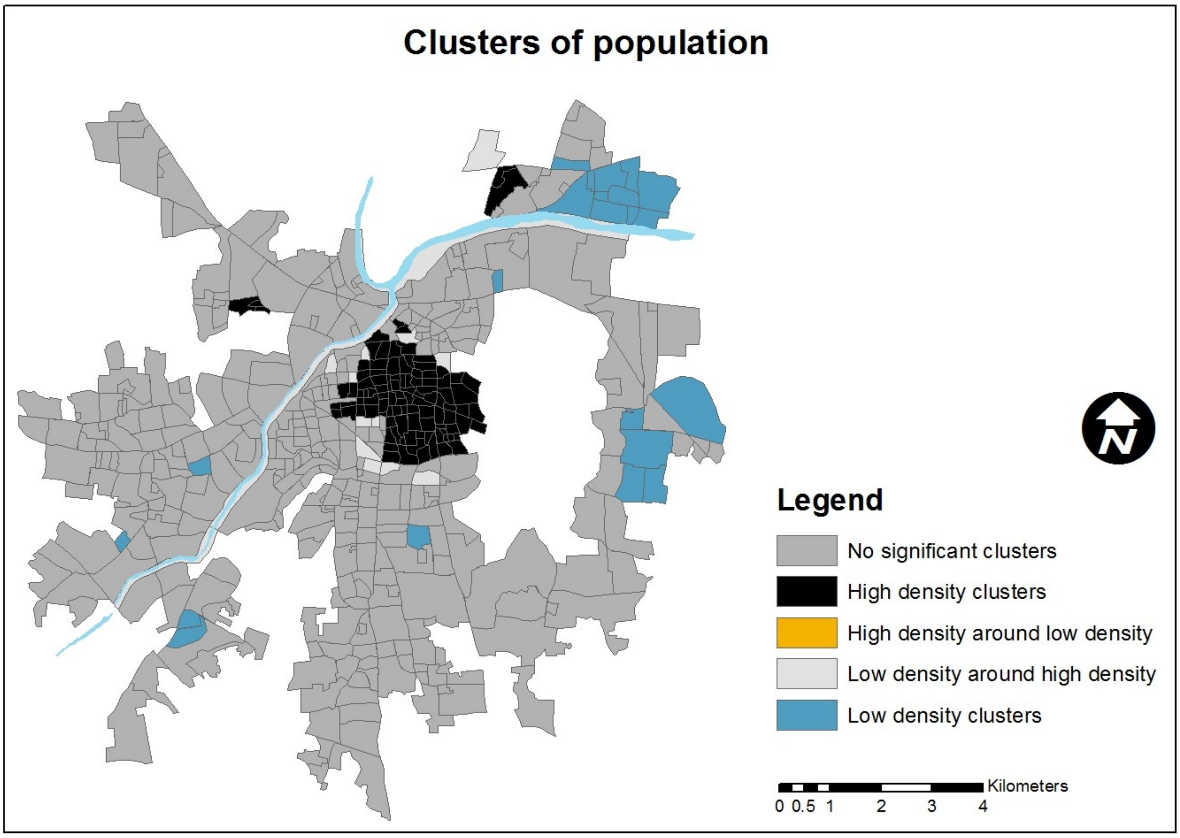

Figure 5-5: Clusters of population

The situation with regard to education opportunities was not any different from that of employment. In this case, a similar distribution pattern to that of employment opportunities was observed (Figure 5-6). The distribution of schools is again seen to be clustered at a few specific zones in the city. This imposes similar cycling demand on residents who live away from these opportunities. This again raises curiosity about their ease of cyclists who live farther away from these clusters to get to them.

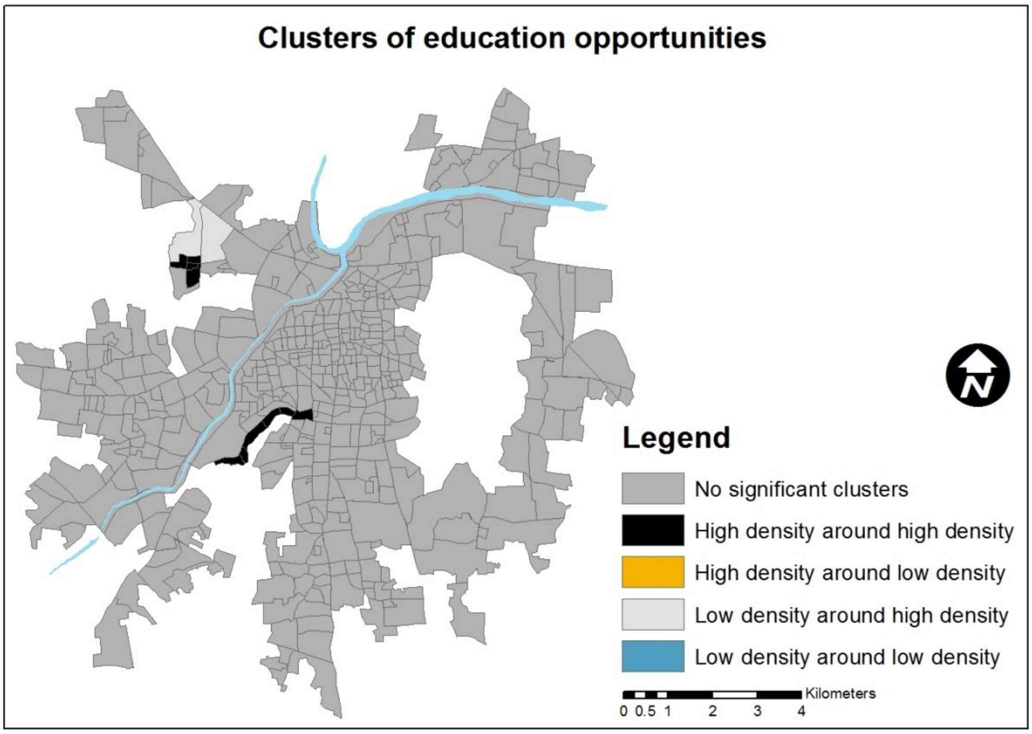

Figure 5-6: Clusters of education opportunities

In view of the foregoing results, the study considers that the distance between the opportunities and residential areas has an important bearing on accessibility for cycling. This was factored into the model developed later in section 5.4.

5.1.2. Effects of distance on the amount of cycling

The current part takes cognizance of the technical and economic theories of land-use and transport interaction discussed in chapter 2. Accordingly, the distance cycled is considered as an important indicator of how easy it is to get to the opportunities located on urban space. Highly clustered opportunities are taken to engender longer travel distances while dispersed blend of land-uses leads to shorter cycling distances.

In view of this, the distances cycled were analysed in order to determine the effects that they had on the amount of cycling. The analysis sought to find out the mean, modal as well as the minimum and maximum distance that were cycled. This analysis also aimed to inform the study in determining the co-efficient of distance as a cost factor in cycling in Pune city. Table 5-2 below shows the results of analysis of distance cycled.

Table 5-2: Statistics for distance between origins and major destinations

Valid cases	273
Missing cases	0
Mean	2.98
Mode	2
Minimum	0
Maximum	6

From the results presented, it is evident that cycling was possible for distances of up to 6 km from the trip origins. Distances of 0km were realised for trip makers who cycled to destinations close by home. On average however, the majority of the respondents could only cycle up to 2.98 km while the modal distance cycled was 2 km from the trip origins. This rather short distance cycled suggests that majority of cyclists could only cycle to opportunities that were not far from their places of residence. Alternatively, this pattern can also be attributed to the existence of barriers which restricted cycling to only a limited area from the trip origins. Considering the clusters of opportunities presented earlier (e.g. Figure 5-3), it is also possible that the majority of cyclists comprised of those who lived close by their places of work.

Given these findings, the accessibility model presented in section 5.4 considers 6km from the trip origins as the cut-off beyond which no accessibility can be realised. In this sense, distance itself is seen as a barrier to cycling since opportunities that are located more than 6km from trip sources cannot be accessed. This is treated further in the model.

The study also analysed for the effects of increasing distances on the amount of cycling. A cross-tabulation analysis was done between the distance and the number of cyclists to obtain this. Table 5-3 below presents the findings of this analysis.

Table 5-3: Effects of increasing distances on the percentage of cycling

Distance between origin and destination	Number of cyclists	Percentage
0	4	1.47
1	40	14.65
2	***81***	***29.67****
3	56	20.51
4	42	15.38
5	25	9.16
6	25	9.16
Total	**273**	

** Modal distance cycled*

The results show a steady increase in the amount of cycling up to distances of 2 km at which about 30% of the respondents reported that they cycle. After this peak, there is a gradual decline in the proportion of cyclists with every additional kilometre that has to be covered. This is probably an indication that the majority of people walked to opportunities that were 2.9km from their origins but their number decreases with increasing distances. The maximum distance cycled was realised to be 6km. consequently, this is considered in the model developed later as the cut-off distance beyond which no cycling is possible. These results identify with the cost minimisation behaviour of individuals as postulated by economic theories of land-use and transport.

The foregoing cycling behaviour was relevant in enabling inferences to be made about accessibility at different zones once the distances from origins to destinations were determined in using the Origin-Destination cost matrix presented later in the accessibility model.

The observed relationship between cycling distance and proportion of cycling further enabled the study to determine the distance decay factor to use in modelling accessibility. To do this, a scatterplot was prepared that related the percentage of cycling and the distances cycled. This was done in Microsoft Excel. Polynomial regression of order 5 was then used to fit the resulting curve that approximated the cyclists' reaction to increasing distances from trip origins. Even though the polynomial regression has a wavy characteristic between data points, it nonetheless fitted the requirement of the current study since the maximum distance was only limited to 6km from trip source. The wavy characteristic of the polynomial regression was not evident within the range of distance that was of interest in the current study. Figure 5-7 below shows the results of this operation.

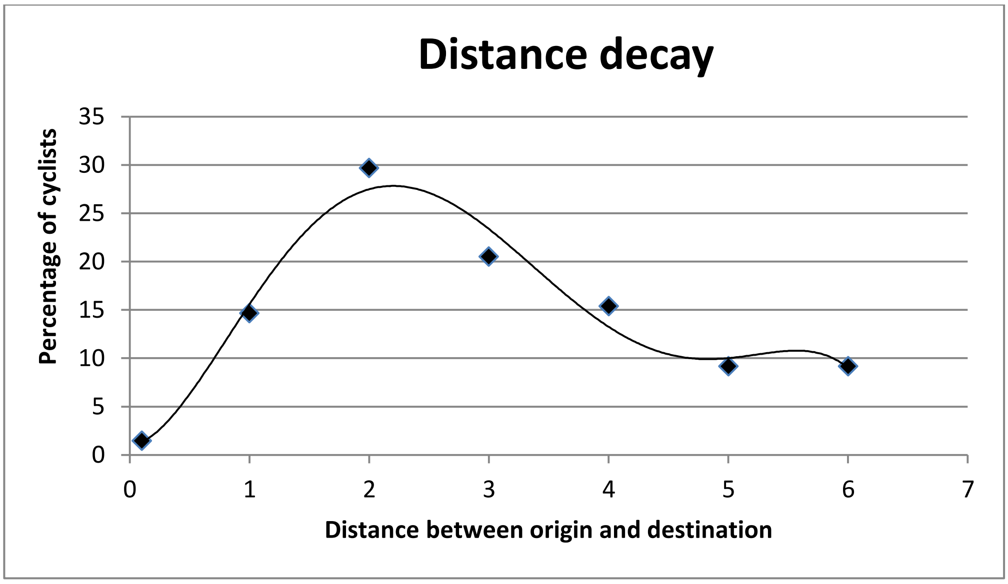

Figure 5-7: Relationship between distance and percentage of cyclists

The model in Figure 5-7 above yielded the following function to fit the pattern observed above.

$$\boldsymbol{Y = -0.1699x^5 + 2.6682x^4 - 13.97x^3 + 24.393x^2 + 1.7659x + 0.885}$$

Equation 5-1

In this case **Y** is the percentage of expected cyclists while **X** is the distance from origin to the destination. The curve could explain up to 96% ($R^2 = 0.9612$) of the possibility to cycle and was therefore adopted in estimating the percentage of possible cyclists in the accessibility model developed in section 5.4.

5.1.3. What potentials attract cycling to trip destinations?

In order to find out the factors that attracted cycling to different destinations, the study correlated the amount of cycling attracted to the zones with the population density, density of employment and education opportunities at each TAZs. The results presented in table 5-4 below were obtained. These factors that attracted cycling to different destinations were required in order to calculate zone potentials for use in accessibility modelling. This latter part is done in section 5.4.

Table 5-4: Correlation between amount of cycling attracted and the opportunities (N=475)

	Density of cycling attracted	Population density	Employment density	Education density
Population density	.192**	1		
Employment density	.092*	.382**	1	
Education density	.932**	.112*	.062	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The results show that there was a significant positive correlation between the densities of cycling attracted at different zones and the density of employment and education opportunities. Education opportunities had the highest correlation with cycling. This identifies with the previous find presented in Table 5-1 where it was shown that education facilities were the leading trip destinations. Cycling attraction was also correlated with the higher population densities. This could probably be because of the kind of activities that cyclists took part in. As shown in table 5-1, hawking and other informal trading activities comprised some of the trip destinations among the cyclists who were interviewed in the revealed preference survey. The study reasoned that these activities were dependent on the presence of people for their markets. In view of these findings, it appears that land-use planning has currently led to concentration of opportunities at the core of the city thereby making the area more attractive to cyclists when compared to other parts of the city.

The densities of these opportunities were mapped in an effort to enable an understanding of their spatial distribution and to enable inferences to be made regarding their influence on accessibility on the basis of their distribution patterns. Figure 5-8 below enables a comparison of the spatial variation of the densities of these opportunities across the city.

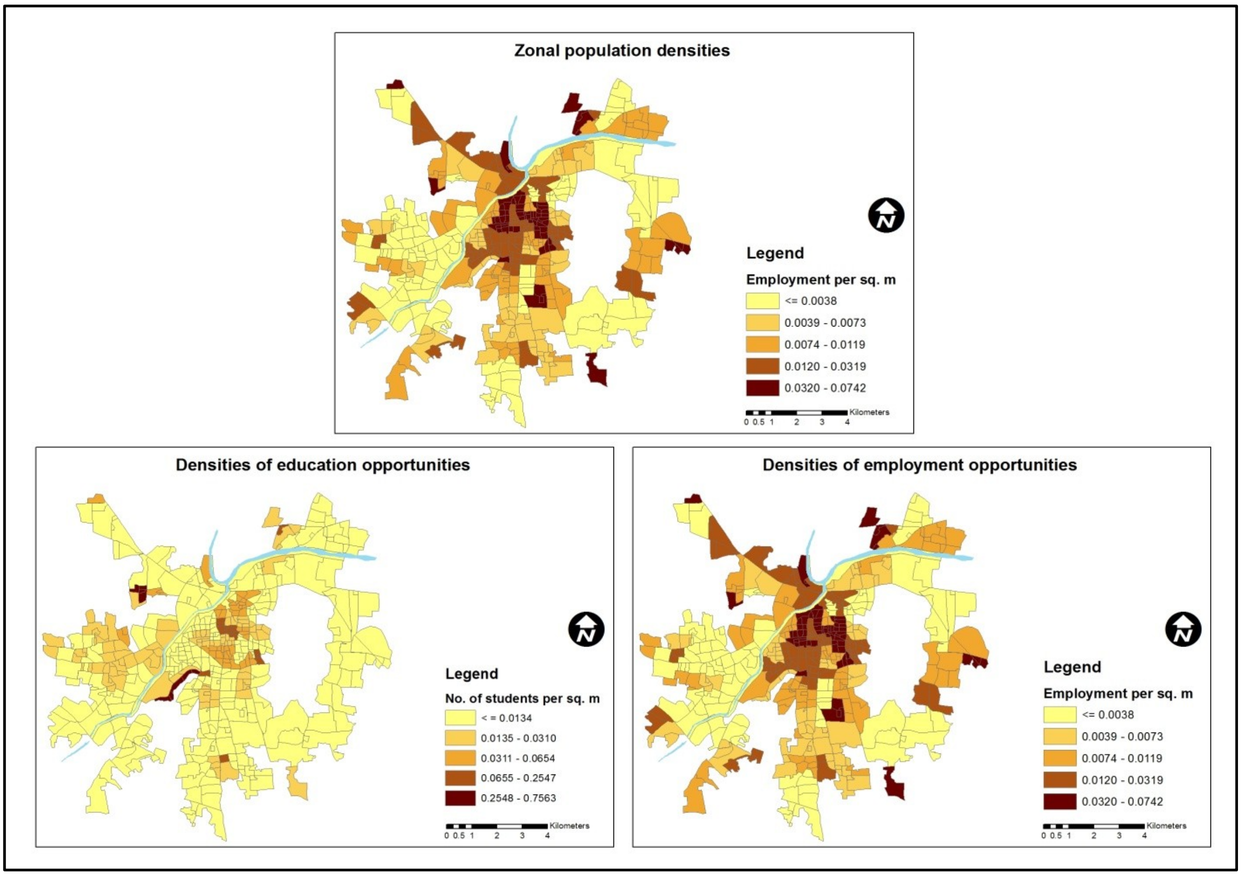

Figure 5-8: A comparison of variation in population, employment and education densities across the city

The results presented above show that employment, population and education opportunities are comparatively more concentrated at the city centre. However, more employment opportunities are found at the centre when compared to education opportunities and population. On the other hand, the city's population seemed to be somehow spread out in different parts of the city. Though the population was denser at the city centre, a gradual gradient can be seen as one moves out of the city centre.

In terms of cycling therefore, the patterns revealed by these analyses suggest that people who live outside the central part of the city would have to cycle longer distances in order to access opportunities at the city centre. These can only be possible for people who live within 6 km of the city considering the findings already presented in part 5.1.2 of this thesis.

5.2. Urban form factors that inhibit cycling

Section 5.1 above has presented the cycling patterns and behaviours in Pune city together with the underlying urban land-use patterns that are likely to dictate these patterns. This current section now looks at the physical barriers that are caused by the way the roads are organised. These either make the roads favourable or unfavourable to cycling. The combined impact of both land-use organisation and road organisation are seen in this study to be responsible for patterning accessibility in the city. In particular, the permitted speeds of motorised transport, the sizes of the carriageways and the number of uncontrolled access were analysed. The volumes of motorised transport, pedestrians and the number of informal activities alongside the roads are also analysed as they were considered to be indicative of the manner of the city's land-use planning. The study argues that the concentration of activities at particular places in the city leads to higher volumes of cars and people around such places.

A multiple regression analysis was carried out in order to find out whether the factors that were thought to impede upon cycling indeed did so. The regression analysis related these factors with the volume of cycling along and across the roads. The results shown in table 5-5 below were realised.

Table 5-5: ANOVA test for significance of relationship between urban form and cycling

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	768389.294	11	69853.572	36.889	.000[a]
	Residual	1030137.872	544	1893.636		
	Total	1798527.165	555			

a. Predictors: (Constant), hourly volume of auto, number of parked vehicles at link(NMV, autos, etc), number of uncontrolled vehicular access, average car speed, size of carriageway in meters, number of informal activities (hawkers, vendors etc), hourly volume of buses, hourly volume of pedestrians, average bus speed, hourly volume of cars, average speed of three wheeler

b. Dependent Variable: hourly volume of bicycles and non-motorised vehicles

The regression analysis yielded a test statistic of 36.889 and a p-value of .000 which suggested that at least one of these factors impeded on cycling in the city. A t-test was then carried out for each of the independent variables to see if they had a significant relationship with the cycling volumes. The results of these are given in table 5-6 on the next page.

Table 5-6: t –test for relationship between urban form factors and cycling volumes

Coefficients [a]

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	34.554	8.129		4.251	.000
***average car speed**	***-0.721***	***0.265***	***-0.135***	***-2.723***	***0.007***
hourly volume of pedestrians	0.124	0.017	0.274	7.358	.000
number of informal units (hawkers, vendors etc)	0.331	0.258	0.046	1.281	0.201
number of parked vehicles at link(NMV, autos, etc)	0.019	0.277	0.002	0.07	0.944
number of uncontrolled vehicular access	-0.389	0.415	-0.032	-0.936	0.349
average speed of three wheeler	0.727	0.34	0.102	2.138	0.033
average bus speed	0.639	0.169	0.163	3.784	.000
hourly volume of cars	-0.04	0.02	-0.088	-2.007	0.045
hourly volume of buses	0.12	0.048	0.097	2.506	0.013
size of carriageway in meters	-1.938	1.016	-0.067	-1.908	0.057
hourly volume of auto	0.261	0.021	0.461	12.502	.000

[a]. Dependent Variable: hourly volume of bicycles and non-motorised vehicles

**The speed of cars on the roads imposes the most deterrence to cycling in Pune city*

According to the results obtained from the analysis, some factors like the number of pedestrians showed positive correlation with amount of cycling while others like the average car speed and the hourly volumes of cars showed negative correlation with cycling. By looking at the significance of the statistics returned, the study was able to identify which factors correlated significantly with cycling. The average car speed with a coefficient of -.72 and a p-value of .007 seemed to exert the strongest negative influence on the volume of cycling and was therefore of much interest in the context of the current study. It seems roads that are designed to permit higher car speed were therefore risky for cycling. Parkin et al. (2007) have shown that such routes are in most cases avoided by cyclists due to the perception that that they expose cyclists to accidents. The results from the hourly volume of cars similarly appear to suggest that wider roads that permit larger volumes of cars also made it hard to cycle. In this case, a coefficient of -.04 was realised with a p-value of .045. Other indicators of urban form that equally seemed to impact negatively on cycling included the number of uncontrolled vehicular access (coefficient of -.389; p-value .349) and the size of the carriageway (coefficient of -1.938; p-value .057). However, these were found to be statistically insignificant.

On the other hand, contrary to the expectation of the study, the hourly volume of pedestrians, the number of informal activities, the bus speed and volume of bus were found not to inhibit cycling. All these predictor variables resulted in positive coefficient which implies that volumes of cycling increased as these variables increased. This probably suggests that most of the cyclists were captive cyclists who were themselves participants of informal activities and other land-use opportunities that attract pedestrians and commuters who use the buses.

In terms of modelling accessibility at different trip origins therefore, the study has given attention to the permitted car speed on the roads. The model developed later in this work assumes that the volume of cars exerts uniform impedance on cycling across the zones due to lack of data to model its impact on accessibility.

It seems the difficulty in crossing intersections and the fear of accidents along the roads, partly due to lack of cycling space accounted largely for the barriers realised in the above analysis. Table 5-7 summarises the reasons that were given by the cyclists and potential cyclists as the reasons that inhibited them from cycling.

Table 5-7: Reasons for limited or no cycling

	Active cyclists		Potential cyclists	
	Frequency	**Percentage**	**Frequency**	**Percentage**
**Fear of accidents from other vehicles*	*115*	*42.1*	*401*	*35.4*
No space on roads	44	16.1	224	19.8
Difficulty in crossing intersections	37	13.6	217	19.1
Bad roads	41	15.0	177	15.6
Not socially acceptable	11	4.0	63	5.6
No bicycle	4	1.5	40	3.5
Others	1	0.4	12	1.1
N/A (really like it and use it everywhere)	20	7.3	n/a	n/a
Total	**273**	**100**	**1134**	**100**

**The fear of getting involved in an accident makes people not to cycle in the city*

The analyses presented above reveal that the fear of getting involved in accidents was a major concern among potential and active cyclists alike. These findings resonate with the findings of Parkin et al (2007) who have shown that this is among the key factors that deter people from cycling certain roads in a city. On the strength of the results presented on the preceding sections and the evidence presented in literature, the current study models roads with motor speed of 50 kmh^{-1} as barriers to cycling. On the other hand, the study assumes that all the roads with speed below 50 kmh^{-1} are cycleable.

5.3. Summary of the key variables for accessibility modelling

The preceding sections of this chapter have analysed the urban form and transport situation as well as the cycling patterns and behaviour in Pune city. Specific focus was given to urban form in the context of the patterns of land-use in the city. Attempts were made to relate the resulting cycling patterns and behaviour to the existing urban land-use situation with the aim of provoking the research to find out how this impacted on accessibility at the trip origins. This section summarises the results from the foregoing analyses with a view to pointing out the key variables that form the input to the accessibility model presented in the subsequent chapter.

The literature-based analysis of the transport-land-use situation in Pune revealed that rapid urban population increase against a backdrop of unresponsive urban planning system led to urban sprawl and subsequent increase in travelling distances. This engendered overdependence on the motorised transport. Furthermore, planning interventions such as the restriction of building heights within the city centre have resulted in urban development sprawling to the peripheries of the city where conditions are less stiff.

These factors have resulted in increased commuting distances and the consequent reliance on motorised transport to the disadvantage of the poor, most of who have to either walk or cycle to their destinations.

The foregoing patterns are confirmed by an analysis of the city's land-use patterns. By and large, the analysis carried out reveals that opportunities like jobs and schools were more dense and clustered at the city centre compared to the city's peripheries where majority of the poor lived. This suggests that residents of such far-off places from the city centre had to cycle longer distances if they were to exploit the opportunities at the city centre. However, what remains unclear is whether they can safely do so considering that some roads are not safe to cycle and as such impose barriers to cycling in the city. Moreover, distance itself has been seen in the analysis to comprise a barrier to cycling once opportunities are more than 6km from the trip origins.

According to the analysis carried out, it is evident that cyclists were attracted to schools and employment opportunities of various types. The latter included *inter alia* hawking, factory jobs and informal jobs. As mentioned in the preceding paragraph, all these opportunities were clustered at the core of the city. The magnitude of these opportunities across the city was considered an important variable in the accessibility model developed in section 5.4. On the strength of the technical theories discussed in section 2.2 supported by the findings presented in part 5.1, this study expects a positive correlation between the magnitude of these opportunities and the amount of cycling that is attracted to them.

On the other hand, the study also takes cognizance of the economic theories of transport and land-use which postulate that trip makers often minimise the cost of traveling between their origins and destinations. In the current study, the cost is considered as the distance between trip origins and destinations. The analysis presented above reveals that the amount of cycling decreases with increasing distance from trip origins and that no cycling was evident beyond 6km. In addition to distance, the analysis has also found out that the speed of cars on the roads and safety of cyclists at junctions also barred them from cycling. Thus high speed roads are modelled in this study as the barriers to cycling. This is supported by researches that have been conducted by Parkin et al (2007) and other authors.

The factors highlighted in this summary form the key variables in the accessibility model presented in the next section.

5.4. Accessibility modelling

This section forms the climax of the current chapter. It draws from the findings presented in the preceding sections and the theories analysed in chapter 2 to model accessibility at various origin points. The section is organised in 4 parts; part 5.4.1 puts together the variables used to calculate the zonal potentials and the distance decay function in the model. The distance decay function takes distances between origins and their corresponding destinations as the cost factor. Part 5.4.2 on the other hand presents the model calibration. The section culminates in part 5.4.4 where the results of accessibility measure are presented. These results are mainly influenced by the manner in which land-use in the city is organised. In order to link these with transport, the study analyses the resulting accessibility patterns using the network indicators to find out the impact of the road barriers on accessibility.

5.4.1. Calculating the zonal opportunities and distance decay function

The results from the analysis presented in part 5.1.3 revealed a positive correlation between the amounts of cycling attracted to the zones and their population as well as employment and education opportunities.

On the basis of the relationship revealed by these results, a regression analysis was carried out to fit a model that could be used to explain the influence of the above variables on the potential at each of the zones. Equation 5-2 on the next page was used to aggregate the potential of the zones.

$$D_{j=}f(P_{ar} + P_{op} + E_{mp} + E_{du})$$

Equation 5-2

Where:

- D_j = potential of TAZ *j*,
- P_{op} = population density at TAZ_j,
- E_{mp} = Employment density at TAZ_j and
- E_t = Density of education opportunities at TAZ_j

Accordingly, the potential of each zone was thus derived from the regression function shown in equation 5-3 below. It should be pointed out that the resulting value from this calculation is a scale value that only enables comparison of the potential of the zones.

$$D_{j=}0.004 + 0.096xP_{op} + 0.005xE_{mp} + 0.392E_{du}$$

Equation 5-3

The potential of each zone was calculated and visualised in ArcGIS10 using the above function. Figure 5-9 below shows the results of this operation.

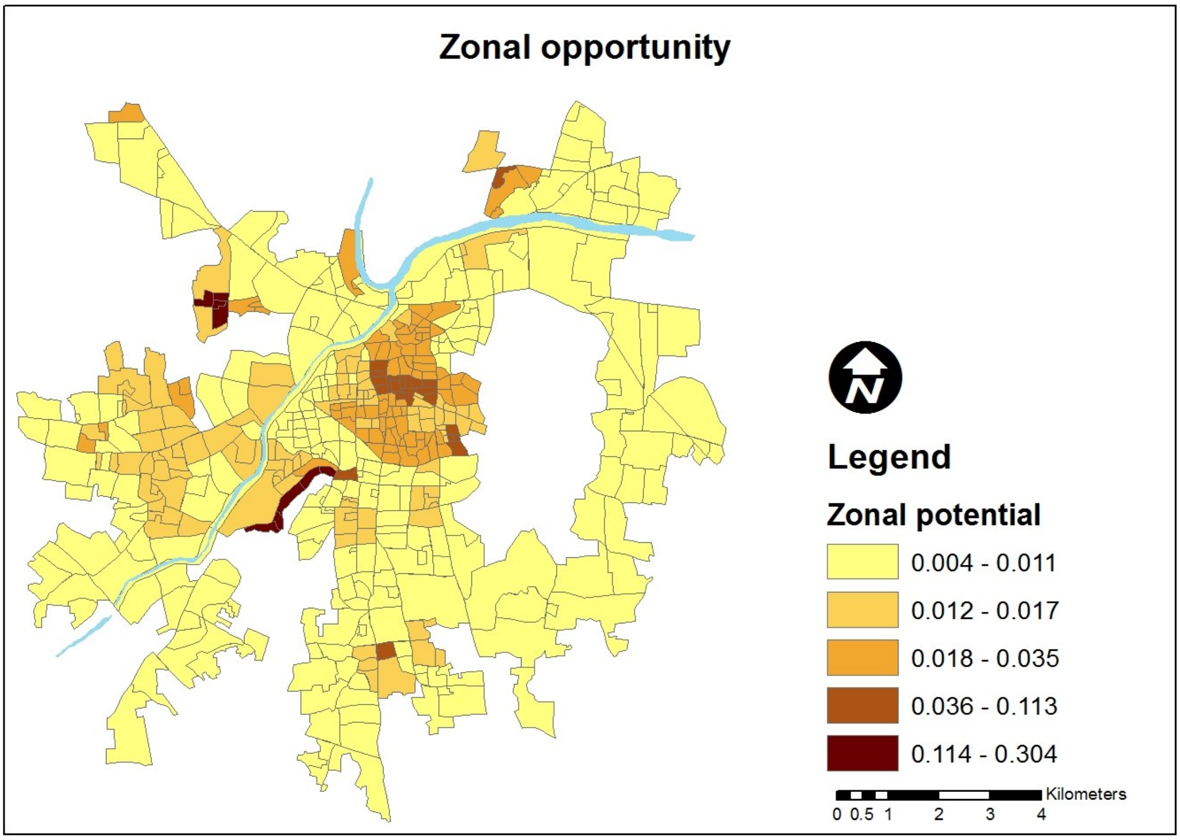

Figure 5-9: Aggregated zonal opportunity

Figure 5-9 shows that the opportunity of the zones decreases from the city centre. This identifies with the results of analysis of the densities of the opportunities that cyclists partake. Some linear developments can also be seen which closely follow the roads. It appears therefore that areas where land-use planning had facilitated more opportunities similarly attracted more cycling to themselves.

On the other hand, the relationship between the percentage of cycling and distance established earlier (See equation 5-1 presented in part 5.1.2) was used to model the influence of distance in shaping accessibility at different trip origins. The distance decay function presented in Equation 5-4 below was used in the model. This function fitted the proportion of cycling to the pattern observed in part 5.1.2 where this proportion peaked at 2km from trip origins before it gradually started to go down with every additional kilometre up to 6km.

$$F\ (C_{ij}) = -0.1699x^5 + 2.6682x^4 - 13.97x^3 + 24.393x^2 + 1.7659x + 0.885$$

Equation 5-4

5.4.2. Assumptions of the model

A number of assumptions were made in the model presented in this section. These are listed below:

i.) All the roads with car speed below 50 kmh^{-1} are assumed to be cycleable;
ii.) A search tolerance of 1200 metres was allowed in order to snap the centroids of the TAZs to the roads;
iii.) The destinations are assumed to have enough opportunities to cater for the needs of all cyclists who can reach them;
iv.) It was also assumed that the volume of cars on the roads exerted uniform impedance to cycling since there was no data to take this into account;
v.) The cost of making turns is equal throughout all cycleable roads;
vi.) It is assumed that roads with car speed of 50 kmh^{-1} impose a hard barrier to cycling. This is partly due to data limitations;
vii.) The observed percentage of cyclists per distance as depicted in figure 5-7 is representing the likeliness to cycle per distance.

5.4.3. Model calibration

Calibration of the accessibility model was done in the Network Analyst extension of ArcGIS10 and MS Excel platform. The centroids of all the zones were first created in ArcGIS10 to represent the land-use characteristics of each zone. Trip origins were then created by exporting a layer comprising only of the centroids of all 411 residential and slum zones in the city. On the other hand, trip destinations were created from the centroids of all the 474 zones in the city. These included residential zones as well.

Modelling was done through two parallel approaches that sought to bring together elements of urban land-use and urban cycling through the use of accessibility measure. In the first case, the formula provided in equation 5-3 was used to calculate the opportunities at each TAZ in ArcGIS10. This gave an output that represented the zonal opportunity for all TAZs in the entire area of study. On the other hand, an O-D cost matrix analysis was carried out on the road networks data to calculate the distances between origins and destinations that were visited. This was done for both scenarios without barriers and with barriers. In the first scenario, the model allowed cycling to any destination as long as it was not more than 6 km from the trip origin. In the second scenario however, the model imposed a barrier on some routes. This was achieved by modelling roads that permitted car speed of 50 kmh^{-1} as barriers. These roads were deemed to be unsafe for cycling on the strength of the analysis carried out in section 5.2 and backed by similar reasoning from other studies like that of Parkin et al. (2007). Though they could have been modelled differently, data limitation dictated the researcher to model them as hard barriers. To achieve this, a layer of these roads was created and specified as the barrier input in the O-D cost matrix analysis. The finding already presented in part 5.1.2 as regards the maximum cycleable distances was on the other hand considered to set a cut-off of 6 km from trip origins. This was the maximum distance beyond which no cycling was expected according to the model developed in this thesis.

The O-D cost matrix yielded several trip lengths between the pairs of origins and destinations. These lengths represented the cost of cycling between origins and destinations. The identity of the trip origins were then extracted from the O-D cost output before it was linked back to ArcGIS for further processing. This was done in MS Excel by taking the origin identity from the Origin-Destination field that resulted from the O-D cost matrix analysis.

The opportunity map and the output of the O-D cost matrix analysis from the above parallel processes were then joined in ArcGIS to make the TAZs had both cost of cycling between origins and destinations as well as the opportunities that attracted cycling to these destinations. The results of this join operation contained the TAZ identity, the opportunity in the TAZ and the cost of cycling between the TAZs. This output was exported to MS Excel where accessibility at each of the trip origins was modelled. The following strategies were adopted to derive accessibility scores at each trip origin.

- The resulting trip lengths from O-D cost matrix were converted to kilometres by dividing them by 1,000 before they were modelled as the cost, C_{ij} of cycling between trip origins and destinations.
- The distance decay function was taken from the model fitted by Equation 5-4 presented on page 47. The values of C_{ij} were put into the function in order to make the trip lengths between each O-D realistic to the effects of friction of distance;
- The opportunities, D_j at each of the zones were taken from equation 5-3 on page 46.

The study proceeded to calculate accessibility using the Hasen's accessibility formula discussed earlier. In this case, $\boldsymbol{F(C_{ij})}$ replaced $\boldsymbol{e^{-\beta C_{ij}}}$ in the accessibility model developed by Hansen (1959). As presented earlier, the former function fitted the cycling patterns in Pune better than the latter which was found to give too much weights to origins that were close by the destinations. The total accessibility at each trip origin was calculated by summing the product of all individual opportunities that could be reached from each zone and their corresponding exponent of the distance decay function.

Table 5-8 below presents a screen-print that shows how accessibility was modelled using the cost of cycling (Cij), opportunities at trip destinations (Dj) and the distance decay function, F(Cij).

Table 5-8: Calculation of accessibility at each origin

Q21 fx =SUMIF(C21:C4009,T21:T274,P21:P4009)

G	H	I	J	K	L	M	N	O	P	Q	R
Cij	**(-0.1699*Cij^5)**	**2.6682*Cij^4**	**(-13.97*Cij^3)**	**24.393*Cij^2**	**1.7659*Cij**	**0.885**	**Dj**	**F(Cij)**	**Dj*F(Cij)**	**∑Dj*F(Cij)**	**MYF_FID**
0.00	0.00	0.00	0.00	0.00	0.00	0.885	0.00769537490	0.885	0.00681041	0.0068	0
0.00	0.00	0.00	0.00	0.00	0.00	0.885	0.00764759479	0.885	0.00676812	0.4144	1
1.05	-0.22	3.26	-16.22	26.95	1.86	0.885	0.00764759479	16.506	0.12623135	0.7373	3
1.10	-0.28	3.97	-18.82	29.76	1.95	0.885	0.00764759479	17.461	0.13353566	0.0145	4
1.21	-0.45	5.79	-24.99	35.94	2.14	0.885	0.00764759479	19.329	0.14782312	0.4536	5

The resulting accessibility scores were then saved as .dbf to enable them to be linked to ArcGIS for visualisation. Figure 5-10 on the next page summarises the procedure that was adopted to model accessibility in the current study.

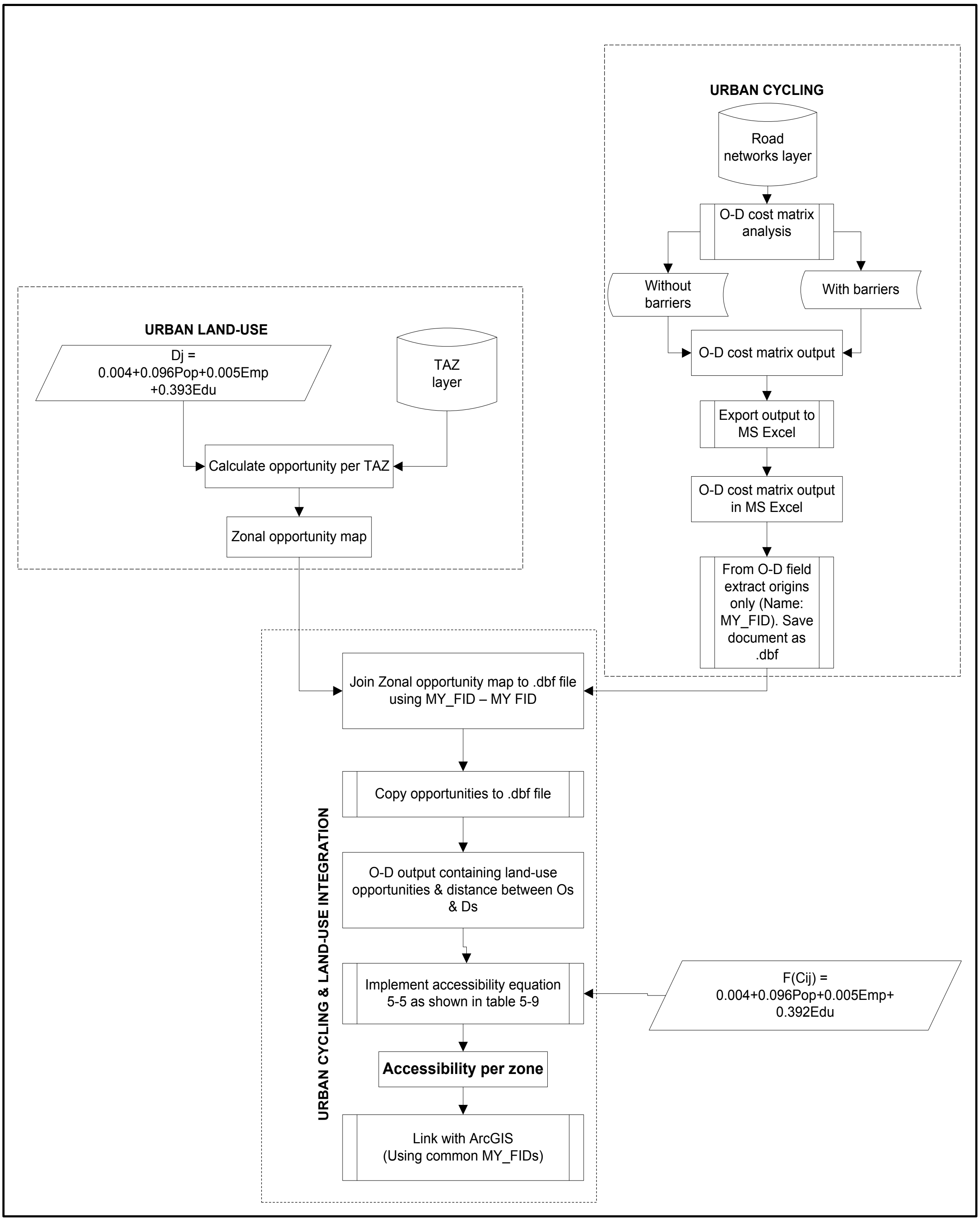

Figure 5-10: Integrating land use and cycling behaviour to determine accessibility levels in Pune

5.4.4. Modelling results and their meaning

The operation above resulted in accessibility measures that were at an interval level of measurement. In other words, the ratios between the resulting scores did not have any meaning. Accessibility scores in the scenario with barriers ranged between 0.005 and 119.88 while in the scenario without barriers it ranged between 2.13 and 1507.12. The measures were standardised by 0.005 in an effort to make them comparable in assessing accessibility and supporting decisions regarding urban cycling and land-use integration. Consequently, the resulting accessibility scores for both scenarios ranged between 1 and 301,424.48. The scores for the situation without barriers ranged between 425.97 and 301424.48 while those for the situation with barriers ranged between 1 and 23,979.51.

These results presented some underlying changes in the ease of accessing various destinations by cycling. In order to understand their meaning, the resulting accessibility scores were mapped and compared in two scenarios, one without barriers and another one with barriers. The former presented the ideal situation while the latter presented an extreme case of the barriers that could be varied in order to find out their effects on accessibility. In this part, the results are interpreted to find out their meaning in the context of land-use distribution and cycling network indicated by network coherency ratio and cycleable path to network density. The network indicators were chosen because of their capability to enable the study to link the network characteristics to the land-use system.

Accessibility situation in the context of land-use distribution

The results show differing levels of accessibility between the two scenarios. By and large, accessibility in the city was found to be better in the scenario with no barriers compared to the scenario with barriers. Accessibility was highest at the city centre where the scores went to the maximum of 301,424.48 when there were no barriers. However, with the introduction of barriers, the scores came down to only 23,976.51. It is notable that accessibility at trip origins that were close to the city centre remained comparatively better in both scenarios. These results identify with the earlier finding which showed that most opportunities were clustered at the centre of the city. It seems the concentration of opportunities at the city centre had a positive effect in shaping the cycling patterns in the city. Figure 5-11 below shows that accessibility at the central part was higher when there were no barriers. Higher accessibility levels could also be seen on the western side of the city centre, probably due to the same reasons.

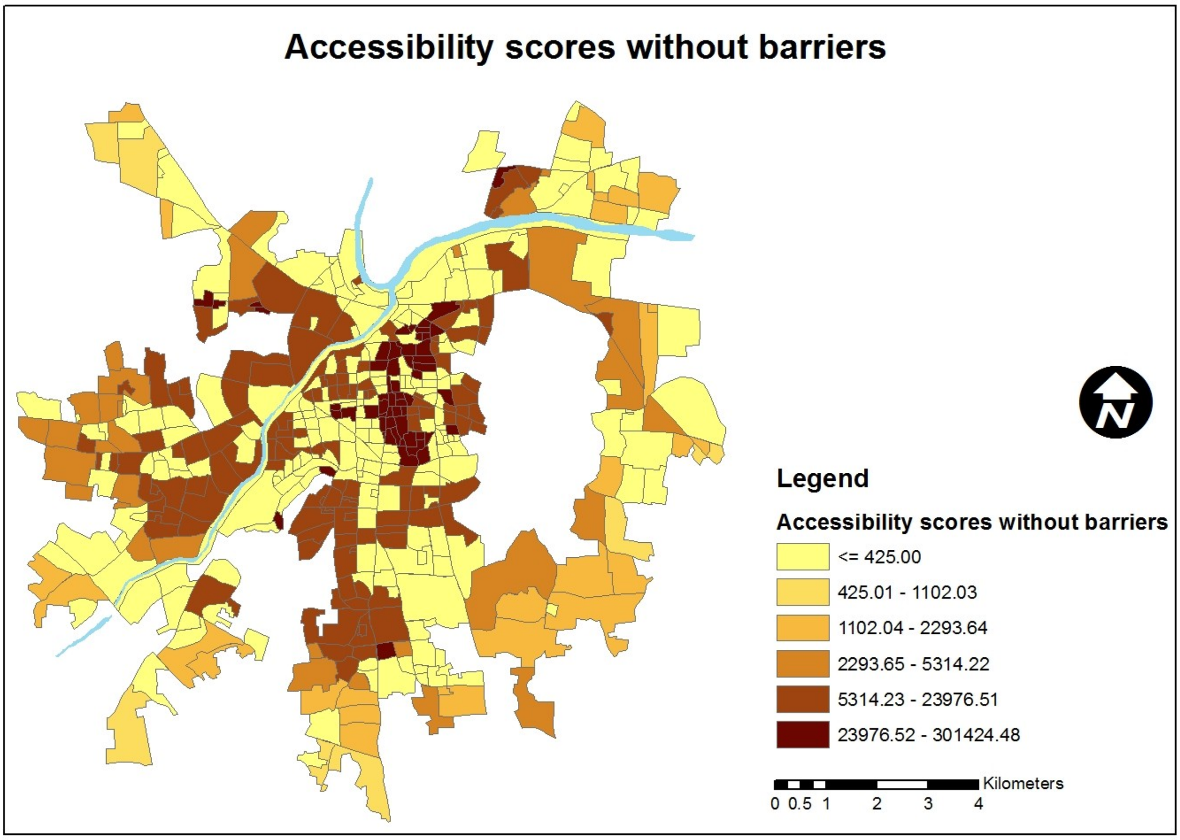

Figure 5-11: Accessibility without barriers

However, with the incorporation of barriers, accessibility suddenly grew very thin as shown in figure 5-12 below. It is remarkable that accessibility scores in range the category 23,976.52 – 301,424.48 could no longer be achieved when barriers were introduced. The study related this to the fact that the barriers cut off a significant proportion of cyclists from reaching the destinations that they could before the introduction of the barriers. Despite this, accessibility at the city centre and the western part of the city centre is again seen to remain relatively better when compared to the other zones. A possible reason for this could be that residential places that were near the city centre continued to enjoy better accessibility compared to their counterparts at the outskirts of the city which were now cut off by the barriers. It could also be possible that the areas had more cycleable roads compared to the other parts of the city.

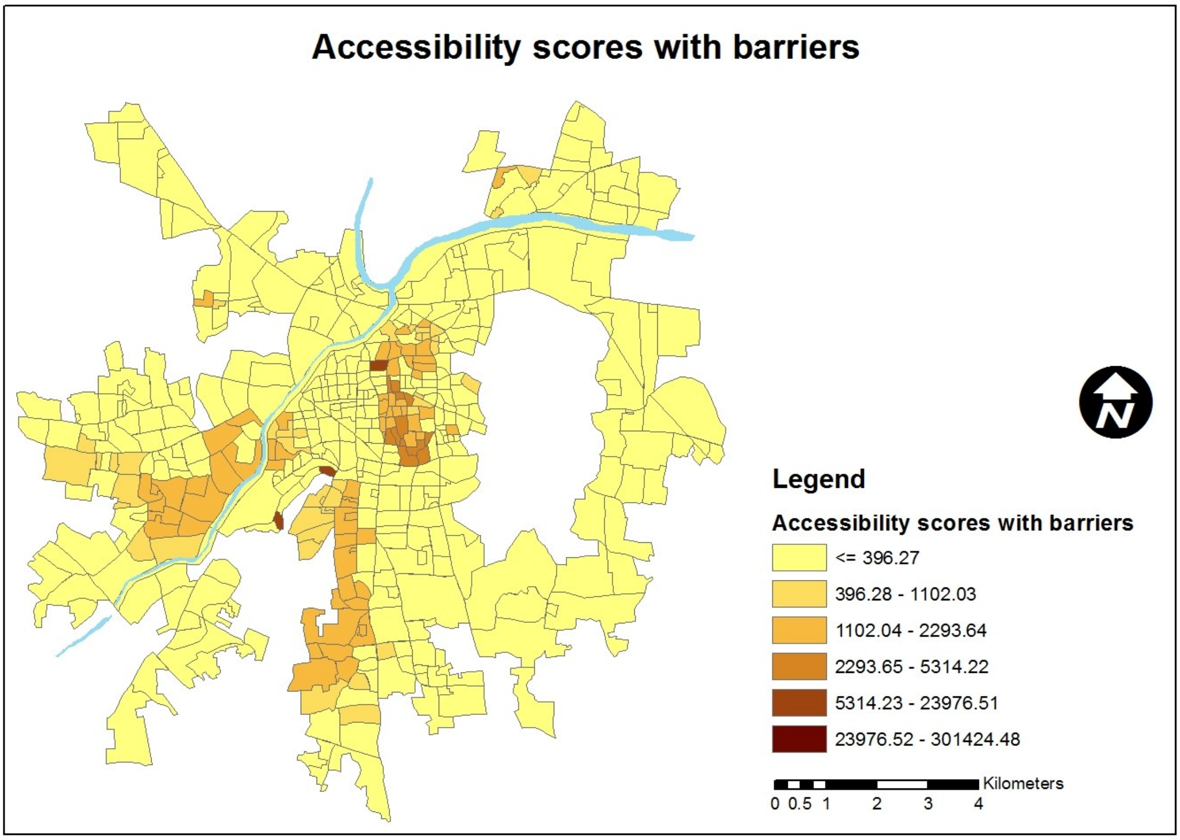

Figure 5-12: Effects of barriers on accessibility

Figure 5-13 on the next page compares accessibility between the two scenarios. Accessibility situation without barriers reflects the ideal cycling situation in the absence of barriers to cycling while the situation with barriers presents the extreme situation when the major roads that permit car speed of 50 kmh^{-1} are modelled as complete barriers. The results of the model show that residents who live close by the city centre enjoy better access to opportunities. It is notable from the figure that even though accessibility decreased with the introduction of barriers, the origins that were close to opportunities still remained comparatively better accessible than trip origins that were far off from the city centre. The concentration of more opportunities at this place and the higher densities of cycleable roads are thought to account for this finding in the current thesis.

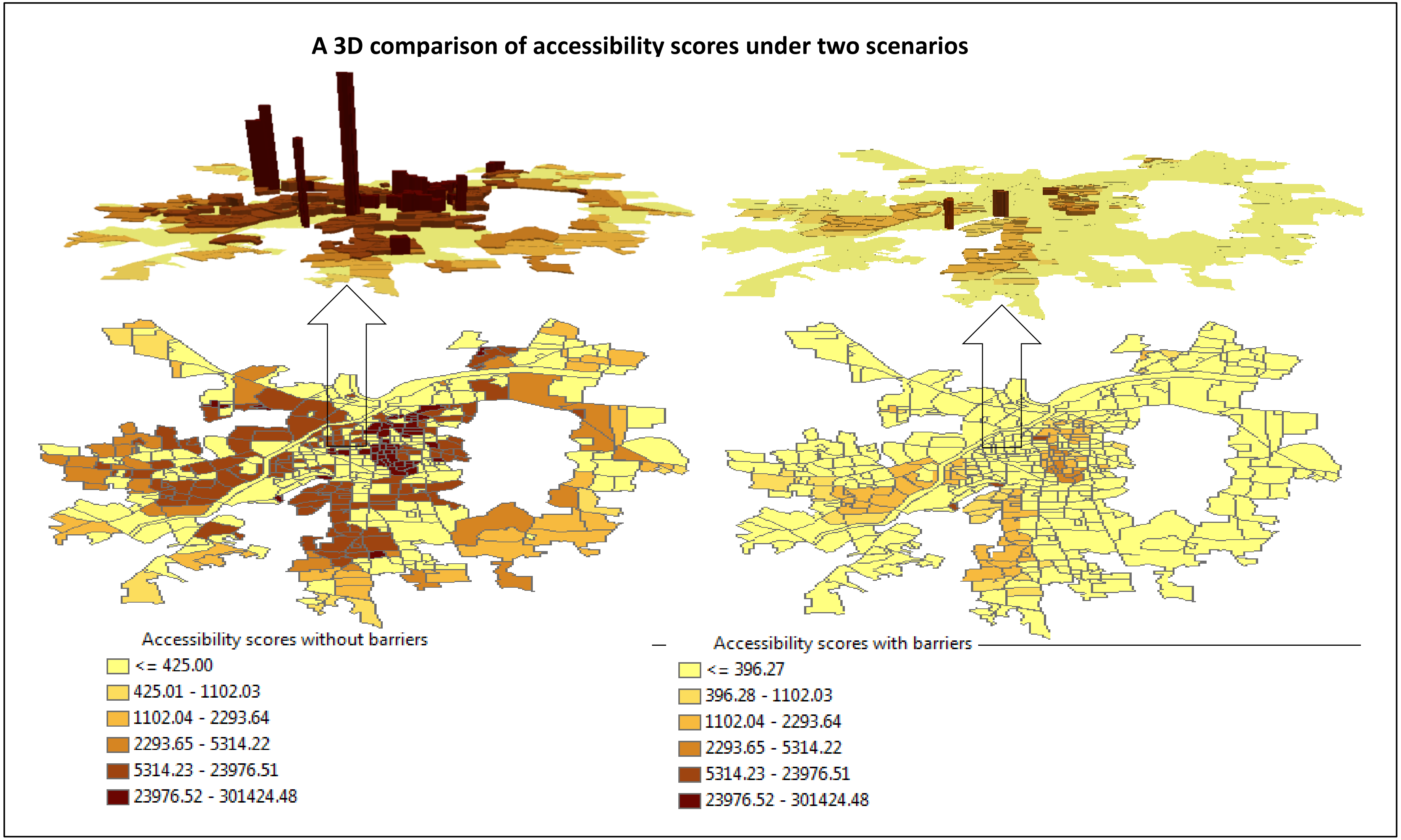

Figure 5-13: Comparison of accessibility without barriers (left) and with barriers (right)

Cycleable path to network density

At the citywide scale, the results show a marked reduction in the density of cycleable paths (See assumptions of the model in part 5.4.2). The introduction of barriers to cycling almost halved the density of cycleable paths in the city. Out of the total of about 470 km of road length that could be cycled when there were no barriers in the city, only about 224 km could be cycled after barriers were introduced. These lengths were obtained by identifying and summing the lengths of all roads that were used to link the origins and destinations. In the first scenario, it was assumed that all the roads could be cycled while in the second scenario, only roads that did not comprise barriers to cycling were considered. The cycleable path to network density was then calculated by dividing the total length of paths that were possible to cycle by the total area of the study area. A higher number indicates more cycleable paths and is related to higher connectivity. Table 5-9 below shows that the density of cycleable paths reduced from 5.52 km/km² to 2.64 km/ km² when barriers were introduced.

Table 5-9: Effects of barriers on bicycle path density

Bicycle path to network density	
Without barriers	With barriers
$= \frac{length\ of\ cycleable\ paths}{Area\ of\ the\ city}$	$= \frac{length\ of\ cycleable\ paths}{Area\ of\ the\ city}$
$= \frac{470}{85}$	$= \frac{224}{85}$
$= 5.52 km/km^2$	$= 2.64 km/km^2$

The reduction in the length of cycleable paths seen above can be explained by the fact that the introduction of barriers cut off roads that could previously be used for cycling if they were safe. This made the new areas defined by these roads only accessible to opportunities that were within the new zones. The lengths of the roads that constituted the barriers were in this case not possible cycle. It seems that the city centre has denser cycleable road networks and is therefore less affected even when it is cut off from the rest of the city. Other factors discussed earlier such as the higher population densities around the city centre could also be responsible for this though. Figure 5-14 below shows the new zones that were created once barriers were introduced into the city's road network.

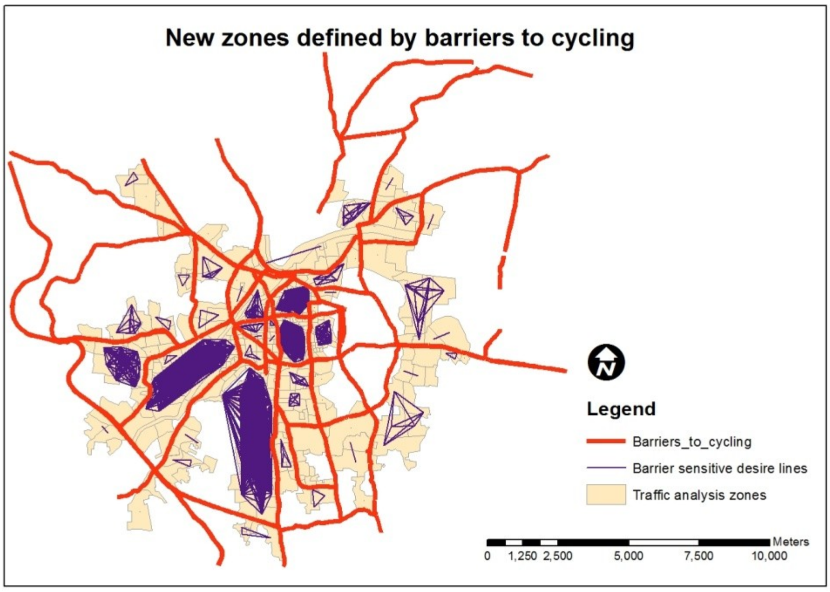

Figure 5-14: Effects of barriers on accessibility

It can be seen from the patterns of the desire lines in the previous figure that cycling is now restricted within the zones that are described by the barriers.

Figure 5-15 on the other hand shows that areas had higher density of cycleable roads also enjoyed better accessibility. This explains the differences in accessibility between the two new zones shown in the figure.

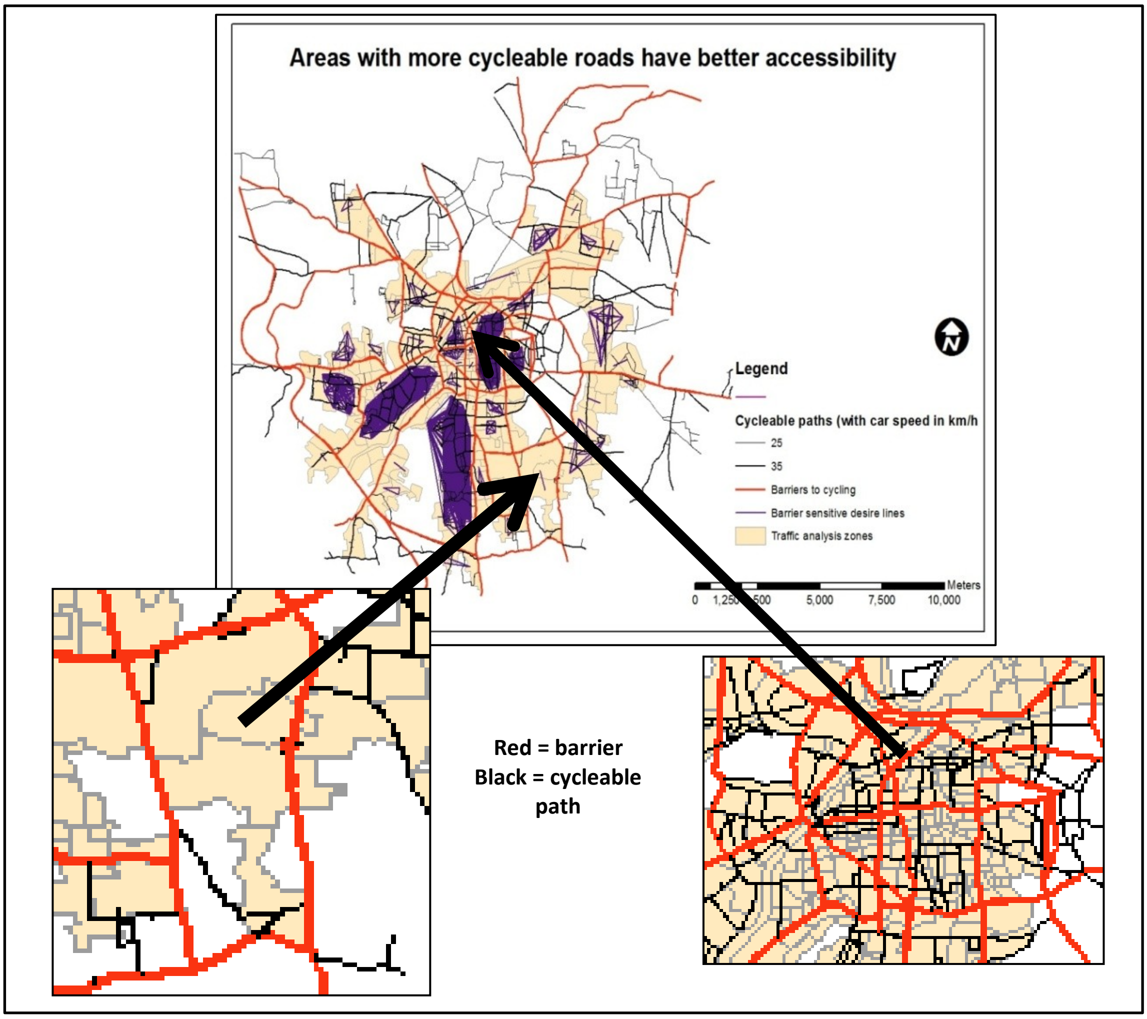

Figure 5-15: Areas with more cycleable roads have better accessibility

Network coherency ratio

The indicator quantifies the number of origins and destinations that are connected in an area. The results of the analysis also show that the presence of barriers as defined in the current model resulted in zones where no cycling could safely go out or come in. This in effect made such zones either unreachable (in the case of destinations) or only capable of internal cycling (in the case of origins). The first category of destinations is shown as 'cannot be reached by cycle' while the latter is shown as 'only intrazonal cycling' in figure 5-16 on the next page.

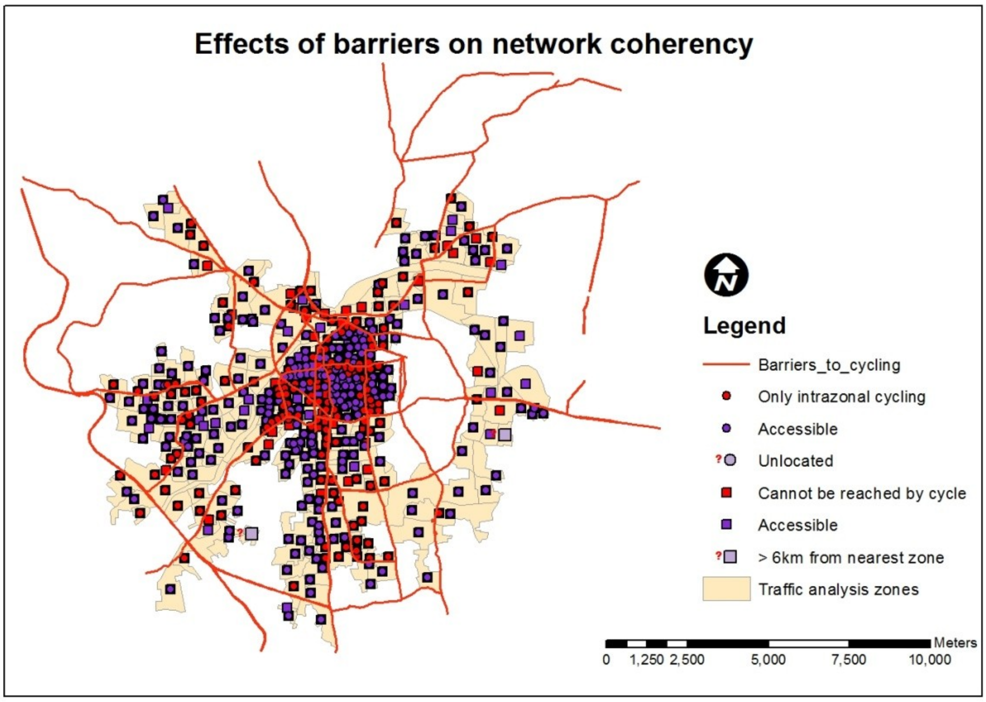

Figure 5-16: Effects of barriers on network coherency

The results also show the presence of zones which were cut off from their origins after the zones which could access them within the 6km threshold were cut off by the barriers. It is notable that the number O-D pairs that could be connected reduced greatly with the introduction of barriers. In the first scenario without barriers, a total of 474 destinations were connected to 411 origins. However, when barriers were incorporated into the model, only 254 pairs of origins could connect to 284 destinations. A network coherency was calculated to assess these changes. This indicator quantifies the number of origins and destinations that are not connected in an area. The results presented in table 5-10 below were obtained.

Table 5-10: Effects of barriers on the network coherency ratio

Network coherency ratio	
Without barriers	With barriers
$= \frac{Number\ of\ O-D\ pairs\ connected}{Total\ number\ of\ O-D\ pairs\ in\ the\ city}$	$= \frac{Number\ of\ O-D\ pairs\ connected}{Total\ number\ of\ O-D\ pairs\ in\ the\ city}$
$= \frac{411\ x\ 474}{411\ x\ 474}$	$= \frac{254\ x\ 284}{411\ x\ 474}$
1	0.37

It is again shown that barriers to cycling can reduce the number of safe connections that cyclist can make across a city. In the current case, the network coherency ratio reduced to 0.37 when barriers were introduced into the model.

The foregoing section has modelled accessibility in Pune city using high speed roads as the barriers to cycling. The section shows that urban land-use and transport planning impose barriers to cycling in two ways: i) the location and distribution of opportunities across the city creates distances between trip sources and destinations. The number of people capable of reaching such opportunities decreases as the distance between the trip destination and sources increases. No more access can be achieved once the maximum threshold is attained. In the case of Pune, this was found to be 6 km from the home; ii) the permitted speed on the roads creates a new urban form that makes it unsafe to cycle on city roads. This results in restricted zones beyond which no safe cycling can take place as it is unsafe to either cycle along the roads or cross them. Through three important network-based indicators, the study has showed that the imposition of barriers to cycling makes a city score poorly in terms of the density of paths that are cycleable, the trip sources and destinations that can be safely connected as well as the number of routes that can safely be cycled. Any attempt to integrate cycling and urban land-use must therefore address both these elements of urban form in order to make cycling safe in the city.

6. DISCUSSION

6.1. Introduction

The foregoing chapter has presented a methodological attempt to develop a spatially-constrained accessibility measure that can inform urban cycling and land-use integration in Pune city. Statistical analyses of the cycling patterns and behaviour in the city was presented together with an analysis of the underlying urban land-use patterns that were thought to dictate them. These reinforced the findings from the literature-based analysis of the urban transport and land-use situation of Pune as earlier presented in section 4.3. The results presented from the analysis of cycling patterns and urban form enabled the study to identify the input variables for the accessibility measure developed at the end of the chapter.

The key findings from the analysis are:

i.) Unchecked urban growth coupled with uncoordinated urban development policies have led to urban sprawl which continues to precipitate growth of motorised transport. This set-up is not supportive to urban cycling;

ii.) Residential areas comprised the primary trip sources while schools and employment opportunities of various types are the trip destinations. As such cycling takes place between these two points;

iii.) Employment opportunities, together with population and education constitute the major opportunities that attract cycling and are mainly clustered at the centre of the city. The densities of these factors are also higher at the city centre when compared to the other parts of the city;

iv.) The cycling distance ranged from distances of 0 km (for intrazonal cycling) to 6km away from trip sources. No cycling was found beyond 6 km. It is notable that the percentage of cyclists increased gradually up to 2 km after which it decreased with every additional kilometre that cyclists had to cover;

v.) The speed of cars imposed the greatest hindrance to cycling on roads of the city as it made the roads to be unsafe. Opportunities that were 6 km from residential areas could also not be reached. In this sense, distance also imposed a barrier to cycling once it was more than 6km from a trip source;

vi.) Accessibility for cycling was comparatively better near the city centre irrespective of whether there were barriers; and

vii.) The inclusion of barriers to cycling created a new urban form characterised by lower cycleable path to network density and network coherency ratio.

The current chapter interprets these findings in an effort to clarify the answers to the objectives that the study set out to address. The chapter as well fits the study into the context of existing knowledge with regard to urban cycling and land-use integration. These are discussed in the proceeding sections.

6.2. Existing urban land-use and transport situation in Pune

This objective was realised through literature-based analysis. The results reveal a number of policy areas that need to be addressed in order to integrate urban cycling and land-use.

To begin with, Pune's urban transport situation has been shown to be in a state of crisis in view of road congestion, inadequate infrastructure, unsafe roads and pollution that it suffers. This state of affairs leads to wastage of time on traffic jams causing losses to the economy; environmental degeneration; traffic accidents; and exclusion of the poor from access to affordable urban transport services and infrastructure.

In this case, the city's situation presents a clear justification for the need to integrate land-use and cycling in a bid to ameliorate this situation. Evidence from the current literature (Frank et al., 2010; The World Bank, 2002a, 2002b) suggests that the promotion of urban cycling can greatly ameliorate some of these urban transport challenges facing the contemporary cities. The challenge to the city's urban planning authorities is therefore to create favourable conditions to enable the vast majority who are currently willing to cycle but are inhibited from doing so by the unsafe cycling conditions of the roads of the city.

Furthermore, the findings present the city's roads as unsafe and non-responsive to cycling needs. This disproportionately affects the poor, majority of who can only cycle or walk to work. This has a great bearing on the perception of potential cyclists and thus their choice to cycle on these roads. In this case, it seems that addressing these issues through responsive design of roads to accommodate cycling would form a good starting point in integrating cycling and land-use in the city. Studies done by Parkin et al. (2007) and Hunt and Abraham (2007) have shown that people cannot cycle when they feel exposed to accidents.

The findings of the current study have also shown that changes in urban land-use patterns particularly the creation of Pimpri-Chindwad as an industrial satellite in Pune facilitates motorised transport which then engenders further urban sprawl. This increases the distances between trip sources and destinations thereby making hard to cycle to such opportunities. Similar findings have been realised by authors like Cao et al. (2007) and Zhao (2010) who note that urban land-use policies impact on key urban transport indicators like trip lengths and mode choice. It is notable however that policies that engender sprawling of job opportunities without concomitant development of affordable housing for cyclists only leads to locking them out of the urban road system since they cannot cycle beyond some distances. It is not evident whether the current urban land-use and transport theories can explain the cycling patterns such as those revealed in Pune.

Interesting findings with regard to coordination between urban land-use and transport planners in the city also emerged from the literature-based analysis. The study finds a disjointed approach to addressing urban transport issues between these authorities. It is clear from the literature that the transport consequences of the imposition of strict floor space index at the city centre in a bid to control congestion were not considered. This is evidenced by the resulting sprawl of residential places to the outskirts of city where there are hardly any meaningful public transport services to link them to places of opportunities. Tennøy (2010) identifies institutional coordination between urban land-use planners and transport planners as key in integrating urban land-use and transport. In this regard, Pune does not seem to be an exception if its current transport crisis is to be ameliorated.

There is likelihood that the aspirations of the National Urban Transport Policy to integrate cycling as part of India's urban transport system may not be realised in Pune unless the foregoing issues are addressed.

6.3. Cycling patterns, behaviour and urban form of Pune

The second objective of the study sought to analyse the cycling patterns and behaviours in Pune city while the third objective aimed to analyse the spatial configuration of the city. These two objectives were addressed together since they were closely interdependent.

Results from the analysis of trip origins of the cyclists shows that cycling in Pune is home-based. This consequently puts the residential places at the focal point in attempts to improve accessibility through better cycling-land-use integration. Interestingly however, the study finds that residential places were scattered across the city making it hard particularly for cyclists who lived in the outskirts of the city to get to the city centre where opportunities were clustered. On the strength of the findings from the analysis of the distance friction, this study reasons that people who live in the outskirts of the city cannot access services that are located at the city centre. It is noteworthy to point out that the fact that no cycling was evident beyond 6km away from trip sources. These findings appear to identify with the economic theories of land-use and transport in as far as minimising the cost of travel is concerned. The findings therefore reveal that though the theory was developed for motorised transport, it equally applies in the case of cycling.

The foregoing suggests that the poor in Pune will continue to be disadvantaged in terms of accessing transport services as long as urban land-use planning keeps concentrating major opportunities only at particular zones of the city. It has been shown that the poor constitute the majority of cyclists to work (Mohan, 2001). This is confirmed by the characteristics of the destinations of the cyclists in Pune. Majority were found to be students, factory workers, hawkers and street vendors. Moreover, while a majority of the city's residents would be willing to cycle to these destinations, the road conditions can hardly favour safe cycling. This at the same time exposes the captive cyclists to accidents as has been shown by Pucher et al. (2005) and Mohan (2001).

The analysis of trips according to the destination of cyclists shows a possible indication of captive cycling. It is conspicuous that education, factories, hawking and informal trading comprised some of the main destinations among the cyclists. These activities are mainly associated with the poorer segment of the society in Pune. Given the evidence from literature presented by Mohan (2001) for instance, it can be said that captive cycling constitutes the larger part of cycling in Pune. This reinforces the need to integrate urban cycling and land-use planning in order make cycling safe in the city. That the city is witnessing rapid urban sprawl makes this an urgent call.

The analysis also reveals the existence of a positive correlation between the opportunities at the zones and amount of cycling that they attracted. This finding reinforces the argument by Zhao (2010) that urban land-use pattern shapes trip making by influencing the location, distribution and densities of opportunities. Similar findings have been reported by Bertolini et al. (2005) who posit that locations with good access to opportunities like employment and schools attract more traffic. In terms of urban cycling and land-use integration therefore, accessibility measures can support decisions to influence redistribution of opportunities across a city in order to make its other zones city equally attractive to cycling. In a study based in the Netherlands, Bertolini et al. (2005) have found that such strategies have been used to shape new patterns of urban development and to influence shorter trip-making by non-motorised transport. This must however go hand in hand with the removal of barriers that deter cycling if their success is to be realised.

The result with regard to the maximum distance cycled in Pune seems particularly interesting in the case of cycling. While the existing theories of transport and land-use have associated higher densities of opportunities like employment to longer trip lengths (See for instance Wegener and Furst, 1999), it seems this does not hold in the case for cycling in Pune. The current study shows that indeed distance itself becomes a barrier to cycling once it exceeded 6km. Given this finding, it appears that concentrating opportunities at specific zones in a city would only lock out cyclists from accessing them. This begs for new theories that can explicitly account for cycling patterns and behaviour in the context of developing cities like Pune. In terms of planning practice, there is a need to identify opportunities that are compatible with residential development in order to promote mixed land-use systems that are sensitive to cycling needs. This is already taking place in the Netherlands where Bertolini et al. (2005) have reported the emergence of a development pattern characterised by redistribution of non-daily services like shopping and public facilities from the old city centres to new centres away from the city centre.

The results of the analysis show that permitted speed of cars on particular roads is the most impeding factor to cycling on the roads of Pune. Indeed most people (potential cyclists) do not cycle because of fear of getting involved in accidents. This finding resonates with the finding of Parkin et al (2007) who have reasoned that cycling behaviour and patterns are the product of the perceived safety among cyclists. In terms of integrating urban cycling and land-use in Pune, the safety of cyclists should be guaranteed. Interestingly however, the hourly volume of pedestrians, the number of informal activities, the bus speed and volume of buses do not inhibit cycling in the case of Pune. Probably this is an indication that those who cycle are captive cyclists who are themselves participants in informal activities that attract pedestrians and commuters who use buses.

6.4. Examining the use of the spatially-constrained accessibility measure in urban cycling - landuse integration

The preceding sections of this chapter have presented the need to integrate urban cycling and land-use. It is evident that urban cycling and land-use can mutually co-determine one another if deliberate strategies are put in place. However, because of the current unsupportive urban land-use and transport planning set-up, cycling has had no influence on the either of them. The sections present a case for the need to have an accessibility measure that can enable urban cycling and land-use to be brought together. This current section discusses the accessibility measure developed in chapter 5 with specific attention being given to its development and usefulness in supporting decisions regarding urban cycling and land-use integration.

To begin with, the measure developed demonstrates that it can enable different urban form scenarios to be analysed in order to find out their implications on urban cycling. In the model presented, only two extreme scenarios were analysed to show this. The model compares what cyclists would desire to do if the cycling conditions were favourable and what they actually do given the urban form situation. The measure reveals that the way in which opportunities are distributed across the city on the one hand and the manner in which the roads are designed on the other hand play an important role in enabling urban cycling. Though the study used a rather hard barrier that might not in reality be the case, its findings nonetheless demonstrate that it is possible to vary the barriers in order to find out their implications on accessibility.

The findings also show the comparative strength of the spatially-constrained accessibility measure in supporting urban cycling and land-use integration decisions. This can be seen in the way that the measure managed to incorporate theory of human behaviour and opportunities at trip ends. These have been identified as some of the essential elements that comprise a good accessibility measure (Handy & Niemeier, 1997). In the analysis presented, the measure incorporates the opportunities that people cycle to and their reaction to increases in distance in order to come up with a measure that unifies land-use and cycling. The measures' most interesting finding is that accessibility remained higher at the city centre even when barriers to cycling are introduced. This finding presents the spatially-constrained measure as better placed when the objective is to study land-use distribution patterns and road design as the barriers to cycling. In this case, distance is more important than for instance time which would have shown that the central part is least accessible on the basis of longer cycling time caused by traffic jams and people at the city centre. This is often the case with other measures like the infrastructure-based measures. In a similar study that was done by Linneker and Spence (1992) in the city of London it was shown that accessibility to jobs was highest in the city despite the fact that it had the highest access costs in the United Kingdom. The researchers pointed out that such findings cannot be obtained using infrastructure-based measures.

Moreover, the use of the network-based measures of urban form like the cycleable path to network density enables the identification of areas that need attention in terms of cycling infrastructure. From the model, it was evident that the city centre and the western side of the city had higher cycleable path to network density when compared to the other parts of the city. This brings out the capability of the spatially-constrained accessibility measure for use in comparing different urban form scenarios in a bid to identify areas that require attention in terms of cycling infrastructure provision. Pucher et al. (1999) have shown that appropriate infrastructure is one of the several factors that positively impact on cycling. Furthermore, the measure can also be used to identify areas that are deprived in terms on land-use opportunities like hospitals, schools and employment. In order to promote urban cycling, such opportunities should be within reach of people. Moudon et al. (2005) have found a significant correlation between cycling and the presence of opportunities like offices, clinics and restaurants. In the present study, higher densities of opportunities that were realised at the city centre are similarly reasoned to lead to better attractiveness of that part.

The results obtained from accessibility measure developed also confirm the fact that developing cities are faced with unique urban cycling challenges, which must be investigated in their context in order to develop appropriate solutions. While this study finds that the absence of cycleable roads played a key role in inhibiting urban cycling in Pune, on the contrary such factors do not seem to matter in the case of developed cities. In their study in King County in Washington, USA, Moudon et al. (2005) for instance found that the presence of bicycle lanes and higher traffic speed and volumes did not have correlation with cycling in their study area.

A number of model development issues that are worth noting also arose during the development of the current model. Key among these is the ability of the spatially-constrained accessibility measure to borrow and modify aspects of motor-based accessibility measures. The current measure shows that distance has a better capability for use when the interest is in understanding the land-use distribution and patterns and its effects on cycling. This addresses some of the concerns that have been raised by authors like Iacono et al. (2010), who have noted that most of the current measures of accessibility are only concerned with motorised transport. The study hence makes a contribution by showing how cycling behaviour and land-use patterns can be studies and merged together to study their co-dependence. The study also shows how the limitation of single destination that has been identified by Iacono et al. (2010) can be addressed through statistical analysis to get their influence on the overall contribution to the opportunities at each TAZ.

Perhaps the most interesting contribution of the current work is its ability to demonstrate how barriers to cycling can be modelled to measure accessibility under different urban form scenarios. Even though only two extreme situations were considered, it would have been more interesting to find out how accessibility would have been between these two extreme conditions. This would allow partial cycling across and along the some of the high speed roads that have been modelled as complete barriers to cycling in this study. Despite this drawback, the measure gave interesting results that can provoke future researches on barriers to cycling and how they can be addressed particularly in the case of developing cities. This however raises issues about data requirement for modelling spatially-constrained accessibility. The findings of the study evidence the need for data at a finer resolution, probably at street level if this is to be achieved. Again, modelling accessibility for cycling requires a good knowledge of what actually constitutes the barriers to cycling and in which segments of the roads they are. Such knowledge would have greatly improved the results of the current study.

In summary it is evident that the meeting point between urban cycling and land-use lies in urban configurations that reduce cycling distances and the physical efforts while at the same time offering the safety that cyclists need to overcome the spatial separation between trip origins and the opportunities. In this regard therefore, urban form must be viewed not just as the relationship between trip origins and destinations but also as the conditions on the routes that link them. These must be taken into account when integrating cycling and urban land-use planning.

7. SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7.1. Introduction

This goal of the study presented in this current thesis was to develop and implement a spatially-constrained accessibility measure for integrating urban cycling and land-use in Pune city. The study incorporated theoretical analysis of transport and land-use interaction, literature review, statistical and spatial analysis to realise its objectives. The climax of the study was the development of a spatially-constrained accessibility measure for integrating urban cycling and land-use. This chapter presents the summary of the findings and the conclusions of the study.

7.2. Summary of findings

The study shows that indeed urban cycling in Pune is related to land-use patterns as well as the perceived safety among cyclists on the roads. While opportunities that attract cyclists were found to be generally concentrated at the core of the city, its population on the other hand was shown to be scattered in several parts of the city. This raised important issues regarding the ease of cycling to the city centre among residents from the far-flung areas. In view of the revealed travel patterns that showed no evidence of cycling beyond 6km, the study argued that distance between opportunities and places of residence was therefore itself a barrier to cycling. At the same time, a number of factors including distance and the car speed on the roads were found to inhibit cycling since there were scarcely any dedicated cycling paths in Pune. When these were taken into account in the accessibility model, a general reduction in cycleable path to network density and network coherency ratio was realised. These results showed a general decrease in accessibility in the entire city when barriers were taken into account. Interestingly though, the city centre still remained comparatively more accessible than the other parts of the city. The concentration of opportunities and the higher density of cycleable roads around this place have been presented as the possible explanations to this. The findings of the study underscore the need for appropriate infrastructure on the one hand and supportive land-use pattern on the other hand in order to promote cycling in Pune city.

At the same time, the findings demonstrate the applicability of a spatially-constrained accessibility measure in integrating urban cycling and land-use. The measure is found to be capable of enabling different urban form scenarios to be analysed in order to find out their implications on urban cycling. The measure is also found to be comparatively stronger when the interest is in assessing land-use patterns and distribution and their implication on urban cycling. Furthermore, the findings demonstrate that developing cities face unique urban cycling challenges that can be explained by their urban form. These challenges can only be addressed if they are studied in their own context rather than transferring the findings from developed cities.

Despite the foregoing strengths, the measures' strongest contribution is probably its greatest drawback. The model could only explain two extreme urban form conditions: with barrier situation and without barriers situation. This limited its capability to address accessibility situation under the intervening conditions between these two extremes. This however opens up an invitation for further researches on this topic.

7.3. Conclusion

In view of the findings of this study, the following conclusions are drawn:

There is need to address the current challenges that emanate from urban transport and land-use situation in Pune city. In this regard, creating favourable conditions for urban cycling can in part contribute to ameliorating the growing environmental challenges, traffic congestion and exclusion with regard to accessing transport services and infrastructure. That cycling is currently neglected in the city yet it has been identified as affordable, efficient and also environmentally friendly makes this a relevant course to pursue.

Integrating urban cycling in Pune calls for the both land-use planners and transport planners of the city to work in tandem with each other. In this regard there is need for an accessibility measure that can provide a common understanding of the current challenges facing urban cycling in the city. This is important because transport and land-use planners have often understood cycling challenges from their own professional point of view, which quite often do not necessarily lead to the same solutions. It would remain hard to sustain the solutions that have been proposed for cycling under the present circumstances.

The spatially-constrained accessibility measure presents a better opportunity for integrating urban cycling and land-use in Pune. In this regard, there is a need to make it more accurate in measuring accessibility situation under different urban form scenarios. While the current study has attempted to develop a spatially-constrained measure, the measure it developed can only address two extreme situations where there are barriers and where there are no barriers to cycling. However, there are also other intervening urban form conditions between these two extremes which need to be considered;

In order to develop a spatially-constrained accessibility measure that explicitly takes account of the physical barriers presented by urban land-use patterns and road conditions of developing cities, there is need for accurate data to enable a better prediction of cycling patterns and behaviours. In the same vein, there is also need for a better definition of barriers to cycling and where these barriers are found on the roads. In this context, data for modelling accessibility should be at a finer geographical scale that can enable cycling patterns and behaviours to be studied better. Smaller TAZs are also required since cyclists often do not go very far away from their home.

Current theories upon which transport and land-use integration is based seem to be limited in terms of their capability to explain the relationship between cycling and land-use in the context of developing cities. In particular, barriers faced by cycling in developing cities do not seem to have been taken into account by the current theories. In view of this, there is need for more investigation about the effect of barriers on urban cycling in order to determine accurately how they influence cycling. Furthermore, there is need to investigate urban form conditions that are favourable to cycling. This is important to ensure that the relevant issues that underlie urban cycling are addressed to make the current pursuit to integrate urban cycling in these cities successful.

7.4. Recommendations

The current study makes a number of recommendations that it hopes can contribute to making the spatially-constrained accessibility measure more useful in supporting urban cycling and land-use integration. These are highlighted in the proceeding paragraphs.

First, there is need to collect data in order to validate the accessibility results that were realised in the current study. These will also be important in detecting the elements of the model that need to be adjusted to make it more accurate for supporting urban cycling and land-use integration.

As well, there is need for further investigations to determine what the specific physical barriers to cycling are in Pune city and which sections of the road they are found. This would be essential in developing different scenarios within which accessibility can then be investigated. Such investigations should consider using data that is deliberately collected for purposes of developing accessibility measures that are sensitive to physical barriers.

It would also be interesting to develop a method for identifying urban forms that are not only responsive to cycling but also more inclusive, economically affordable and less vulnerable environmental challenges posed by climate change.

Finally, the study has shown evidence that different parts of the city have different levels of accessibility. It would be interesting to investigate how these relate to socio-economic variables like income in order make accessibility scores developed relevant in terms of aiding decisions regarding prioritising and targeting areas in need of bicycle infrastructure provision.

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ANNEXES

Annex i: Questionnaire used for household survey

IIT Delhi, India and ITC, The Netherlands

Individual travel stated choice Questionnaire form

RPSP-B09 - PUNE/2

Bicycle and other short trips – Pune / Pimpri Chinchwad, India, January, 2010

The purpose of this survey is to explore and understand the bicycle user's problems, attitudes and preferences towards an improved / new state of art Bicycle network facility. The bicycle planning and integration in the current transportation and city development needs to incorporate user's participation. Your answers will assist us in prioritizing the efforts and investments. Thank you for your co-operation.

Surveyor information

1. Initials of the surveyors: ………………..and ………………
2. Survey ward / zone no. as per map: ………………………………
3. **Invalid House Numbers**….+…..+…….+……+…….(nobody lives there)
4. **Non-Respondents** …..+….+….+….+…..+… +……..(no answer / refuse to cooperate)
5. The distance between origin and major destination (workplace/ school) -………… (If less than 6 km – continue)
6.

	Cyclist	Potential Cyclist
Chose one		
	For commuting	*Not using*
	Travel any distance	*Short distance travel*

Socio-Economic Details – respondent

1. Name & Address:……………………………………………………ph………………
2. Age-Sex Information of R1(Respondent) and M2, M3, M4……. (Members of family)

	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70+
Male	M							
Female	M							

3. Education: (maximum level)

Illiterate	1	Sec / higher sec.	5
Literate	2	Graduate	6
Primary	3	Post graduate / diploma	7
Middle	4	Others	8

4. Occupation status (tick all that apply)

Full time	1	Unemployed	5
Part time	2	Student	6
Retired	3	Part time student	7
Home maker	4	Other (specify)	8

TRIPP, VREF and CAN India Survey 1

5. Work place

Hawker/ vendor	1	Office	5
Factory	2	Roadside / informal	6
Shop / comm..	3	School / college	7
House	4	Other	8

6. Which means of transport are available to you? (tick all that apply)

Auto / taxi / van	1	Car	4
Bicycle	2	Afford Public Transport	5
Scooter / motor cycle	3	Other vehicles	8

7. Monthly household Income: ………………………….INR / month (for household)

Trip profile

8. How many days a week do you commute for purpose of work/ education? …..

9. How many TIMES A WEEK do you travel for OTHER trips (like grocery shopping, picking /dropping kids, health, bank, post office visits, etc.)? ………....

10. Trip details of the previous working day – (* mention each activity in the trip separately – detailed trip chain including walk)

Origin address	Destination address	Mode	Distance	Time	Starting Time	Expense	Purpose
Zone	Zone	Name/code	km	minutes	Eg - 1355	INR	Write

11. Do you take the shortest route between the house and workplace? Yes [1] No [2]

12. If no, then why do you not take shortest possible route?

NOT APPLICABLE (when yes)	0	NA (when yes)	0
Roads closed	1	Bad Roads	4
One way	2	Fear of accident from other vehicles	5
Difficulty in crossing intersection	3	Other (specify)	8

13. Accessibility to other activities / frequent trips -

Accessibility to Activities	Travel time by walk
	(min)
Access to Grocery / Daily Shopping activity	
Access to Recreational (parks)/ Social (religious etc.)	
Access to Tuition facility (for students)	
Access to other common destination (pl specify)	
a)	
b)	

14. Secure parking facility at HOME: Yes [1] No [2]

15. Place of parking at HOME:

Inside boundary in open	1	In common parking (guarded)	4
Inside house doors	2	Common parking in locality	5
Garage	3	Others (specify)	8

16. Secure Parking facility at DESTINATIONS : **(use code from above)**

Destination	Yes	No	Details of parking (facility) -code
School/ college			
Work place			
Grocery shop			
Market			
Recreation spot			
Social /religious place			
Tution			
Post office/bank			
Others (specify)			

Preferences of Users / Potential Users (Latent Demand) for land use (NH) aspects

17. Why do you not like to use bicycle to go to work / school / other?

No space on roads	1	Fear of accidents from other vehicles	5
Difficulty in crossing intersections	2	Bad roads	6
Not socially acceptable	3	Others	7
No bicycle	4	NA (really like it and use everywhere)	8

18. What is the **Most Important** while cycling on road? Rank them in order. (Most important is 1, then 2 and so on….)

Physical safety (fear of accidents)		
Social security (lighting, informal sector)		
Safe Intersection Crossing		
Removing Barriers on roads		

19. What do you think should be order of priority to improve SAFETY? (Ranking –most important is 1, then 2 and so on….)

No buses in curb lane		
Low speed of motorized vehicles		
Lesser cars and two wheelers		
Dedicated /segregated bicycle tracks		

20. What do you think should be order of REDUCING BARRIERS to cycling? (Ranking- most important is 1, then 2 and so on….)

Pedestrian on way		
Parked vehicles		
Poor Pavement quality		
Gradients / slopes		

21. Where do you find the CONFLICTS with motorized vehicles as most dangerous? (Ranking- most important is 1, then 2 and so on….)

Crossings (signalized)		
Crossings (un-signalized)		
Roundabouts		
Uncontrolled motorized traffic entry / exit on road		

22. What is the order of importance for inducing perception of SOCIAL SECURITY? (Ranking- most important is 1, then 2 and so on….)

Formal Land use aspects (diversity and intensity of mix)		
Informal LU sectors on road side		
Lighting		
Other bicyclists and pedestrians		

23. Which one do you think is better situation for cycling? **(choose1/2) Table 1**

Attributes	**Levels**
Pedestrian on way	Less pedestrians
	Many pedestrians
Parked vehicles	Less than 30%
	Above 30%
Pavement quality	Good
	poor
Gradients	Normal
	Rolling

Choice set	**Chosen set (pl tick one)**		**Undecided**
1	A	B	
2	A	B	
3	A	B	
4	A	B	
5	A	B	
6	A	B	
7	A	B	
8	A	B	

24. RANK the diversity in order of more preferred environment for bicycling -

Diversity in Mix	Ranking top 3	Code
Resi (Chandan nagar)		1

IIT Delhi, India and ITC, The Netherlands

Resi + comm. (Old city)		2
Comm. (Yerawada)		3
Resi +comm.+ industrial (Hingewadi)		4
Vacant / green/ low pop density (Nagar Road)		5
No perceived effect		6

25. Choose from the pair which is more comfortable - **(Choose ½) Table 2**

Attributes	**Levels**
Intensity of mix	1-35% mix
	30% mix and above
Road width	4.5-12.0 m
	12m and above
Density	< 1000 dus / ha (low)
	> 1000 dus / ha (high)
Informal sector	Presence of informal sector
	Absence of informal sector

Choice set	**Chosen set**		**Undecided**
1	A	B	
2	A	B	
3	A	B	
4	A	B	
5	A	B	
6	A	B	
7	A	B	
8	A	B	

26. Choose from the pair which is more comfortable -(Choose ½) Table 3

Attributes	**Levels**
Travel Time	5 – 15 min
	15 – 30 min
Travel Cost	0 - 4 INR
	4 - 8 INR
Safety	Unsafe perception up to two times (low)
	Unsafe perception > two times (high)
Comfort	Less Physical labor/ effort (kids/luggage)
	More Physical labor/effort(kids/ luggage)

Choice set	**Chosen set**		**Undecided**
1	A	B	
2	A	B	
3	A	B	
4	A	B	
5	A	B	
6	A	B	
7	A	B	
8	A	B	

27. Which mode will you use in the situation?–when bicycle infrastructure is available

BASE OPTION	**Current mode/trip (2w, 3w, 4w, bus)**	**Specify mode**
Travel cost	Cost of his mode	INR
Travel time	Time by his mode	min
Safety	Current mode value	level
Comfort	Current mode value	level

	Current mode/trip (2w, 3w, 4w, bus)
Travel cost	15% more travel time
	25% more travel time / waiting time
Travel time	25% more travel cost
	50% more travel cost / parking cost
Safety	Risky travel
Comfort	Crowded
	Standing in bus

Choice set	**Chosen set**		**Undecided**
1	Mode	Bicycle	
2	Mode	Bicycle	
3	Mode	Bicycle	
4	Mode	Bicycle	
5	Mode	Bicycle	
6	Mode	Bicycle	
7	Mode	Bicycle	
8	Mode	Bicycle	

TRIPP, VREF and CAN India Survey 5

Annex ii: Sampled zones

Land use	**Area (Sq. Kms)**	**Percentage of area**	**Share for inventory survey (km sq)**	**Count of zones**	**Sampled zone numbers**
Residential	166.4	62	21.0	163	32, 33, 34,35 (1 KM BUFFER FROM CBD) 434, 24, 231, 181, 191, 489, 359(3 km BUFFER FROM CBD) 399,353, 175,308,220 (5 KM BUFFER FROM CBD) Geographically Distributed
Slum	3.54	2	0.7	29	342, 245, 469,480, 426 Distance from CBD/ Geographically Distributed
Commercial	3.02	2	0.7	21	538, 510, 193 Distance from CBD/ Geographically Distributed
Industrial	6.87	5	1.75	31	473, 517, 366, 327, 257 Distance from CBD/ Geographically Distributed
Public and Semipublic spaces	18.46	9	3.15	98	506, 178, 196, 360, 379, 454, 282, 168, 147 Distance from CBD/ Geographically Distributed
Vacant /Barren / Agricultural	48.56	20	7.0	167	332, 465, 172, 117, 402, 251 Distance from CBD/ Geographically Distributed
Total	**246. 85**	**100**	**35**	**509**	**NA**
Note: Zone number 23 is considered as the city center (Laxmi road) **Radius of the city from the zone no. 23 is approximately 6-8 Kms.** **Zones falling under river, cantonment etc. are considered in vacant category**					

Annex iii: Sample sizes within the selected residential and slum zones for survey

Residential				SAMPLE	SAMPLE
	zone number	**Population**	**% of total**	**Q required**	**Q collected**
(1 KM BUFFER FROM CBD)	19	26184	7.64	37	42
	25	16525	4.82	23	27
	29	51310	14.97	72	84
	30	33595	9.80	47	41
(3 km BUFFER FROM CBD)	434	7091	2.07	10	4
	24	49808	14.53	70	74
	231	9582	2.79	13	16
	181	4709	1.37	7	8
	191	22034	6.43	31	29
	489	27787	8.10	39	37
	359	31948	9.32	45	42
(5 KM BUFFER FROM CBD)	399	1963	0.57	3	12
	353	9235	2.69	13	13
	175	24206	7.06	34	36
	308	11630	3.39	16	16
	220	15248	4.45	21	23
		342855	100.00	480	
Special zones / recommended	19			50	53
	148			100	106
	372			50	53
				200	
SLUMS					
(GEO SPREAD; VARIETY IN TYPE OF SLUMS, LU AROUND)	342	15395	19.92	64	71
	245	23896	30.93	99	115
	469	1839	2.38	8	13
	480	1499	1.94	6	11
	426	4283	5.54	18	39
	425	10481	13.57	43	43
	165	19872	25.72	82	83
		77265	100.00	320	
special slums / recommended	256			50	44
	510			250	272
				300	
GRAND TOTAL				**1300**	**1407**
Possible Error forms				**100**	
Forms to be filled				**1400**	**1407**

Annex iv: Origins of the cyclists

Zone in which respondent come from (based on map) * cyclist or potential cyclist? Crosstabulation

Count

		cyclist or potential cyclist?		
		cyclist	potential cyclist	Total
zone in which respondent come from (based on map)	19	2	51	53
	24	32	42	74
	32	13	29	42
	33	4	23	27
	34	12	72	84
	35	6	35	41
	148	7	99	106
	165	17	66	83
	175	6	30	36
	181	1	7	8
	191	10	19	29
	220	3	20	23
	231	2	14	16
	245	33	82	115
	256	7	37	44
	308	1	15	16
	342	24	47	71
	353	1	12	13
	359	9	33	42
	372	3	50	53
	399	1	11	12
	425	5	38	43
	426	10	29	39
	434	0	4	4
	469	5	8	13
	480	3	8	11
	489	3	34	37
	510	53	219	272
Total		273	1134	1407