Multi-modal Urban Transport:
Integrating Non-Motorized and Bus Transport

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Abstract

Public transport has been seen to be efficient in curbing increasing road congestions in many cities. It however does not provide door to door service needed to compete with private cars and to improve living conditions of the poor. A door to door service could mean extending bus routes to all parts of the city. Public transports has however been seen to work efficiently in high demand areas and extending routes to low demand areas would be inefficient. Using bicycles as feeder mode can be instrumental, increasing coverage of public bus to inaccessible areas. Providing bicycle infrastructures is important as it has the potential of inducing significant number of commuters who would not have chosen to make bicycle trips into doing so. Financial constraints make provision of these infrastructures on all bus stops and roads unviable. Bus stops and roads need to be prioritized for bicycle parking facilities and bicycle lanes.

This research seeks to prioritize bus stops using maximal coverage algorithm, incorporating distance decay in determining potential demand. An origin-destination multi-modal distribution curve yielded distances of about 6.5 and 9.5 kilometers as acceptable for walking and cycling respectively in Pune city, India. Considering these to be very long distances for accessing bus stops, the generalized distances of 0.4 and 3 kilometers for walking and cycling to bus stops under normal conditions were used in the prioritization model.

Two criteria were used in a heuristic reduction model, removing redundant bus stops and prioritizing bus stops to serve as transfer stations for bicycle-bus integration. Potential demand and distance to the farthest demand point been served by bus stops.

Bus stops with least potential demand (below 25th percentile) were removed from the next iteration. This was repeated until the total potential demand starts to drop.

The second method involved removing bus stops having the smallest distance to the farthest demand point (below 25th percentile) from the next iteration. This was also repeated until the total potential demand starts to fall.

The number of bus stops to total potential bicycle-bus demand served was plotted for both cases. Reduction by farthest distance resulted in a much less bus stops with maximal potential commuters. The reduction by the farthest distance was therefore concluded to be the better criteria for reducing bus stops.

Using the optimal number of bus stops, the access roads were prioritized for the provision of bicycle lanes and paths through networks analysis. The route with the highest potential bicycle-bus commuters along its path was given a higher priority.

Findings of the research are hoped to help planners and decision makers in integrated cycling and public transport planning in Pune and elsewhere.

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1. Introduction

1.1. General Introduction

The evolution and growth of a city is much related to the transportation of its people between activity locations (Murray, Davis et al. 1998; Rodrigue, Comtois et al. 2009). Transportation planning is therefore a critical element in the development of a city. A good transportation network forms the basis by which the economic development of a city evolves and the means of interaction in society. The inefficiency of such infrastructures therefore hinders the development and interaction of a city.

Increase in the population and economic status of a city leads to an increase in the number of trips produced. This could be due to the increase in population growth, rural-urban migration, and growth in the economy. As the economic status of the population increases, the rise of car ownership is often observed, which tends to generate even more trips. Without the provision of an efficient public transport system, the use of private vehicles for such trips will increase.

The efficiency of the transportation infrastructure is much affected by the demand for such infrastructures. It is most efficient in areas with higher demand for such transportation. However when the demand exceeds the supply level (e.g. capacity) of those infrastructures, they tend to reduce in their efficiency. This demand for transportation is brought about by the increased population of a city, the rural-urban migration, and the economic viability of the people which leads to an increase in the usage of private vehicles.

1.2. Background and Justification of Research

1.2.1. Background of Research

The increase in population and economy in a city leads to higher trip rates. Without proper spatial planning of the city in terms of land use distribution, this may lead to long travel times as well. With the increase in the economic status coupled with the lack of alternative transportation modes, private automobile ownership and trips may increase (Palmner, Astrop et al. 1996; World Bank 1996; Badami and Haider 2007). The increase in private automobile use which typically has a lower occupancy rate may lead to an increase in congestion on the roads without the proper transportation infrastructures. High congestions have been attributed to the increase in traffic accident rates, air and noise pollution (Gwilliam 2002; Martens 2004; Alterkawi 2006; Beirão and Sarsfield Cabral 2007). Increase in air pollutants such as carbon dioxides and ozone which are by products of the combustion of fossil fuels leads to increase in global warming.

The provision of public transport has been seen to reduce on the level of congestion on the roads as these modes of transport have a higher occupancy rate as compared to the private automobile (Badami 2005). Public bus transport however doesn't provide a door-to-door service as compared to the use of private vehicles. Commuters thus need to access these public bus transports through bus stops. Access time is an important part in the provision of a bus transport system. An increase in access and egress times to and from public stops causes a reduction in the patronage of the system (Krygsman, Dijst et al. 2004; Martens 2004). For the public transport to be competitive with the use of private vehicles, the access time needs to be reduced as much as possible. Even though this may not be evident in developing countries, the reduction in access times may lead to a better quality of life for the poor and also increase catchment coverage.

Walking as a mode of transport has been seen to be the main mode of transport to bus stops. Because of the low travel speed walking, it is much time consuming and thus the potential for people to walk to bus stops diminishes over a short distance. Bicycles on the other hand are a much faster mode of transport than walking. Because of its relative fastness, the distance to which people are willing to travel becomes longer, which increases the catchment area of the public bus transport system. However without the provision of proper cycling infrastructure, this is not realised. People become much more willing in using the public transport when these infrastructures are in place. Thus for an efficient public transportation to help curb the use of private automobile, reducing congestion on the road and increasing quality of lives, there is the need for non-motorised infrastructures to be in place. These infrastructures have to be provided both at the bus stops and on access routes to these bus stops.

1.2.2. Justification of Research

In trying to control congestions on the roads, options like the integration of land use and transport, widening or construction of new roads have been explored. However, the provision of public transport has been seen to be much efficient in controlling congestions.

The spatial location of activities determine the general cost of transport between them (van Wee 2002). This affects the travel behaviour of commuters as people tend to reduce cost of transportation by participating in activities closer to them than in activities farther away giving the same opportunity. Compact cities thus have been found to generally impact on the travel patterns of the people. Researches show that highly compact cities result in more trips but shorter average distance (Badoe and Miller 2000; Gordon 2008). Anderson et al (1996) confirm this by concluding how significantly car trips are reduced by a compact and mixed land use. It is therefore known that a proper spatial design of a city could have an impact on commuters' travel behaviour. It may result in the use of much slower modes of transports (van Wee 2002). However, the implementation of such policies become difficult or virtually impossible in the case of an already developed city as this is mainly implemented in the planning of a city.

The widening of roads or construction of new roads has also been seen to have an impact on the level of congestions on our roads (Gwilliam 2002). However experiences in most countries show the construction of new roads or widening of roads only solves the problem of congestion only for a while (Tiwari 2002). It encourages the use of private vehicles which lead again to congestions and its associated side effects like air and noise pollution (Beirão and Sarsfield Cabral 2007).

As a result of the financial constraints faced by many countries, especially the developing countries, an improved public transport system seems the most likely solution to controlling congestion on our roads as compared to investing in the construction of road infrastructures (Palmner, Astrop et al. 1996). It has also been seen that the provision or extension of additional roads only solve this problem in a short term as it lure people into using private vehicle. This move to tell us that the provision of an efficient public transport is a more likely answer to curbing congestion in future plans of a city (Newman and Kenworthy 1999; Mackett 2001).

Public transport aside its benefits over the use of private vehicles, such as reduction in air and noise pollution (Martens 2004), lower fatalities and road space on a passenger-kilometre basis and its affordability (Badami and Haider 2007), needs to compete in terms of travel time with the use of these private vehicles in order to achieve its aim of causing reduction in the use of private vehicles. Access and egress times determine the availability and how convenient a public transport is. It has an impact of the mode choice of trip makers. Increase in access and egress time of public transport has been seen to be a major deterrent to its patronage (Krygsman, Dijst et al. 2004; Advani and Tiwari 2006). Reducing access and egress times to and from transit points therefore increase the catchment and potential ridership of the public transport.

Walking is the main mode of transport to transit stops in many cities. As distance from transit stops increases, this mode of transport decreases rapidly. A five minute walk has been considered reasonable (Murray and Wu 2003). The use of bicycle as access mode to transport to bus stops have been seen to reduce access times compared to walking making the transit much accessible thus increasing the catchment of the transit (Martens 2004; Martens 2007).

Brunsing (1997) as cited by Martens (2004) explains that a well integrated bicycle and public bus transport can be an alternative to the use of private vehicles. This may not be the case for developing countries however, a well integrated system may increase the quality of lives of the people. Integration can be defined in terms of infrastructure provision or in terms of the mode of transport.

In terms of infrastructure provision, integration can be classified into two main types thus node integration and route integration.

Node integration includes the provision of non-motorized infrastructures such as the provision of secure parking facilities. The provision of secured parking facilities includes bicycle racks, bicycle lockers and staffed bicycle parking facilities. These give commuters assurance of finding their bicycle safe on their return (Doolittle and Porter 1994; Schneider 2005; Advani and Tiwari 2006).

Route integration of bicycle and bus transport includes the provision of non-motorized infrastructures such as bicycle lanes, bicycle paths and bicycle phases in traffic light on routes to bus stops. The safety and comfort of cycling is a main factor for cyclist. The provision of secured access infrastructure is thus important (Advani and Tiwari 2006).

In terms of the mode of transport, bicycle bus integration can also be classified into two main types, thus bike-to-bus and bike-on-bus.

Cyclists have the option of bringing their bicycles on board the bus in the case of bike-on-bus integration. Cyclists take their bicycles to the bus stop and can get it onboard the bus. Some of the disadvantages associated with this type of integration include the distortion of headlight and limited capacity in the case of front rack provisions. It may also be difficult for drivers to monitor the security of bicycles at the rear racks. There are also issue of delays due to the slow nature of loading the bicycles. Bicycles allowed in the bus causes overcrowding on the bus (Doolittle and Porter 1994; Schneider 2005). For the efficient operationalization of this type of integration, the route integration needs to be in place. Since cyclists do not park their bicycles, there is no need for the node integration.

With bike-to-bus integration, cyclists are only allowed to cycle to bus stops, park their bicycles and get on board the bus for their trip. For an efficient integration at this level, both types of infrastructure integration should be present. A safe and comfortable route is necessary for accessing bus stops and parking facilities for a safe parking (Doolittle and Porter 1994; Schneider 2005).

This study would be concern with the bike-to-bus integration, thus looking at both node and route integration. Bus stops are prioritized for the provision of bicycle parking facilities. Access roads to bus stops are then prioritized for the provision of bicycle lanes.

1.3. Research Problem

Public transit is most effective in high demand areas. Because of this public transports do not extend to areas with low demands. The number of transit stops has also been seen to have an effect on the travel times. Stop times in a transit system increase the travel time of the transit. More bus stops reduce the stop spacing. It also reduces the average speed of the bus system increasing the travel times. For a faster transit system fewer bus stops with longer bus stop spacing are required (Murray and Wu 2003). This however increases the access times to the transit system reducing its coverage. To increase the coverage of a bus transit, the access and egress times need to be reduced.

Walking is the main mode of transport for accessing bus stops. Using walking as a feeder mode to bus transit only increases the coverage of the transit system to a few meters. Bicycle usage has been seen to increase the coverage of a bus system much more than walking because of its relative fast speed compared to walking. Safe bicycle routes and parking facilities have been seen to encourage cyclist in using their bicycles. Bicycle routes thus needs to be introduced in places without access to these stops. Its importance is stressed by the many researches showing the importance of bicycle infrastructures in expanding the catchment coverage of transits (Doolittle and Porter 1994; Murray, Davis et al. 1998; Martens 2004; Advani and Tiwari 2006; Givoni and Rietveld 2007; Martens 2007; Brons, Givoni et al. 2009). The provision of these infrastructures on all routes and stops is virtually impossible because of limited resources. Choices are therefore to be made about which route and bus stops to be upgraded. Little has however been done in prioritizing bus stops for non-motorized infrastructures.

This research looks at prioritizing bus stops and access roads for the provision of non-motorized infrastructures through a prioritization model. It stresses the importance of bicycle access in the operation of bus transits. It also seeks to incorporate the issue of distance decay in prioritizing bus stops for non-motorized infrastructures. To help do this, there is the need for a multimodal distance decay curve for walking and cycling in combination with bus trips in order to know how far the path should be constructed. The multimodal distance decay distribution curve will be used to determine how the integration of non-motorized transport with bus transport can support the bus transport by increasing its catchment and potential ridership.

1.4. Research Objectives and Questions

The main objective of this research is to integrate non-motorized transport with bus transport by prioritizing routes and stops for bicycle infrastructures in order to increase the bus-bike ridership catchment under limited resources.

To aid in achieving this objective, several sub-objectives have been set:

1. To understand the travel behaviour of the people of Pune.
2. Establish (hypothetical) multi-modal distribution curves for trip makers in Pune.
3. Prioritize bus stops to be upgraded with a bicycle parking facility.
4. Prioritize access routes to bus stops for the provision of bicycle infrastructure.

1.4.1. Research Questions

To help address these sub-objectives, the following questions have been asked. It is deemed that answering these questions is going to help in answering the main objective of this research.

Table 1-1: Research Questions

No	Research Objectives	Research Questions
1	To understand the travel behaviour of the people of Pune.	How do people move from their origin to destination?
		What are the different modes of transport?
		Does the choice of mode depend on the distance travelled?
2	Establish a modal distribution curve for the people of Pune.	What shape does the distribution function of people's willingness to walk to the bus stop take? What it the function of the distribution curve?
		What shape does the distribution function of people's willingness to cycle to the bus stop take? What it the function of the distribution curve?
3	Prioritized bus stops to be upgraded with bicycle parking facilities	What is the catchment coverage of a bus stop?
		What is the potential demand at each bus stop?
4	Prioritize access routes to bus stops for the provision of non-motorized infrastructures	What bus stops are going to be upgraded?
		Which routes to the bus stop has the highest demand along it?

1.5. Conceptual Framework

Public bus transport is usually provided to transport commuters from one place to the other. Public bus transports however do not offer a door-to-door service. Commuter thus need to access bus stops over some distance. Walking is one of the major modes of transport for accessing these stops. Because of the slow nature of walking, access travel time increases over small increases in distance. This reduces the catchment area of the public bus system. Bicycles on the other hand provide a much faster mode of accessing these bus stops as compared to walking, reducing the access travel time even more. This also increases the catchment area of the public bus transport as the distance covered within the same travel time as walking become longer. For safe cycling to bus stops, there is the need for cycling infrastructures on the roads which are mostly lacking in most countries. In trying to make inaccessible areas, accessible, there is the need for the provision of such infrastructures. This research seeks to integrate bus transport with bicycle mode of transport to increase public bus transport catchment.

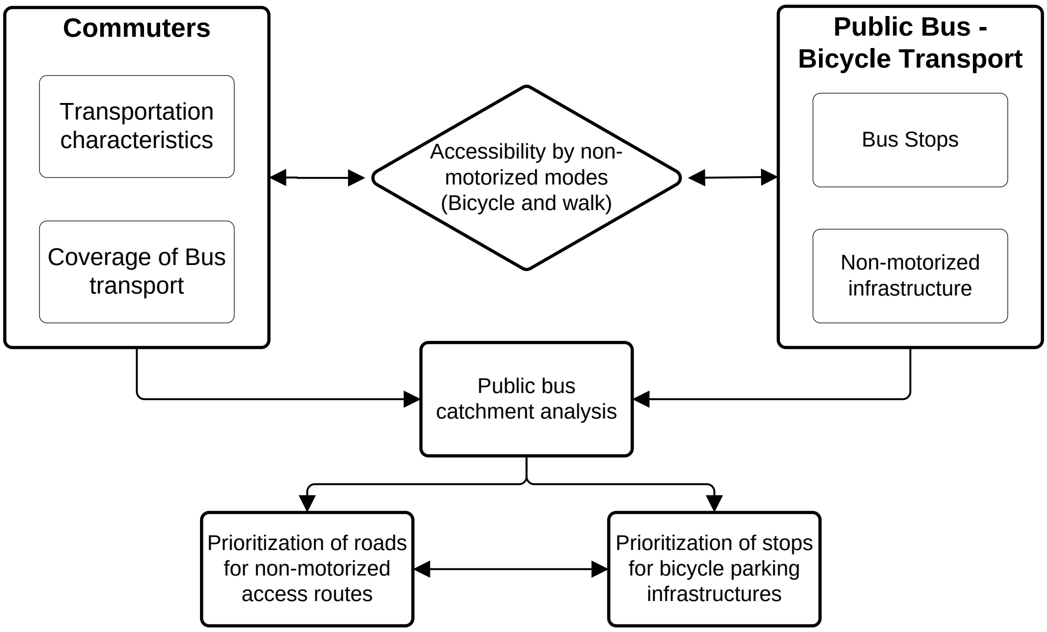

Figure 1-1: Conceptual Model

1.6. Research Design

Through literature review, the research problem, thus prioritizing bus stops and routes for the provision of non-motorized infrastructures has been defined. This is to help in efforts to increase the coverage of a public transit system. The research objectives and questions were then formulated from this problem. With the help of literature, the required data for this research was identified and was used in the analysis. These data included the transportation characteristics of commuters, population data, public bus stops and the general road network. During the analysis, some assumptions were made which based on literature. The analysis done includes the determination of the modal distance decay function. The distance decay function helps in knowing how far commuters are willing to travel. A regression analysis in Excel through curve fitting can be used for the establishment of this function. Because of the lack of resources for the provision of these infrastructures at all stops, bus stops have to be prioritized to know which ones need these infrastructures most for maximal coverage. This is based on the public transport demand and willingness of commuters to cycle to bus stops using an optimisation model. Through a heuristic reduction model, bus stops would be selected. The access routes to these bus stops were then prioritized for the provision of non-motorized transport facilities. This was done by determining which of the route would give the highest potential commuters along it. Conclusions were then made and recommendations for a much refined model made based on literature.

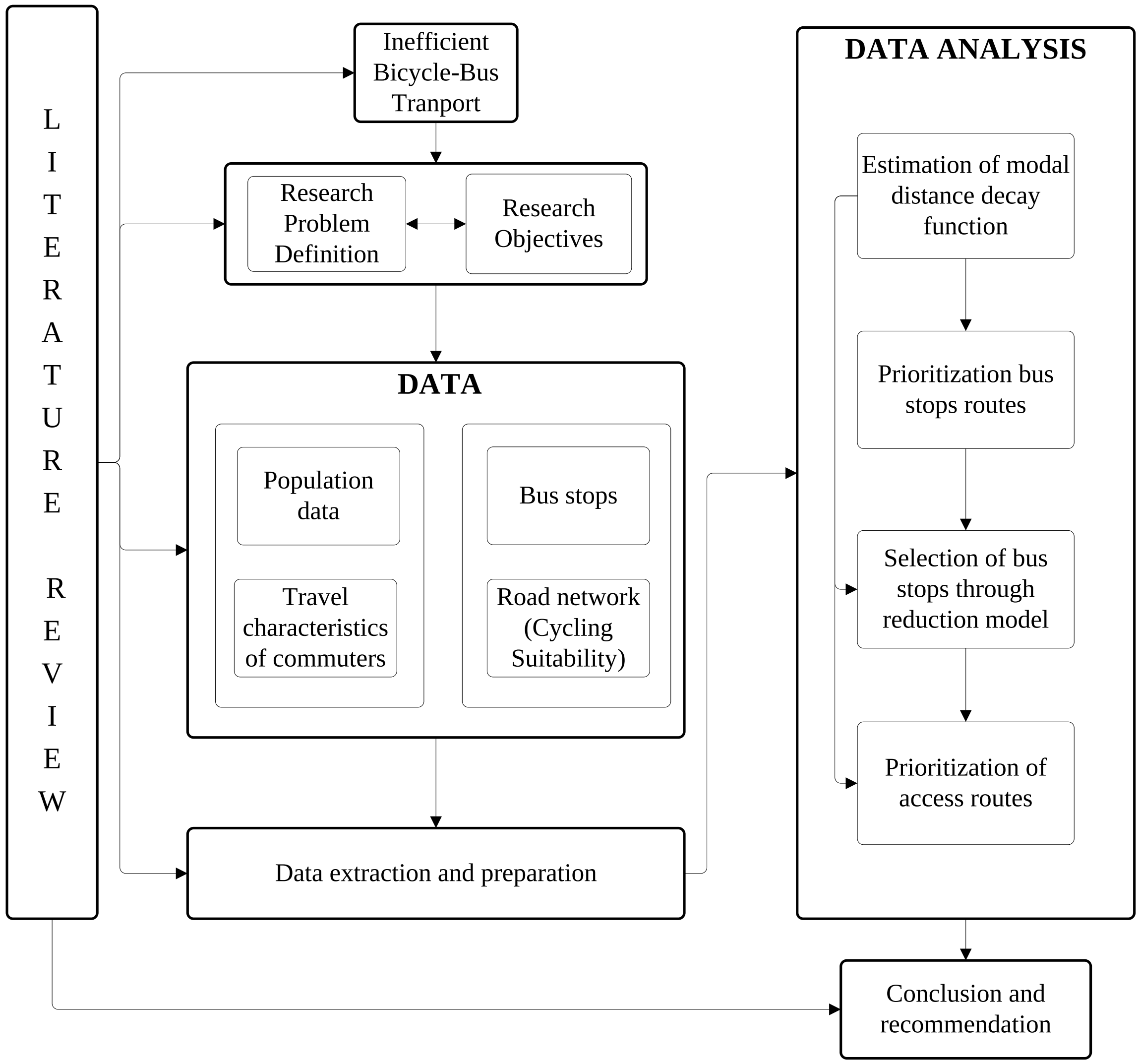

Figure 1-2: Research Design

1.6.1. Research Matrix

The research matrix below indicates the required data, their sources and the tools needed to complete the various thesis sub objectives. These were done in achieving the main objective of the research.

Table 1-2: Research Matrix

No	Specific Research Objective	Data Required	Data Source	Methodology
1	To understand the travel behaviour of the people of Pune.	Relevant literature on cycling and walking behaviour	Secondary	Literature review
		Traffic Survey (Non-motorized study)	Secondary	Statistical analysis

2	Establish a mutli-modal distribution curve for the people of Pune.	Various statistical processes	Secondary	Literature review
		Percentage of modal share	Secondary	Statistical analysis
3	Prioritize which bus stops to be upgraded with a bicycle parking facility.	Bus stops, Residential land use, Population	Secondary	Optimization model by CommunityViz
4	Prioritization of access routes	Bus stops, Residential land use, Population	Secondary	GIS Network analysis

1.7. Limitations of Research

The main limitation of this research is the reliance on secondary data. Due to my inability to go for fieldwork, it became necessary to rely on secondary data. The credibility of these data was difficult to attain. The result can therefore not be confirmed with 100% surety. Despite the uncertainty in data used, it is shown that the possibility of incorporating distance decay function in prioritizing bus stops for non-motorized infrastructure for optimal service coverage.

Secondly, the research uses a general origin-destination multi-modal curve for the distance decay function. This does not necessarily represent trips made in accessing bus stops. It was no wonder higher distance thresholds were obtained. This was used because of the lack of data on trips made in accessing bus stops. A multi-modal curve developed from trips made in accessing bus stops could have given a much realistic curve considering the non-motorized trips to bus transports. Determinants such as access-main haul ratio, topography etc which determine the choice of bicycle-bus commuters could be incorporated in the estimation of the multi-modal curve.

Most of the demand points were off the road network. Network distances from these demand points to the bus stops were going to be with a degree of error as they are snapped to the closest roads. In efforts to reduce this error, the Euclidean distances were calculated from the demand points to their closest roads. This was multiplied by a detour factor estimated for road network in the city. Even though this error was reduced, it was not eliminated. Distances would have been better estimated if local road networks were available

The lack of time and knowledge of a requisite software led to the use of a heuristic reduction model. During this reduction model, more than one bus stop was removed after each iteration because of the number bus stops. This may have effect on the optimization as the effect of removing each bus stop on number of demand points served was not assessed. It would be much better if bus stops were reduced in single steps.

1.8. Outcomes of Research

At the end of the research, the following outcomes were produced.

- A modal distribution curve for commuters of Pune city.
- An optimization model (conceptual and implemented) to prioritize bus stops and routes for non-motorized transport infrastructure.
- A change map from walking to cycling due to the reduction in bus stops.

1.9. Benefits of Research

Since the construction of non-motorized infrastructure involves finances and it is a virtually an irreversible decision, it should be made with much certainty. It is hoped that transportation planners will be able to use the optimization model in prioritizing bus stops to be upgraded with a non-motorized transport.

The construction of such non-motorized infrastructure will lead to a safer transport for cyclist in the city making the city much liveable. It has the potential of drawing a number of commuters using private vehicle to use public transport. This would help in reducing congestions on the roads.

Making public transport accessible also introduces social equity issues as the deprived people in the community would also have access to transportation. This would increase the interaction of people and has to potential of increasing economic activities.

1.10. Thesis Structure

Chapter one starts by introducing a transportation bottleneck faced by most motorized cities, congestion. It then briefly states some of the main causes of this problem followed by possible solutions to it. The research problem is then introduced, thus the integration of bicycle and bus transport along with the research objectives and questions. Limitations faced during this research are also discussed here.

Chapter two provides a discussion on the importance of urban transport and the problem faced. Development of sustainable urban transport in reducing congestions and related effects are also discussed. The provision of bus transportation system and its challenges were also discussed. Possible solutions to these challenges were also discussed.

Chapter three presents the methodological framework by which this research was carried out. It introduces concepts such as accessibility and distance decay. Optimization models for the prioritization of bus stops and access roads in this research were also thought upon.

Chapter four then discussed the city for the case study, Pune. It provides a background of the city, the physical characteristics (including geographical location, administrative boundaries, land use and the road network) and the demographic characteristics (population growth trends and population density). A brief discussion on the modal share and current situation of public transport system in the city is also presented.

Chapter five firstly present a brief discussion of the data sources. Methods discussed earlier were operationalized to yield results. The modal curve was estimated; bus stops and access routes were prioritized using CommunityViz and ArcGIS spatial analysis. The results of the analysis were then presented.

Chapter six discussed the results obtained. Possible reasons for some of the results were discussed. A comparison of the two criteria used in reducing bus stops was made.

Chapter seven then conclude the research by comparing the research objectives and the results obtained. Recommendations for the improvement of the model were then.

2. Urban Transport

2.1. Introduction

Transportation is the movement of people and goods from one point of activity to the other. It is the backbone for the development of a city, socially and economically (World Bank 1996; Murray, Davis et al. 1998). Gwilliam (2002), put is as cities been the engine for the economic development of cities with the oil for preventing the seizure of this engine been urban transport. He also argues that a congested road infrastructure however slow down the economic growth. This is as a result of time lost in congestion which has been seen by industries as a lost in business money (Banister 2008)

As cities increase in size, the total travel time increases and the number of car trips also increase. As the city becomes much developed, the land price at the city centre also increases and the city centre also becomes congested. The poor become displaced and move to the city outskirt for settlement. The rich on the other hand because of their quest for more space also move much further from the city centre. This introduces urban sprawl and makes the city size big introducing longer distances between activity places. With the long distances between activities, walking and cycling become unsuitable modes of transport any more. Without the provision of an efficient public transport, people tend to rely on the use of private automobile (Gwilliam 2002; Banister 2008).

The use of private automobiles apart from the creating of congestion on our roads has other environmental and economical detrimental effects. These include the pollution of the atmosphere with gases from the exhaust generated from the fuels used in cars. The provision of an efficient transportation system is thus needed to curb the continual increase in private automobile use.

Several management policies such as widening of the roads have been seen to address the problem of congestion for a short period of time. However public transports such as bus has been seen to help address this problem. Buses however do not provide a door to door service. The integration of the bicycle and bus has been seen to provide a strong alternative to the use of the private car (Tiwari 2002).

2.2. Concept of Sustainable Transport

Sustainability has been seen as a big concept for a lot of authors and people as well. The United Nations (1987) defines sustainability development as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Thus a sustainable development should be able to meet the needs of today but should not deprive the future generation of their own needs.

Sustainable development can be viewed from three main perspectives, thus environmental, economic and social sustainability (World Bank 1996; Banister 2008). For a development to be considered economical it has to achieve the three aspects, thus should be environmentally, economically and socially sustainable. This is usually difficult to achieve. As a result, there is usually a trade off between these aspects of sustainability.

Economic sustainability refers to a development which has the funds to finance it and has the capability of recouping it investments (World Bank 1996). Such development should be able generate enough fund to sustain it during its life time.

For a development to be socially sustainable, it should offer equitable service to the whole community (World Bank 1996). Such a development should be able to cause improvement in the general life of the people thus reducing poverty.

On the other hand an environmentally sustainable development should make lives much liveable by reducing the side effects to environmental degradation (World Bank 1996). This aspect has been of main focus in the mist of recent global warming. With demand for transport increasing coupled with the use of private automobiles have increase the consumption of fuel. More private automobiles with a relatively small occupancy rates on the roads leads more congestion.

Congestion causes reduction in speeds, thus more fuel needs to be burnt. This causes both air and noise pollution (Gwilliam 2002; Martens 2004; Beirão and Sarsfield Cabral 2007). Air pollution has detrimental effects to the human health. It causes diseases such as asthma, bronchitis, leukaemia and other lung diseases (Gwilliam 2002; Banister 2008). Aside these immediate effects of pollution, there are a long term ones such as climate change which is causing global warming. A study done in six cities by Lvovsky et al (2000), suggest that about 40 percent of nitrogen oxides in these cities are emitted from the use of vehicles. Nitrogen oxides cause damage to the ozone layer which absorbs ultraviolent light which can be dangerous to humans and life on earth. The reaction of this gas with volatile organic compounds in the presence of heat and sunlight produce the ozone gas which is detrimental to the human lung. The effects of ozone can be global as it can be transported by wind currents over long distances (Wikipedia). Hensher (2008) also confirms the effect of improperly managed transport on climate change by stating that about 14 percent of all greenhouse gas emissions come from transport.

Congestion is mostly evident in large cities without proper public transports. Gwilliam (2002), identified four main characteristics of a city which explain the transportation differences between cities as income level, size and size distribution of the city, the political history and the population growth rates. Gwilliam stated that as the spatial extent of a city, increases, the average trip length also increases. This coupled with an increase in the economic levels of the inhabitants of a city leads to the acquisition of vehicles. Vehicle ownership on the other hand has a strong correlation with the number of trips made. This is evident both in the developing and developed countries leading to congestions.

Efforts been made to achieve a sustainable transport includes technological developments for alternative fuel, reduction in travel needs by the use of information and communication technologies (ICT) and changes in land use and transport management policies (Bertolini, le Clercq et al. 2005; Banister 2008). The development of alternative fuels for transportation may cause a reduction in the amount of pollutants released by automobiles into the atmosphere but may not cut down on congestion levels which is directly linked the development of a city. On the other hand, although reduction in travel needs by internet may reduce congestion and pollution, this option does not seem viable in the context of developing countries where internet is not accessible by all. Even in the developing countries, this may not work properly as people may not trust each other over the internet.

Changes in land use from single land use to mix land uses, may contribute to the reduction in the average trip distance travelled. It is assumed that people do not travel just for the sake of travelling but to participate in activities such as working, shopping etc. (Bertolini, le Clercq et al. 2005). These activities when not integrated well with transport could cause increase in traffic congestion. Policies geared at increasing population density with mixed land use development could cause a reduction in the distance to travel (Banister 2008). This could cause a reduction in the use of automobiles leading to reduced congestion. However such policies are only good in new development and difficult to implement in already developed areas.

Another way of reducing congestion in the urban areas has been in the management of the traffic in urban areas. These include but not limited to the expansion of road infrastructures, demand management and modal shifts such as promoting walking and cycling and the use of public transports (Gwilliam 2002; Banister 2008). The expansion of road infrastructure has been seen to only provide the answer for congestion for only a short term. This is evident in cities like Beijing, Shangai, Shenzhen etc. (Tiwari 2002; Beirão and Sarsfield Cabral 2007). Policies which concentrate on encouraging the use of public transport have been seen as a much more effective way of reducing congestions on the road (Newman and Kenworthy 1999; Mackett 2001). This is so because of the large occupancy rate of public transports as compared to the use of private cars. Among the public transports available, public bus provision in the city is seen as the most economical to provide. This is because of its relatively low cost of investment as compared to other public transports like for rail where rail lines have to be provided. Moreover, because of the financial constraints of most developing countries, improved public bus transport may be the likely solution (Palmner, Astrop et al. 1996).

2.3. Public Bus Transport

Public bus transport has been seen to be a sustainable (economical, environmental and social) transport in the urban areas which has the potential of competing with private automobiles (Tiwari 2002). Compared to other public transports such as rail and trams, it has a low cost of investment since it uses the same road and only on rare cases that extensions need to be done to the road. Because of its public nature, it become accessible to all in the community and has less detrimental to the environment.

Public bus transport can cause a reduction in the congestion levels on the roads. This is achieved by the large occupancy nature of public bus as compared to the use of private automobiles. The large occupancy nature of the public bus means that it can transport more people at the same time as compared to private automobile, reducing the road space used per person per trip thus reducing congestion (Badami 2005). The amount of energy used per person for the trip is also reduced (Martens 2004). The reduction in the energy use may lead to the reduction in air pollutant from fossil fuels such as carbon dioxide, nitrate oxides and other green house gases (Banister 2008).

Access to bus stops has been seen to be the weakest part of a bus transport system (Krygsman, Dijst et al. 2004; Martens 2004). For a public bus to cause a reduction in the use of private automobiles, its total travel time should not be more than that of the private automobile. The access times to bus stops are thus very important in public transport patronage.

2.3.1. Access to Public Transport

Access to public bus transport can be defined as the opportunity for commuters to use the transport system. It can be defined in terms of the proximity to commuters or the cost of using the services (Murray, Davis et al. 1998). The cost of using the service can be in terms of the fares incurred in using the public transport. When cost is set very high, the transport becomes inaccessible to some group of people in the society who cannot afford. Accessibility of bus services in terms of proximity on the other hand look at how close the bus stops are from the commuters either in terms of the physical distance or time. This research however focuses on the proximity of bus stops to commuters.

Walking as a mode of transport is seen to have a large portion of total trips made per day. This is so because commuters have to walk to their mode of transport even if for a short distance in all modes of transport. Walking is also considered to be the main mode of transport to access bus stops. (Murray and Wu 2003; Pucher, Korattyswaropam et al. 2005). However the distance commuters are willing to cover to access bus stops are relatively short. Murray et al(1998) estimates a 400m walk to bus stops as the distance most people can walk comfortably under normal conditions. Depending on the terrain of the area, this distance can reduce. Murray and Wu (2003) estimated access in terms of time, stating an access time of 5 minutes to bus stops as reasonable for commuters. This causes the coverage of the public bus to be only accessible to commuters within this threshold reducing the total coverage of the public making public transport not accessible to commuters living beyond this threshold by walking.

The use of bicycle as a feeder mode to bus stops has however been seen to increase the coverage of the public bus transport. The bicycle is much faster than walking and does increases the distance covered within the same 5 minutes access time. The bicycle is seen to be about three times faster than walking (Advani and Tiwari 2006). Cycling does increases the distance covered by walking three times within the same time. This increases the catchment area of the public bus transport providing much mobility for commuters. Because of the flexibility of the bicycle, commuters are much able to plan their trips to be on schedule with the bus transport (Martens 2004; Schneider 2005; Martens 2007; Pettinga, Rouwette et al. 2009).

The use of bicycle as a feeder mode to bus stops has also been seen to be much healthy to the users (Banister 2008). The regular use of bicycle has been seen to reduce the risk of incurring health problems such as high diabetes, depression, back problems, high blood pressure, high cholesterol etc. It improves lung capacity and oxygen absorption (Pettinga, Rouwette et al. 2009).

Apart from the benefits accrued by the cyclist, there are some benefits also to the society when commuters use bicycles when used to access public bus. The integration of these modes of transport has been seen to provide a competitive alternative to the use of private automobiles (Schneider 2005; Pettinga, Rouwette et al. 2009). The private car offer a door-to-door service to commuters which public transport cannot offer. With the bicycle having a high spatial penetration rate, virtually reaching every location, its integration with bus transport could be a solution to this problem (Zuidgeest, Brussel et al. 2009). The use of the bicycle however provides easy access to these stops. The public bus then helps in taking commuters over long distances which otherwise would have been tiring to do with the bicycle saving travel time in addition. A proper integration of the use of bicycle and the public transport is thus important in providing a much sustainable transport which can reduce congestion and its related side effects whiles providing health benefits to the commuters. A research in the Netherlands shows that the travel time ratio between public transport and private car use reduces from 1.4 to about 1.25 with a good access provision to bus stops (Arends & Samhoud 1993 as cited in ; Martens 2007). Apparently a ratio of 1.25 people is inclined to use public transport given other benefits of the trip. They accept a 25% longer travel times.

2.4. Integrating Bicycle and Public Bus Transport

Among the many reasons for the integration of bicycle and public transport is its potential of increase the coverage area of the public bus transport. Study shows that public bus transport with more comprehensive bicycle integration tends to attract more commuters (Victoria Transport Policy Institute ; Schneider 2005; Pettinga, Rouwette et al. 2009). For this reason a proper integration of bicycle and public bus is needed if a competitive mode of transport to the door-to-door service of the private automobile is needed.

Ibrahim (2003), defined integration as the movement of commuters from one place to another through rider-friendly intermodal facilities and interconnections. He identified four types of integration thus; fare, information, physical and network integration.

Fare integration of modes involves the provision of a one ticket system for all modes of transport. For the integration of bicycle and bus transport, this could be realised in various ways such as integrating the cost of parking bicycle with the bus fare (Zuidgeest, Brussel et al. 2009).

Kenyon and Lyons (2003) defines multimodal traveller information as the provision of information about the different modes of travel within a single source. The provision of such information helps travellers in making trip decisions and also planning them. It is an important factor in the provision of quality public transport (Grotenhuis, Wiegmans et al. 2007). With the integration of bicycle and bus transport, a unimodal traveller information which provide information about single mode would be sufficient. This is so because of the flexibility nature of bicycle mode. Its scheduling depends solely on the commuters understanding of the bus transports schedules. Information such as bus schedules could be provided on the internet or at bus stops (Kenyon and Lyons 2003).

Physical integration involves the provision of transfer facilities at nodes to enhance the transfer of commuters from one mode of transport to the other and can be referred to as node integration used in this research. Facilities such as bus shelter, park and ride, bike and ride could be provided for a smooth transition of different modes (Potter and Skinner 2000). In the case of bicycle-bus integration, such facilities give cyclist parking spaces for their bicycle and the assurance of meeting their bicycles on return.

Another factor for the smooth transfer from different modes of transport is the integration of the different hierarchical levels of network and can also be referred to as route integration used in this research. For example, for a well integrated bicycle and bus transport, bicycle lanes or paths need to be connected to bus routes at bus stops. They need not to be disconnected as it influences cycling commuters.

All these types of integration can be combined into operational integration (May, Kelly et al. 2006). For a well operated integration of different transport modes, all these types of integration have to be present. This research focuses on node (physical) and route (network) integration. Two types of integrating bicycle as a feeder mode to public bus transport is discussed, thus; bicycle on bus and bicycle to bus (Schneider 2005).

2.4.1. Bicycle on Bus

This method of integration involves the accommodation of the bicycle on the bus transport. This provides the commuter with benefits such as using the bicycle on both the access and egress trips. There are different ways of accommodating bicycles on bus. This includes mounting racks on the bus or allowing bicycles in the bus (Doolittle and Porter 1994; Schneider 2005).

Figure 2-1: Bicycle rack on front of bus (Burden)

Figure 2-2: Bicycle in Bus(Holliday)

Mounting bicycles on the bus can be done either at the front (figure 2-1) or rear of the bus or on both sides. It has been seen that most of the transport agencies in the United States having a front-mounted racks can carry about two or three bicycles. Rear-mounted racks can however carry about five bicycles. However, more racks on the bus also make the bus longer. This makes it difficult in manoeuvring junctions. Some agencies also allow bicycle to be brought onto the bus (figure 2-2). In this system the bus driver is given the discretion of allowing the bicycle on board the bus or not (Schneider 2005).

Bicycle on bus aside allowing cyclist to use their bicycle at both ends of the trip, have some other disadvantages. The front mounted racks have limited capacity. This is to prevent the racks from blocking the headlight of the bus and the vision of the bus driver. Although the rear-mounted rack poses no threat to the headlight and vision of the driver, activities at the back of the bus cannot be monitored by the driver. The process of loading the bicycles on the racks also slows down the bus operation. Allowing bicycles on the bus however introduces congestion in the bus. There are conflicts between the bicycle and the passengers (Doolittle and Porter 1994).

In this type of integration, only network integration such as the provision of bicycle lanes on access routes to bus stops is required. Node integration can be neglected as cyclists tend to take their bicycle on the bus.

2.4.2. Bicycle to Bus

The bicycle to bus transport integration involves using the bicycle as a feeder mode to the bus transport without taking it on board the bus. Commuters have to use bicycle in accessing bus stops, park and to get onboard for the main trip to their destination. In this type of integration the commuter does not have the opportunity of using the bicycle at the destination end of the trip (Schneider 2005).

Figure 2-3: Bicycle racks at Bus Stop (Burden)

Figure 2-4: Bicycle lockers(Antoine)

Bicycle facilities which offer comfortable and safe parking to cyclist at bus stops are important in this type of integration thus nodal integration. The assurance of cyclist meeting their bicycles on their way back is a very important factor for cyclist. Some of these bicycle parking facilities include bicycle racks (figure 2-3) and bicycle lockers (figure 2-4). It has been estimated that the cost of constructing a one car park can cater for a rack which can accommodate about six to twelve bicycles (figure 2-5) (Hasan ; Pedestrian and Bicycle Information Center). Bicycle racks may offer no extra cost to the cyclist in parking. One would need a locker to be able to lock their bicycle. Commuters may have to pay a minimum cost for the securing their bicycles in a bicycle locker (figure 2-4). This however provides a much safer parking.

These are installed at the transit stops to provide safe parking for cyclist using the bus transport. Bicycle parking could be short-term or long-term parking (Pedestrian and Bicycle Information Center ; Schneider 2005). Parking facilities for short-term parking includes lockers or racks in open areas or unsupervised areas. This is because of the short time of parking of about two hours only. On the other hand parking facilities such as lockers, racks in enclosed areas are provided for long-term parking since bicyclists leave their bicycle all day or overnight or even for longer durations.

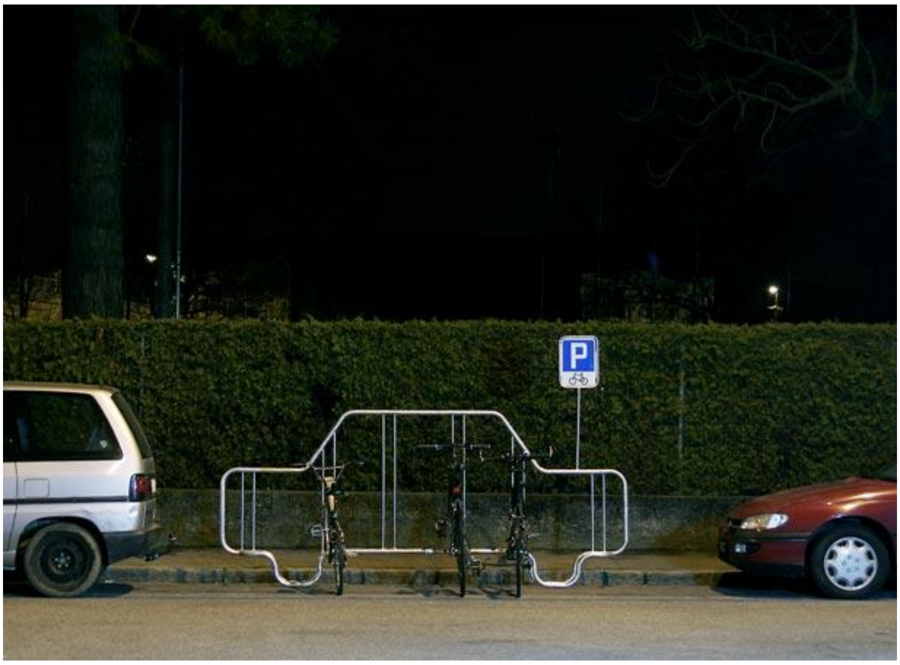

Figure 2-5: On-street bike corral in Spain(Hasan)

Another important factor in the integration of bicycle to bus transport is the provision of bicycle infrastructure on access roads. Bicycle infrastructures on access roads include bicycle lanes and paths. To encourage commuters in using their bicycle, these infrastructures should be consistent, direct, attractive, safe and convenient (Bach 2006). The selection of the bicycle route should be the shortest possible route from departure points to the bus stops and should be continuous. It should be of smooth pavement and void of dangerous junctions providing, steep slopes, dangerous curves, open drainages, street hawkers and parked vehicle for convenient flow of cyclist. Lighting of routes, intersection priorities and bicycle phase in traffic lights along the route have also been seen to encourage cyclist into cycling (Doolittle and Porter 1994)

Figure 2-6: Bicycle Lane in Scheveningen, The Netherlands (Sandt)

Figure 2-7: Bicycle Path in Scheveningen, The Netherlands (Sandt)

Figure 2-8: Bicycle Phase in Traffic Light, Den Haag, The Netherlands (Sandt)

As explained in earlier sections, this research is going to be focused on bicycle to bus integration, incorporation both node and route integration. Bus stops would be prioritized to identify potential transfer stations for the provision of non-motorized transport infrastructures such as bicycle parking facilities. Access roads to these transfer stations would then be prioritized for the provision of bicycle lanes and paths.

3. Methodological Framework

3.1. Introduction

For bicycle-to-bus integration to function efficiently there is the need for safe bicycle infrastructures at transfer stations and on access routes to these transfer stations. These may include the construction of bicycle routes and the inclusion of a bicycle phase at signalled intersections.

However, this is not feasible to implement because of the financial limitation faced by most cities of the world. Non-motorized infrastructures can thus only be provided to some bus stops and to a limited number of access routes. The selection of which bus stops and access routes to be upgraded to provide that optimal results then becomes the problem for the planner to solve.

Given a set of bus stops, this research seeks to provide a tool for the prioritization of bus stops to be upgraded with non-motorized infrastructure. The routes to these stops would then be prioritized for the provision of bicycle lanes or paths.

3.2. Accessibility Measures

Accessibility may be defined as the opportunity for an individual to participate in a particular activity or set of activities (Odoki, Kerali et al. 2001) Because activities are spatially distributed, accessibility cannot be present without mobility which is a measure of the ability to move from one place to the other.

Odoki, Kerali and Santorini (2001) identified five categories of constraints which prevent individuals from participating in activities. Thus;

- Transportation constraints: that limits the distance an individual can travel within a particular time span using available transportation system, that is mode, routing, scheduling and cost

- Temporal constraints: which determine the time and duration an individual can participate in an activity.

- Spatial constraints: determining the spatial availability of activities an individual can participate in.

- Economic, social and cultural constraints: determining who has access or not to activities as a result of cultural rules, laws, income levels, gender and social relationships.

- Coupling constraints: that fixes individuals at a point in space for a period of time.

All these constraints could be used in determining the accessibility of a transportation system. Transportation and spatial constraints are going to be of focus of this research. Bus stops locations optimally serving individuals (giving accessibility) is to be determined. In terms of the transportation constraints to bus transport, accessibility could be defined in terms of the cost of using the public bus or the proximity (physical distance or time) of the services to commuters. (Murray, Davis et al. 1998). Public transport need to be affordable to all individuals resulting in equity in the transportation system (Ahmed, Lu et al. 2008). This makes sure that all individuals have access to transportation irrespective of the economical status. Despite the importance of this dimension of accessibility, it would not be looked at in this research as it is mainly achieved through policy making. Accessibility by proximity, which defines the closeness of individuals to bus stops in terms of physical distance or time, would be considered. Physical proximity depends on the number and spatial locations of the bus stops. Despite the importance of the access-main trip-egress ratio in determining the choice of mode of transport, only the access trip would be considered in this model. The physical access distance from distance for a commuter to move from his or her location to a bus stop is considered.

To determine how accessible a bus stop is by cycling commuters, the potential number of cyclist have to be calculated. As the distance to the facility increases, the potential number of individuals using that particular facility also decreases until a point beyond which the facility become inaccessible. This introduces us to the concept of distance decay.

3.3. The Concept of Distance Decay

Distance decay can be seen as the effect of distance between two points in space. It has an effect on the interaction between two points. It states that the more the distance between two points of activities, the lesser the interaction between these points. This concept has been used in many fields including the economic and social sciences. (Wikipedia ; Taylor 1983; Iacono, Krizek et al. 2008). Economists have been relating this to transport costs in economic location theories whiles sociologists have used this theory in the explanation of social behaviours such as the pattern of friendships. This theory has been used in locating facilities such as retail stores, fire station, etc. Given the same level of services served by a facility, people would choose the facility closer to their home. It can also be seen that the attractive power of a facility diminishes as the distance to people using that facility increases.

The concept of distance decay has been seen to be a good basis for the understanding of the travel behaviours. It provides an estimate of how far each mode of transport can be used and this serves as a basis for planning activities. It has also been used in calculating how accessible a facility is (Iacono, Krizek et al. 2008). Accessibility of a facility determines the catchment coverage of such facility. Facilities with low accessibility have low catchment coverage and vice versa.

The catchment coverage of a facility is important when sitting facilities to ensure its success. This helps in proving the sustainability (economic) of such facility and to know whether it is worthwhile investing in such facilities. The patronage of a service has been seen to decrease as the distance to the facility increase (Taylor 1983). The issue about distance decay is therefore an important issue in locating facilities. A threshold is usually used in defining the catchment coverage of facilities.

Walking has been considered to be the main travel mode for distances below one kilometer by transport planners. The bicycle has been considered to be used for distances between one and six kilometers with the use of private automobile dominating for distances over six kilometers (Zumkeller and Nakott 1988 as cited in; Scheiner 2009). However this threshold is not the same across all cities. This may change between regions and countries (Badland and Schofield 2005). These changes in the threshold may be due to the cultural, economic, topographical or climatic differences in different regions and countries. It is therefore important to establish this threshold for the city or region under study. This research seeks to establish the threshold through the development of a modal curve for walking and cycling mode of transport.

3.4. Development of a Distance Decay Curve

In determining the spatial accessibility of a facility, the distance decay curve is developed. Two main mathematical methods in estimating distance decay function have been identified, thus linear regression using ordinary least squares and nonlinear models using maximum likelihood estimation techniques (Myung 2003; Iacono, Krizek et al. 2008).

Ordinary least squares regression is the most common statistical analysis in the field of social sciences. It is a data fitting model which estimates unknown parameters in a linear regression model. It minimizes the sum of squared residuals or distances between observed points (Pohlman and Leitner 2003) Under a normally distributed assumption, ordinary least squares can be derived as a maximum likelihood estimator.

Maximum likelihood estimation techniques are procedures of estimating statistical parameters by choosing them in a way that make the data most likely to have happened (Field 2005). If the likelihood of getting the observed data is high, then the parameters yield a good fit for the observed data and vice versa. The method is considered to more robust yielding parameters with good statistical properties (ReliaSoft Corporation 2007). The estimation techniques has been seen to be asymptotically unbiased, thus the bias goes to zero as the sample size increases to infinity. The procedure thus becomes biased with small sample sizes (Myung 2003). Polynomial, exponential, power, logarithmic fittings are only a few examples of other fitting techniques.

In this research because of the small sample size, Microsoft Excel curve fitting will be used in fitting a curve to the observed data. The curve fitting methods is going to be varied for each of the modes. Only the method yielding a reasonable curve with a higher coefficient of correlation will be chosen as the final fitting method for that mode. The distance threshold derived from the curves for walking and cycling will then be used in the optimization model. The decay function for bicycle mode will be used in calculating the potential cyclist at each origin which would be used in optimizing bus stops and bus routes.

3.5. Optimization Models

Over the years, there have been a lot of researches into the use of coverage models. Some of these include the location of park-and-ride facilities (Farhan and Murray 2008), the determination of bus stop spacing (Furth and Rahbee 2000; Chien, Qin et al. 2003; Alterkawi 2006; Ziari, Keymanesh et al. 2007), routing problems such as the determination of best route for public bus (Matisziw, Murray et al. 2006; Guihaire and Hao 2008), scheduling of buses (Guihaire and Hao 2008) and the improvement of coverage catchment through accessibility (Murray, Davis et al. 1998; O'Sullivan, Morrison et al. 2000; Murray and Wu 2003; Tong and Murray 2009).

The Location Set Covering Problem (LSCP) and the Maximal Covering Location Problem (MCLP) first to be conceived by Toregas and ReVelle (1972) and Church and ReVelle (1974) respectively are considered to be the two main spatial optimization problems. The LSCP identifies the minimum number and location of facilities ensuring that all demand points are served within a specified distance while the MCLP searches for the location of facilities which gives the maximum coverage within a specified distance or time with limited facilities (Toregas and ReVelle 1972; Church and ReVelle 1974). Optimization problems such as the Anti-Covering Location Problem (ACLP) by Murray and Church (1997), the Hybrid Set Covering Problem (HSCP) by Murray (2003), the Continuous Maximal Covering problem by Matisziw and Murray (CMCP) (2009), only to mention a few are all based on either of the two basic location problem, LSCP or MCLP.

In all these models, the determination of potential demand is very important. Usually a summation of the population with a specified maximum distance to the facility is used in the calculation of this demand. This maximum distance has been defined by Toregas and Revelle (1972) as the distance by which a user would have to travel to reach a facility reflecting the worst possible performance of the facility. Most of these models do not take into account the issue of distance decay within the threshold when calculating for the demand which has been seen as an important factor in locational science (Olsson 1970). Over the years little have been done about the inclusion of the effect of distance decay in facility location (Taylor 1983; Farhan and Murray 2006)

This research seeks to prioritize the bus stops needed to be upgraded with non-motorized facilities such as bicycle racks or lockers under financial constraints. A maximum coverage algorithm taking into account the effect of distance decay would be used for the prioritization of the bus stops for an optimal coverage. It would be assumed that all access roads are equipped with non-motorized infrastructures. Based on the prioritized bus stops, the access roads would be the prioritized based on the demand along each route.

3.5.1. Maximum Coverage Algorithm

Using the maximum coverage algorithm, the bus stops would be prioritized. Commuters are assumed to go to the nearest bus stop. Below is the optimization algorithm for the prioritization of the bus stops;

$$pO_i = [P_i \times Formula\ for\ Cycle\ modal\ curve] \quad (1)$$

$$X_i = \begin{cases} 1 if\ \ W < d_{ij} \leq S \\ 0\ else \end{cases} \quad (2)$$

$$pB_j = \sum_{i}^{n} pO_i \times X_i \quad if\ nearest\ bus\ stop = j \quad (3)$$

$$Maximize \sum_{j} pB_j \quad while\ minimizing\ number\ of\ bus\ stops \quad (4)$$

$$B_j = Bus\ stop\ j$$

$O_i = Origin\ i$
$S \ = Bicycle\ distance\ threshold$
$W \ = Walking\ distance\ threshold$
$d_{ij} \ = the\ shortest\ distance\ from\ origin\ i\ to\ the\ nearest\ stop\ j$
$P_i = Population\ at\ origin\ i$
$pO_i = Potential\ commuters\ at\ origin\ i$
$pB_j = Potential\ commuters\ at\ stop\ j$

Equation (1) calculates the potential bicycle-bus commuters at each of the demand areas. This uses the multi-modal function estimated for bicycle mode. The distance from each demand point to the closest bus stops is used in estimating these potential bicycle-bus commuters. Binary operation (2) decides if a demand point is considered in the calculation of potential demand at each bus stop. Demand points with distances greater than walking distance threshold but less or equal to the bicycle distance thresholds are considered to be part of the model. All other demand points are excluded. Equation (3) sums up the potential demand in all points according to the bus stops serving them. The objective of the model (4) is to maximize the total bicycle-bus commuters served by all bus stops while reducing the number of bus stops.

After finding the optimal number of bus stops and their spatial location, the access roads was then prioritized.

3.5.2. Prioritization of Access Routes

The access routes leading to the bus stops to be prioritized will be selected for the route optimization. Using an area analysis, the potential commuters at each origin (hexagon) was calculated. This was based on the access times from each origin to the bus stops. The road layer was then intersected with the hexagon layer containing the potential commuters to get potential commuters on the road layer. The route with the highest attraction of commuters along it was selected to be the optimal route.

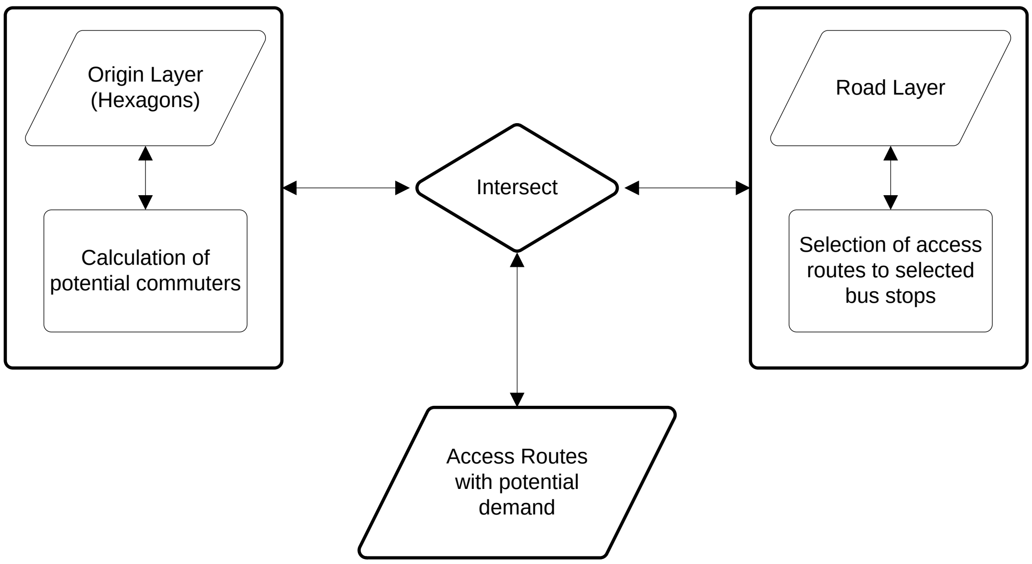

Figure 3-1: Route Prioritization Model

4. Study Area Descriptions

4.1. Background of Study Area

Pune, formerly known as Poona (derived from Punya Nagari meaning City of Virtue) is the seventh largest city in India and the second largest city in Maharashtra after Mumbai. The existence of the city is believed to date back to the 8th century where it existed as an agricultural settlement known as 'Punnaka'. In the 16th century the city of Pune saw major developments like the construction of the Kasba, Somwar, Ravivar and Shaniwa Peths. The city was seized from the Peshwas, who ruled over the city in the early 18th century by the British in the third Anglo-Maratha war at the battle of Khadki. The city was then put under the administration of the Bombay Presidency. A large military cantonment which is now used by the Indian army was then built. Pune Municipality was then established in the mid-18th century.

The city saw major development after India got its independency. The city of Pune has several nicknames such as 'Queen of Deccan', 'Detroit of India', 'Oxford of India', 'Pensioners Paradise', 'Cultural capital of Maharashtra' because of its elevated position on top of the Deccan plateau, its long standing urban tradition, numerous educational institutes, pleasant climate, and its vibrant culture. The city was also known as a 'Cycle city' because of its cycling history but now known as the 'Scooter city'. This is so because the people now tend to use scooter most often than bicycles as it used to be in the past (Nalawade ; National Information Center 2008; Wikipedia 2008).

4.2. Physical Characteristics

4.2.1. Geography

Pune is the second largest city in the state of Maharashtra. It is located on the leeward site of the Sanhyadri Hills (the Western Ghats) between $18^{o}32^{'}$ and $72^{o}51^{'}$ East longitudes about 177km south east of Mumbai. The city is located at the confluence of the Mula and Mutha rivers (Bhima plains and Nira River basin). The city is relatively hilly with its tallest hill (Vetal Hill) rising to about 800m above sea level with the city on itself sitting at about 560m above sea level on top of the Deccan plateau. The city has been one of the fastest growing cities in India over the last two decades. The location of the city makes it well connected to other cities in the region. Its connection to the north-east to Mumbai

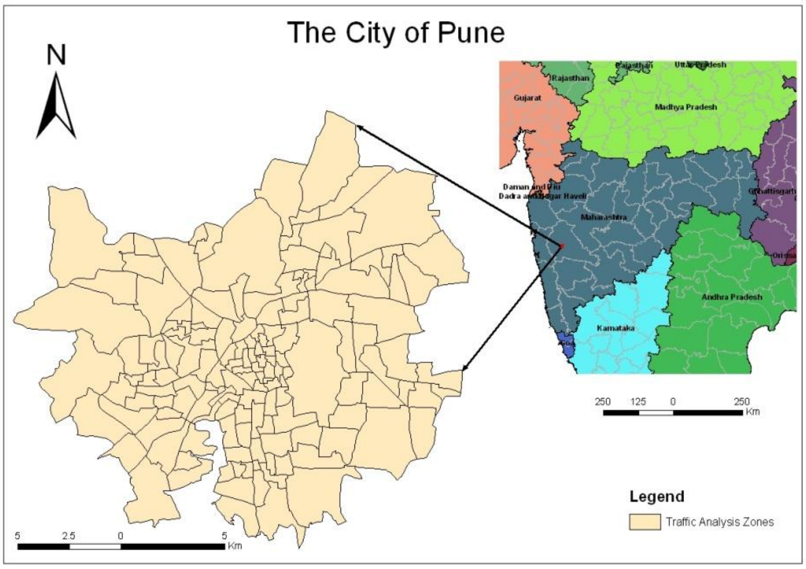

Figure 4-1: Location of Pune City

(both through road and rail) serves as the main economic link of the city. It is connected to the north with Nashik, north-east with Ahmednagar. It is also connected to the southern part of India via the Solapur and Satara roads. All of these connections makes the city accessible from other cities and thus promote economic trade and movement of people into the city (Roy 2005; WilburSmith Associates and Urban Infrastructure Services Limited 2007; Ramboll Natura AB 2008).

4.2.2. Administrative Boundary

Pune, the district headquarters of Pune district extends to an area of about 243 square kilometers. This is almost a double increase from 125 square kilometers in 1951 with the decision of addition of 23 surrounding villages in the Pune administrative area in 1997 and 2001(Pune Municipal Corporation 2006; Ramboll Natura AB 2008). The area under the Pune Municipal Corporation (PMC) is sub-divided into 144 municipal wards which also serve as the traffic analysis zones for the city (figure 4-1).

4.2.3. Land Use

The spatial location of activities in a city has an effect on the travel behaviour of people. As per development plan of 2001, about 43 percent of the city is for residential use, 13 percent for transportation, and 12 percent for agricultural and forest areas. About 5 percent of the city is covered by hills and hill slopes and 6 percent by water bodies. The rest of the city is used for commercial, industrial, recreation and public purpose (Pune Municipal Corporation 2006). The land use distribution is presented in figure 4-3.

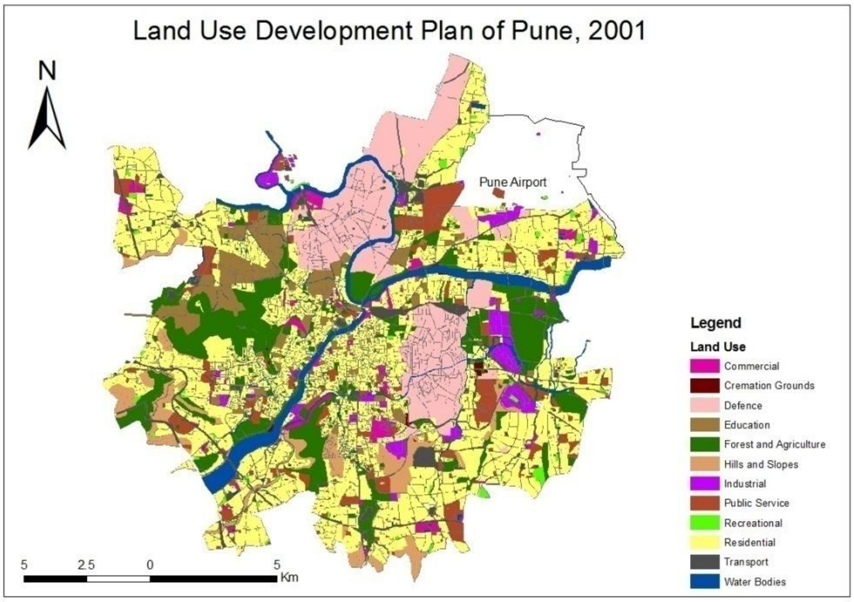

Figure 4-2: Land Use Development Plan

The inner city of mostly dominated by residential, commercial and public and semi-public land uses. A mixture of residential, water bodies, public and semi-public and green spaces characterize the middle portion of the city. Agricultural lands however dominate the outer part of the city with few areas covered with hills, industrial, residential land uses (Ramboll Natura AB 2008).

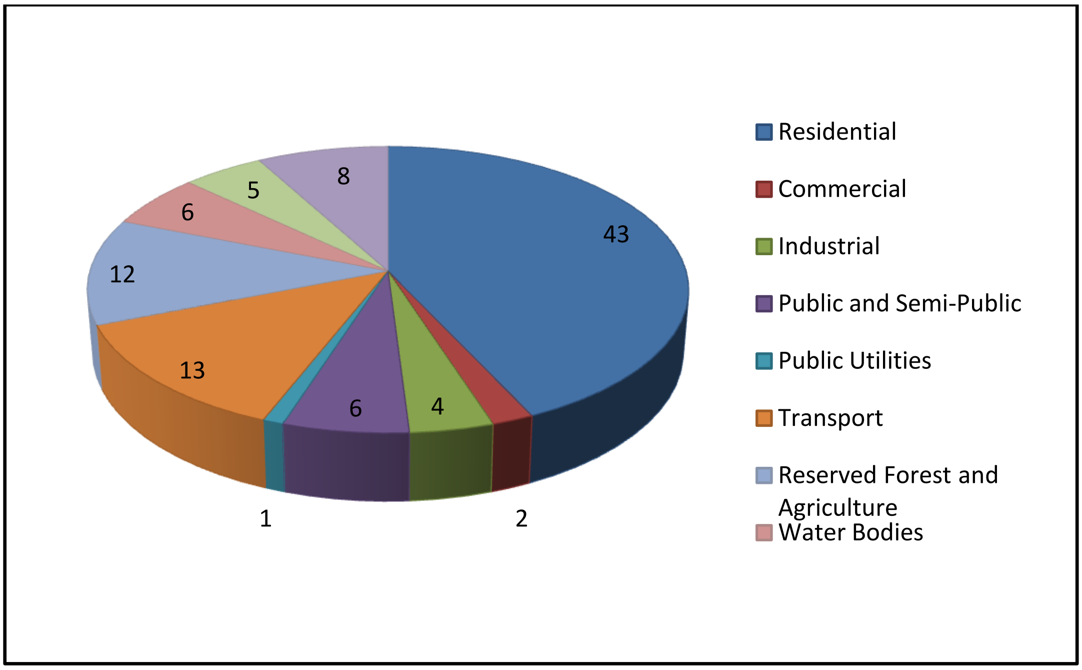

Figure 4-3: Land use distribution, 2001

4.2.4. Road Network

The road network in Pune (figure 4-4) is primarily radial and rectilinear or circumferential. The evolution of its road network is primarily based on the three segments of the city resulting from the two rivers (Mula and Mutha). The road networks in Pune total to about 1800 km in length including about 50 km of National and State Highways which is not under the jurisdiction of the PMC.

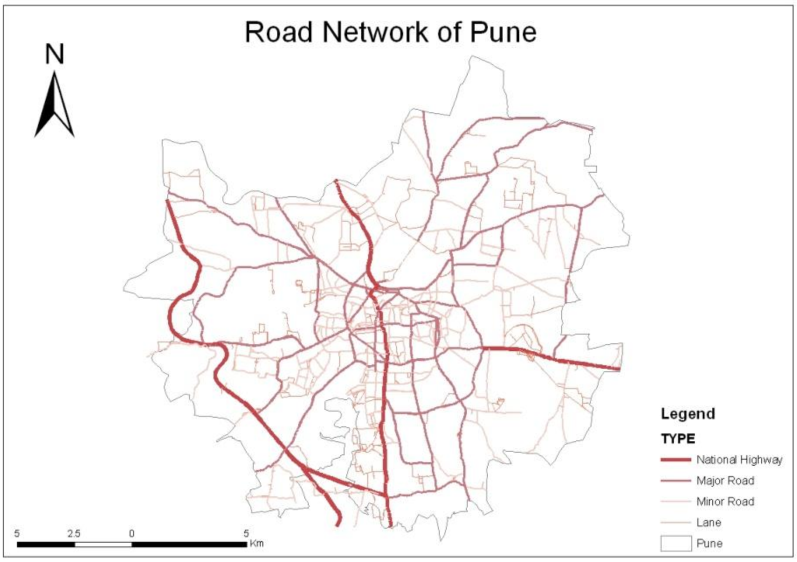

Figure 4-4: Road Network of Pune

As stated in the city development plan of (Pune Municipal Corporation 2006), a comprehensive traffic study showed that about 10.4 square kilometer of the city (making about 4.46 percent) is covered by roads. This is very small as compared to the proposed 13.04 percent of road cover in the development plan of 2001. The study also showed that about 85 percent of the roads have a width less than 24 with most of the roads in the central areas having road width of about 8 to 12 meters though surfaced (Table 4-1). It was also noted that about 60 percent of the roads lack sidewalks for pedestrians leaving them to struggle for space on the roads. The once bicycle city is now known as a two wheelers city.

Table 4-1: Road Length according to Surface type in Pune (Pune Municipal Corporation 2006)

Surface Type	**Length (km)**	**Percentage**
Municipal Roads		
Concrete	32.00	2
Black-topped	1202.00	69
WBM	258.00	15
Gravel and Earthen	258.00	15
Total Road Length	**1750.00**	**100**
Other Agencies' Roads (NH/SH/PWD Roads)	**50.00**	**---**
Grand Total	**1800.00**	**---**

4.3. Demographic Characteristics

4.3.1. Population Growth Trends

As per 2001 census of India, the population of Pune city stands close to 2.54 million. This represents about 500 percent increase over five years (Table 4-1) from a population of about 0.49 million people in 1951. About 62 percent of the population falls below the age of 30 years with the age group of 25-34 years forming the larger portion (Table 4-3).
About 50 percent of the population increase in the city has been estimated to result from immigration of people from neighbouring cities (Pune Municipal Corporation 2006).

Table 4-2: Population Trend (Pune Municipal Corporation 2006)

Census Year	**Population**	**Decadal Change**	**Growth Rate (%)**
1951	488419		
1961	606777	118358	24.23
1971	856105	249328	41.09
1981	1203363	347258	40.56
1991	1691430	488067	40.56
2001	2538473	847043	50.08

Table 4-3: Population Distribution (Pune Municipal Corporation 2006)

Age Group	Male	Female	Total	Male %	Female %	Percentage
0-9	283378	270551	553929	11.3	10.7	22.0
10-14	133110	129615	262725	5.3	5.1	10.4
15-19	126728	114805	241533	5.0	4.6	9.6
20-24	135567	131953	267520	5.4	5.2	10.6
25-29	126849	123166	250015	5.0	4.9	9.9
30-34	112182	97481	209663	4.5	3.9	8.3
35-39	99606	89338	188944	4.0	3.5	7.5
40-44	81508	63165	144673	3.2	2.5	5.7
45-49	61262	49026	110288	2.4	1.9	4.4
50-54	49007	37807	83814	1.9	1.5	3.3
55-59	31429	26876	58305	1.2	1.1	2.3
60-64	30288	29969	60257	1.2	1.2	2.4
65-69	17342	17648	34990	0.7	0.7	1.4
70-80+	24550	26544	51094	1.0	1.1	2.0
Total	**1312806**	**1207944**	**2517750**	**52.1**	**48.0**	**100**

Based on the population trend in Pune, forecast put the city's population to about 5.6 million in the year 2031(Pune Municipal Corporation 2006; WilburSmith Associates and Urban Infrastructure Services Limited 2007; Transportation Systems Engineering Group 2008). This was done by applying growth rates per ward on existing population of that ward which was summed up to the city level.

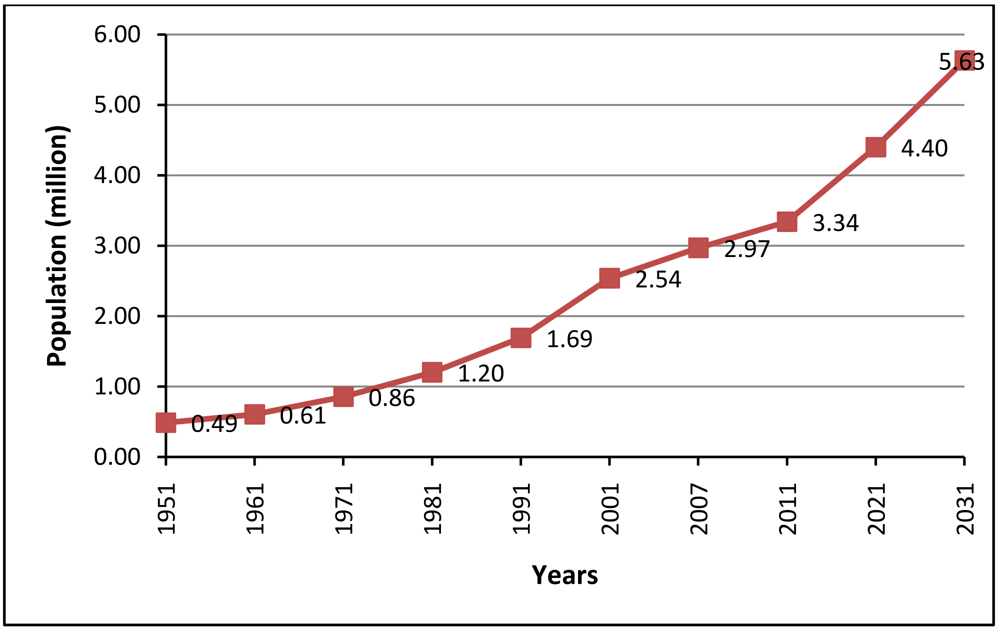

Figure 4-5: Population Growth in Pune City (WilburSmith Associates and Urban Infrastructure Services Limited 2007)

4.3.2. Population Density

Based on the 2007 estimated population of the city of Pune, the population density (figure 4-6) was calculated. The average population density was seen to be around 300 people per hectare with the highest population density recorded to be around 2000 people per hectare (Lohiyanagar). An increase of about three times could be seen when compared to the average population density of 105 people per kilometers in 1991(Pune Municipal Corporation 2006). In general the central part of the city was seen to be highly dense, reducing as you move to the fringes.

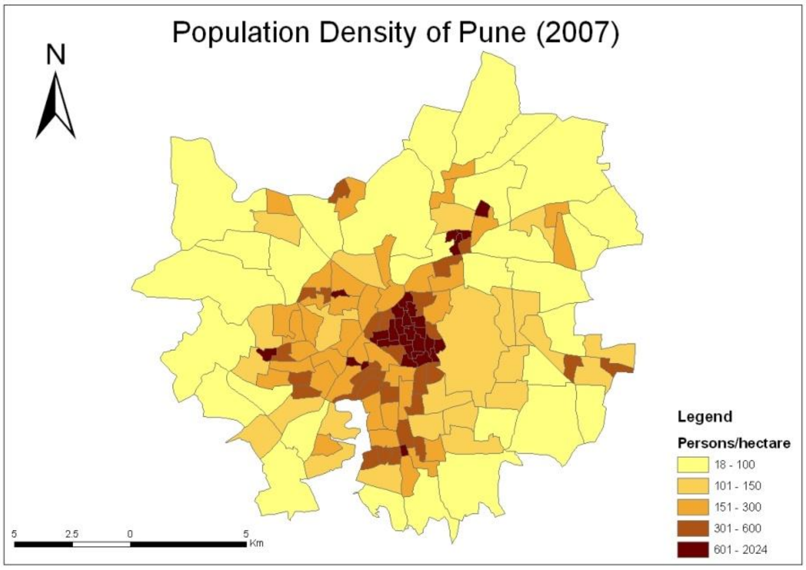

Figure 4-6: Population Density

4.4. Modal Share

Even though motorized two-wheeler is the predominant mode of transport in the city of Pune, the predominant number of trips is still done by non-motorized modes. About 37% of trips are done on foot, 18% by bicycle, 22% by bus, 6% by auto-rickshaws with the four-wheelers (private cars) taking about 17%. Despite the high modal share of the bus in trips made, the number of public bus plying on the roads in a day has been estimated to be around 2% (Pune Municipal Corporation 2006).

4.5. Current Situation of Public Transport in Pune

The Ministry of Urban Development of India formed a National Urban Transport Policy to provide safe, convenient and much efficient transport for the people concentrating mostly on pedestrian and non-motorized transports rather than on private vehicles. However at the moment, the public transportation system of the city has been characterized by poor services. The lack of enough infrastructure and facilities at bus stops in addition to the poor geographical coverage of the bus transport has led to the usage of more private modes of transport. This has led to the bus transport having a load factor of about 51% as estimated in the CTTP report (Pune Municipal Corporation 2006).

It was also estimated that the mere encouragement of the people to use public transport was not going to increase its use. Infrastructure and facilities thus need to be provided to encourage commuters to use the public transport.

5. Analysis and Results

5.1. Data Source

This study would be based on secondary data acquired from the infrastructure wing of Infrastructure Leasing & Financial Services (IL&FS), an infrastructure development company with its headquarters in Mumbai, India. Partnering with WilburSmith and Associates, a comprehensive mobility plan was done for the city of Pune. During the study, a house hold travel survey was done to know the existing travel characteristics of the people of Pune. This contains about 1700 household surveys on transport. Data were collected about the trips members of the household make and their mode of transport. Also collected about the trip were the distances covered in each trip.

Based on the passed data about population collected during the study such as population and employment distribution, projections were made into the future up to 2031 according to the traffic analysis zoning of the city.

Other data acquired for this research include a shape file of the Traffic Analysis Zones (TAZ), a shape file of the roads network in the city and an AutoCAD drawing of the land use.

5.2. Modal Curve Estimation

Using the household traffic survey, the modal curves for the various modes of transport available was estimated. The following procedure was undertaken to develop these curves.

5.2.1. Aggregation of trips

The household travel survey collected information about how far individuals travel and the mode of transport used for each trip. The data was grouped based on the distances travelled by individuals in groups of one kilometer increase (table 5-1). The number of trips made by each mode of transport within each group was expressed as a percentage of the total number of trips made in each category (table 5-2). This was done to get the modal share of each mode of transport within a specific distance. This was then put into Microsoft Excel for the curve fitting.

Table 5-1: Modal Count

Distance	Walk	Cycle	Cycle Rickshaw	Scooter and Motor	Car, Van or Jeep	Auto Rickshaw	Taxi	PVT Bus	Other Bus	Train	Total
0 - <1	354	34	4	13	0	9	0	13	9	4	440
1 - < 2	112	25	1	38	11	21	2	13	4	2	229
2 - < 3	70	95	10	28	6	70	2	30	5	2	318
3 - < 4	148	64	5	54	23	79	2	194	60	0	629
4 - < 5	5	18	2	38	17	68	2	124	22	2	298
5 - < 6	10	22	5	73	19	28	1	69	14	6	247
6 - < 7	3	28	1	51	13	125	4	129	33	6	393
7 - < 8	0	28	0	41	14	99	2	120	2	2	308
8 - < 9	14	8	9	61	14	129	2	89	61	3	390
9 - < 10	3	2	1	36	16	25	4	100	13	2	202
10 - < 11	3	5	3	151	14	24	0	251	18	2	471
11 - < 12	1	0	0	6	4	26	0	34	14	0	85
12 - < 13	1	4	2	62	13	49	0	111	14	0	256

Table 5-2: Modal Share in Percentages

Distance	Walk	Cycle	Cycle Rickshaw	Scooter and Motor	Car, Van or Jeep	Auto Rickshaw	Taxi	PVT Bus	Other Bus	Train	Total
0 - <1	80.45	7.73	0.91	2.95	0.00	2.05	0.00	2.95	2.05	0.91	100
1 - < 2	48.91	10.92	0.44	16.59	4.80	9.17	0.87	5.68	1.75	0.87	100
2 - < 3	22.01	29.87	3.14	8.81	1.89	22.01	0.63	9.43	1.57	0.63	100
3 - < 4	23.53	10.17	0.79	8.59	3.66	12.56	0.32	30.84	9.54	0.00	100
4 - < 5	1.68	6.04	0.67	12.75	5.70	22.82	0.67	41.61	7.38	0.67	100
5 - < 6	4.05	8.91	2.02	29.55	7.69	11.34	0.40	27.94	5.67	2.43	100
6 - < 7	0.76	7.12	0.25	12.98	3.31	31.81	1.02	32.82	8.40	1.53	100
7 - < 8	0.00	9.09	0.00	13.31	4.55	32.14	0.65	38.96	0.65	0.65	100
8 - < 9	3.59	2.05	2.31	15.64	3.59	33.08	0.51	22.82	15.64	0.77	100
9 - < 10	1.49	0.99	0.50	17.82	7.92	12.38	1.98	49.50	6.44	0.99	100
10 - < 11	0.64	1.06	0.64	32.06	2.97	5.10	0.00	53.29	3.82	0.42	100
11 - < 12	1.18	0.00	0.00	7.06	4.71	30.59	0.00	40.00	16.47	0.00	100
12 - < 13	0.39	1.56	0.78	24.22	5.08	19.14	0.00	43.36	5.47	0.00	100

5.2.2. Curve fitting

Using the modal share of each of the modes in each distance category, a scatter plot was done in Microsoft Excel. The curve fitting procedure was then used in adding a curve (trend line) to the points, choosing each mode at a time (figure 5-1). These curves were mostly polynomial curves with only one of them yielding a power functional curve as shown in (table 5-3). This was to give a general share of each mode of transport in relation to distance travelled. As expected, the modal share for walking mode was very high in distance below one kilometer. This however reduces rapidly as the travel distance increases. A distance threshold of about 6.5 kilometers was observed for walking modes. A similar curve was observed for bicycle mode. A gradual increase in modal share as the distance increases till about 3 kilometers was observed. After which a gentle decrease in modal share was observed until about 9.5 kilometers which was considered to be the threshold for cycling in Pune. Even though the modal share of private car, van or jeep did not show much relation with the travel distance, the values were small in relation to the other modes of transport apart from cycle rickshaw which showed the least modal share. The curves for scooter and motor and for public transport did not seem to be dependent on distance at longer travel distances. A random modal share was observed for these two modes of transport.

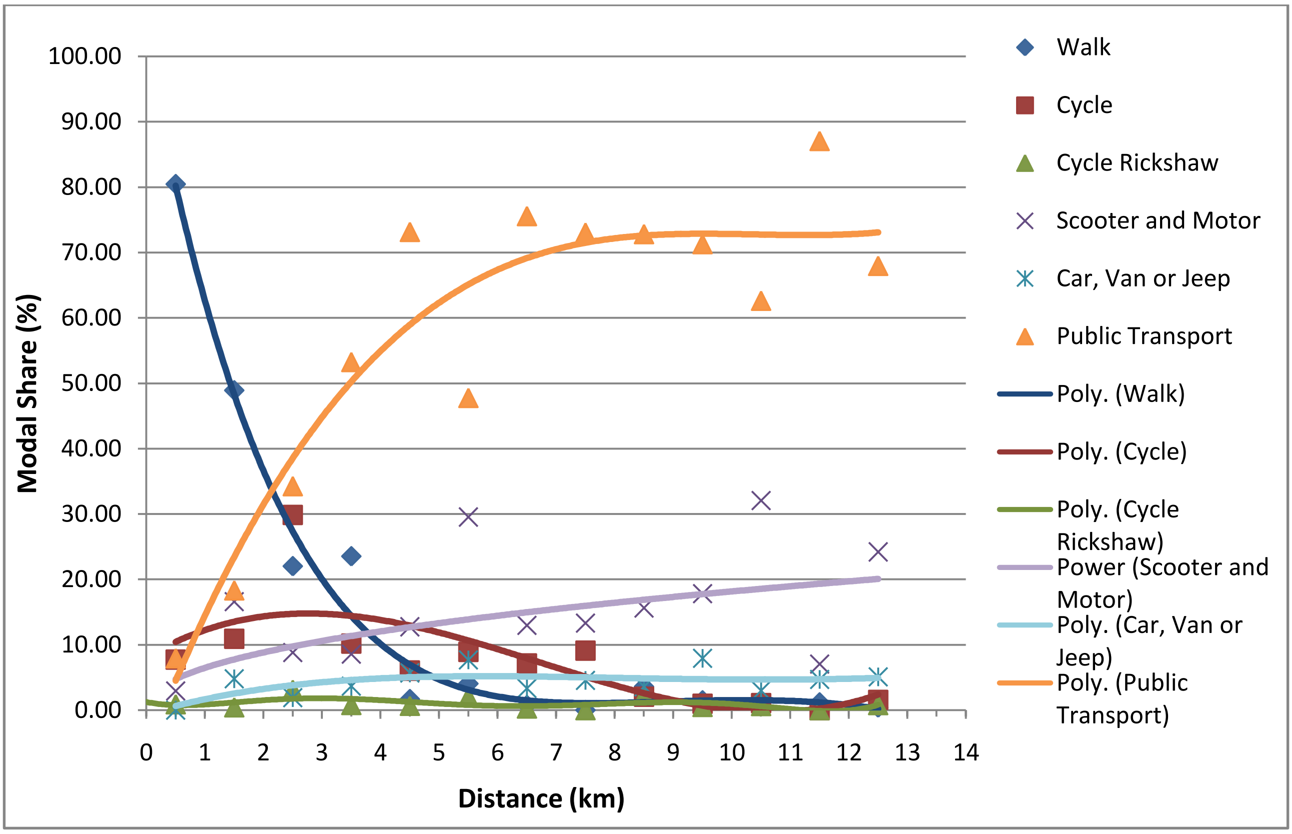

Figure 5-1: Modal Distribution Curves

Table 5-3: Modal Functions

Mode of Transport (%)	Modal Function	R^2
Walk	$-0.0007x^5 + 0.036x^4 - 0.7811x^3 + 8.5549x^2 - 46.718x + 101.54$	0.9793
Cycle	$0.0599x^3 - 1.2109x^2 + 5.315x + 8.0885$	0.5469
Cycle Rickshaw	$0.0002x^6 - 0.009x^5 + 0.1238x^4 - 0.7736x^3 + 2.1036x^2 - 1.8367x + 1.2485$	0.2669
Scooter and Motor	$6.462x^{0.4487}$	0.4217
Car, Van or Jeep	$-0.0005x^4 + 0.0243x^3 - 0.4068x^2 + 2.6193x - 0.5516$	0.3659
Public Transport	$0.072x^3 - 2.2465x^2 + 23.205x - 6.5585$	0.8622

5.3. Population Disaggregation

Over the years due to the simplification of handling data, point representation has been used in representing areas in location modelling (Church 2002). Households in an area are assumed to commute from a central point representing the area. Errors in the calculation of distances between households and the facility are observed as this does not originate from the individual houses but from a generalized point for them. This also introduces errors in assessing the coverage of the facility. Areas covered by the facility spatially may be neglected from the calculation because its generalization point is not covered. On the other hand areas not covered by the facility may be considered as covered because its generalization point is covered (figure 5-2). The magnitude of this error is related to the level of aggregation of data (Daskin, Haghani et al. 1989). The higher the level of aggregation, the higher the errors introduced.

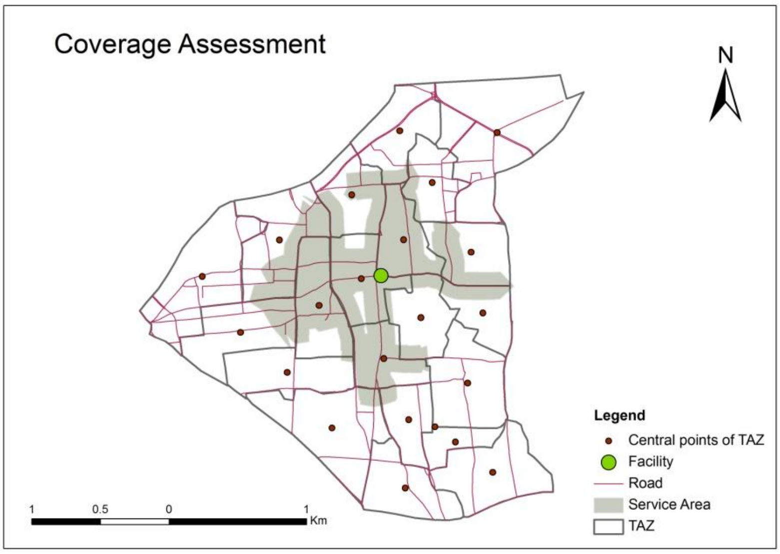

Figure 5-2: Coverage assessment

Because of this, the population data acquired at the TAZ level was to be disaggregated. The disaggregation was done assuming that population is distributed evenly over the residential areas in the city, thus people do not live in other parts of the city for other land uses such as commercial, industrial etc. The residential density for each TAZ was calculated by extracting residential areas from the land use layer and dividing the number of people in each zone by the area obtained. The resulting layer was then intersected with a hexagon layer of 200 metres by size. This introduces the residential density in each of the hexagons. The population of each hexagon is again calculated by multiplying the residential density by the area of the resulting hexagon after the intersection to get the population. However some of the hexagon split up during the intersection. For this reason, the population is summed up using the hexagon ID before the intersection as a base for the summation using the summarize function of attributes in ArcGIS. The resulting table is then joined to the hexagon layer to get the population per hexagons (figure 5-3).

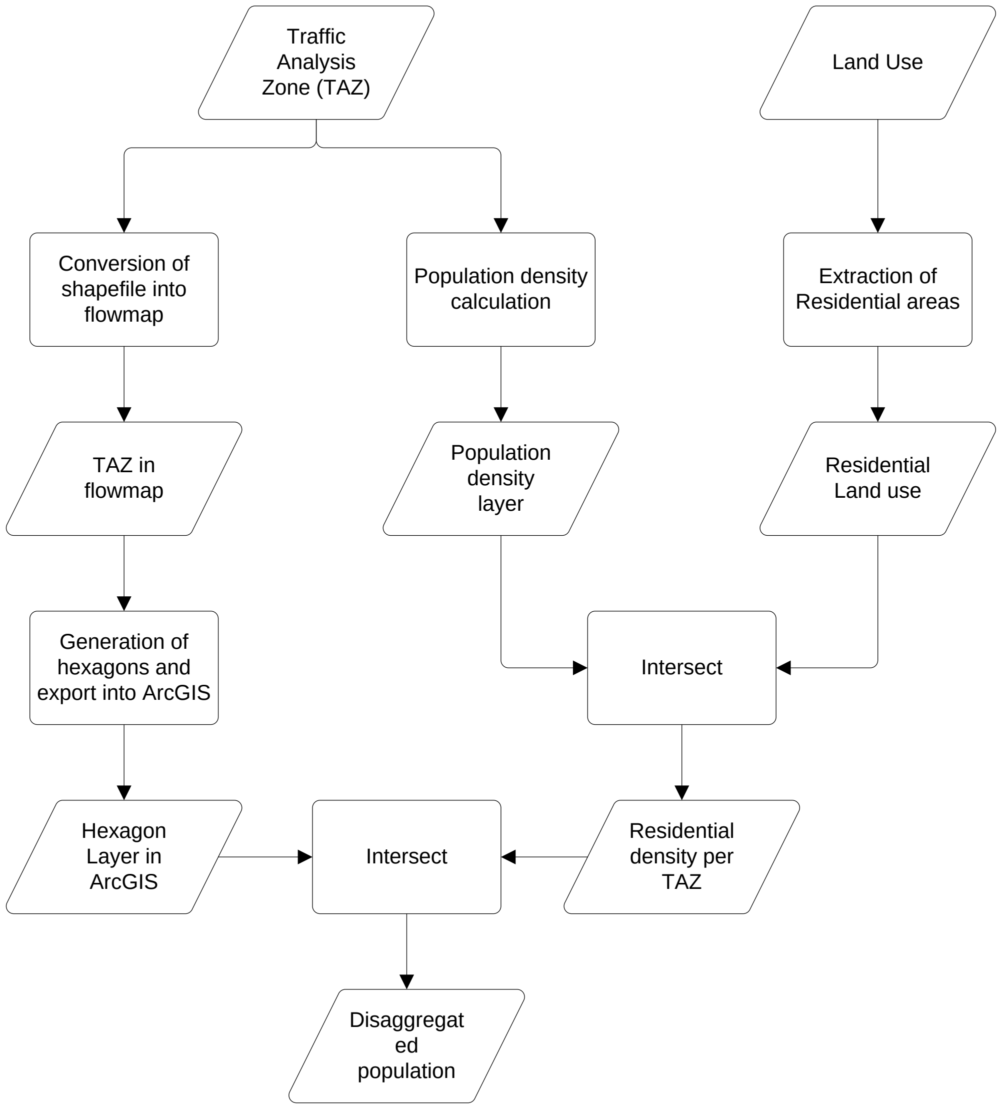

Figure 5-3: Population disaggregation flowchart

5.4. Network Analysis

5.4.1. Building Network Dataset

In order to calculate the distances from each point of departure to the bus stops, a network needed to be built. The network dataset was therefore built from the road layer in ArcCatalog. The length of the road segments were used as a cost for using the road network. Commuters were allowed to make any kind of turns at any intersection throughout the network without incurring any cost. There was no distinction in the driving direction. The same cost was therefore going to be attained for moving in both directions on the road network.

Most bus stops were realised to be either on road segment or very close to them. However the departure points were seen to be off the road network. Snapping of departure points to the closest facility was going to introduce errors in calculating the distances. Euclidean distances were therefore calculated from each origin point to the closest road layer. To approximate this to a network distance, it needed to be multiplied by a detour factor. This factor was estimated for the road network of Pune.

5.4.2. Estimation of detour factor

The lack of local roads in the road network meant that some of the demand points were not going to be connected to the road. To get them connected the snapping tolerance during the closest facility analysis need to be big to get all demand points to participate in the analysis. This was however going to create errors in the determination of distance from each demand point to the bus stops. Two demand points sharing the same closest road and lying on a perpendicular line to the road where thus going to have the same distance to a bus stop if that is the closest facility on the network. To help reduce this error, the Euclidean distances from each demand point to the nearest road were calculated.. To approximate these Euclidean distances to network distances; there was the need to multiply it by a detour factor. The detour factor for the road network in Pune was calculated as follows;

The bus stops were used in the estimation of the detour factor since most of them are located either on or close to the road network. All bus stops more than 5 meters from the road network were excluded to reduce the errors in determining the network distances to each other.
One point (bus stop) located in the central part of the city was selected to be travelled to. Using this selected point as the facility and the other points (bus stops) as the incident, a closest facility analysis was done. This resulted in network distances from each incident to the facility.
Using the near function, the Euclidean distance from the incidents to the facility was also attained.
To get the detour factor, the network distance was divided by the Euclidean distance per incident point. An average was then found of all the resultant detour factors. A generalised detour factor of about 1.2 was found for the Pune road network available.

5.4.3. Closet Facility Analysis

Based on the idea that commuters would use the nearest bus stop to their origin, the closest facility analysis (figure 5-4) was used to calculate the distance and time taken for each commuter to move from their origin to the closest bus stop. During the analysis, origin points were to be snapped to the closest road network since very local road networks to connect them were not available. This meant that points closer to the road networks and those far sharing the same road network as their closest road network was going to have the same travel time and distance. To help minimize this error, the Euclidean distances from each of the origin points to the closest road network was calculated. This was then multiplied by a detour factor of 1.2 to approximate it to a network distance. This helped in simulating the model much better as locations farther away from the road networks were indeed given a higher cost of travel as compared to those closer.

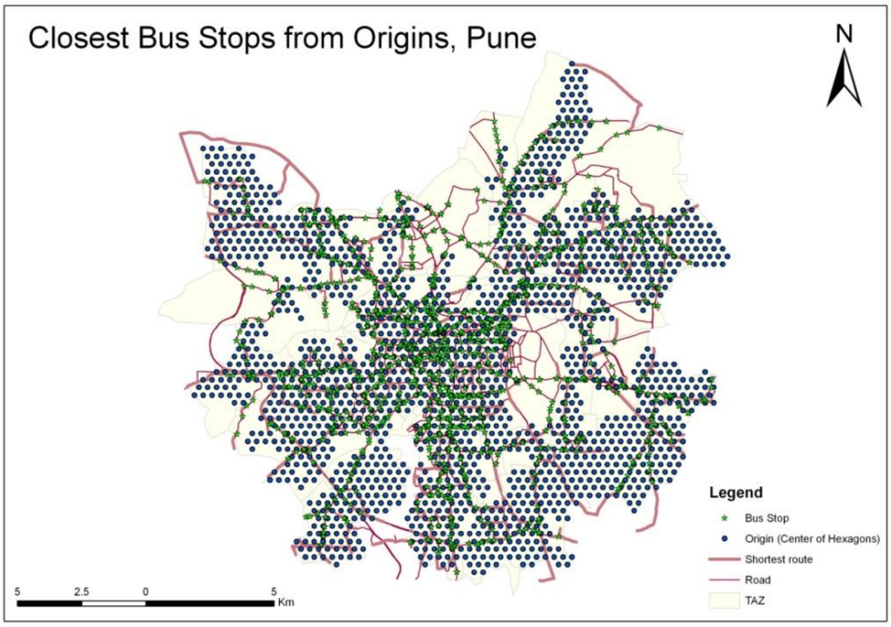

Figure 5-4: Closest Bus stops from origins

5.5. Optimization Model

5.5.1. Bus Stop Prioritization

Using the maximum coverage model, the bus stops were prioritized based on potential demand at each stop. CommunityViz and ArcGIS Desktop extension were used in the setting up of the model. This software was used because of its dynamic attribute features and flexibility in using conditional syntax which was needed in the calculation of the demand per bus stop. Commuters were to be selected and summed up according to their closest bus stops. These selections involved the use of conditional syntax. Analysis performed can easily be visualized because of its integration with ArcGIS.

With the integration of bicycle and bus as the main focus, only the decay function for the bicycle mode of transport was used in the calculation of the potential commuters in each hexagon. Each demand point was assigned to the closest bus stop to it assuming commuters go to the closest bus stop. The distance from each demand point was then calculated to its closest bus stop. The demand was then calculated using the distance and the decay function.

A standard distance thresholds of 0.4 kilometers and 3 kilometers (O'Sullivan and Morrall 1996; Martens 2004) were used for walking and cycling to bus stops respectively. This was so because the threshold of about 6.5 kilometers and 9.5 kilometers attained from the modal distribution curves were too long as compared to the standard distance thresholds. Commuters making these long trips were therefore considered to be captive riders. The introduction of public transport was however going to change them from captive riders to choice riders. Commuters living within 0.4 kilometers to bus stops were considered to walk to bus stops and thus excluded from the model. Only cycling commuters within 0.4 to 3 kilometers from bus stops were included in the calculation. To do this a binary operation was set up. A value of one was assigned to demands within 0.4 to 3 kilometers from the closest bus stops with the rest attaining a value of zero.

The potential number of commuters at each bus stop was then calculated. This was done by finding the sum of the multiplication of the potential demand and the decision factor of all origins having that particular bus stop as the closest bus stop.

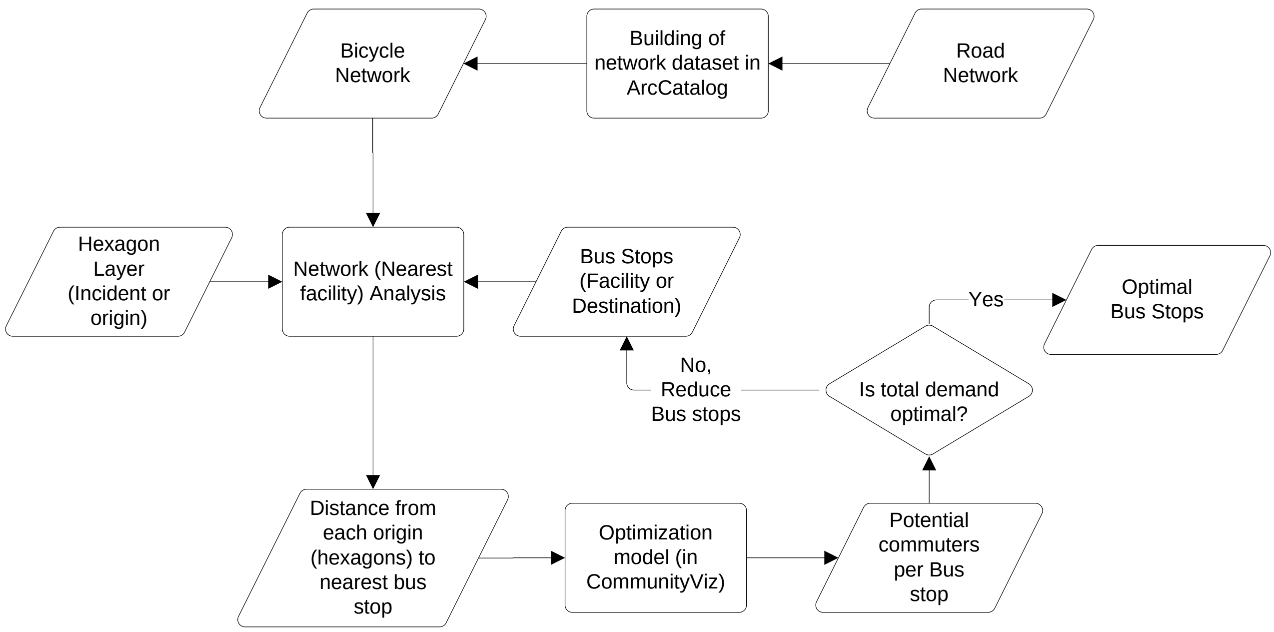

Figure 5-5: Bus stop prioritization flowchart

5.5.2. Reduction Model

To find the optimal bus stops required for covering all potential commuters, a reduction model was adopted in removing the redundant bus stops. This was to determine which of the bus stops would serve as candidate as transfer stations for bicycle bus integration. It was assumed that commuters which were served by the removed bus stops would be attracted to other bus stops if they are still within the distance thresholds. The total potential commuters served, was expected to decline after a certain number of bus stops. This point was considered to be the optimal point yielding the optimal number of bus stops and spatial location giving the maximum potential coverage. The reduction model was terminated at this point where the total potential commuters starts to decline. In doing this reduction model, a criterion needed to be set up by which bus stops would be removed.

Two criteria were used in the reduction model for comparison; thus reduction by the potential demand at each bus stop and reduction by using the farthest distance within 3 kilometers been served by a bus stop.
The first ideology when prioritizing facilities to be upgraded was to determine the potential demand served by each facility. Facilities with potential higher demands will have the highest revenue return and as such would be upgraded first. With this criteria, bus stops with the highest potential cyclist would be upgraded with bicycle infrastructures first. However, this criterion does not give an assurance of a maximum spatial coverage. With population distribution of most cities been much concentrated in the central part than at the fringes, bus stops in the fringes were going to be removed leaving these areas inaccessible. This may therefore not give the largest spatial coverage of the bus stops.

The second criterion looks at keeping bus stops with farther demand areas served. This means that if a bus stop serves a demand area with a small number of potential commuters that are located far but within three kilometers from the bus stop, it will not be removed. This ensures that the demand areas on the fringes of the city with low commuters which are usually far from bus stops be kept in the reduction process. In doing this the initial catchment coverage of bus stops is maintained even as the number of bus stops is reduced.

5.5.2.1. Reduction by Using Potential Demand

The potential cycling demand within 0.4 to 3 kilometers (the generalized walking and cycling distance thresholds) to each bus stop was calculated as described earlier. Bus stops attracting the least potential commuters, thus below the 25th percentile were removed from the next iteration. The number of bus stops, total potential walking demand and the total potential bicycle commuters and total population covered were recorded (table 5-4). Using the selected bus stops (above the 25th percentile), the heuristic reduction model was re-run. It was expected that, the total potential commuters served would start to decline giving a certain number of bus stops. The reduction model was terminated at this point where the commuters starts to decline.

Twelve iterations were made using this criterion for reducing bus stops. A total number of 1540 bus stops were used in the reduction model (table 5-4). Even though this number of bus stops gave the highest number of non-motorized transport commuters, it did not induce the highest number of potential cyclists. This was so because of the large number of demand areas being close to bus stops which were below 0.4 kilometer, the threshold for walking modes.

Plotting the number of bus stops against total potential cycling demand yielded the eleventh iteration to be the turning point, serving potential commuters of about 324,000 with 27 transfer stations (figure 5-6). A total number of 1217 demand points were served. A plot of the number of bus stops against the total population served (figure 5-7) showed the third iteration to be the turning point covering the same number of people of about 2940963 as with the initial situation with 286 bus stops.

Table 5-4: Reduction Results using Demand Criterion

Iteration	Number of Bus stops	Total Potential Demand Covered			
		Bicycle	Walking	NMT	Population
1	1,540	121,814	1,707,786	1,829,600	2,940,963
2	382	238,279	755,278	993,557	2,940,963
3	286	244,744	706,040	950,784	2,940,963
4	214	257,812	613,154	870,966	2,938,289
5	160	270,771	524,346	795,117	2,932,005
6	120	282,086	459,037	741,123	2,920,338
7	90	295,473	377,665	673,138	2,908,154
8	67	308,264	290,469	598,733	2,866,852
9	50	319,623	220,855	540,478	2,831,673
10	37	322,850	176,992	499,842	2,769,695
11	27	324,341	118,329	442,670	2,676,592
12	20	307,623	97,201	404,824	2,492,852

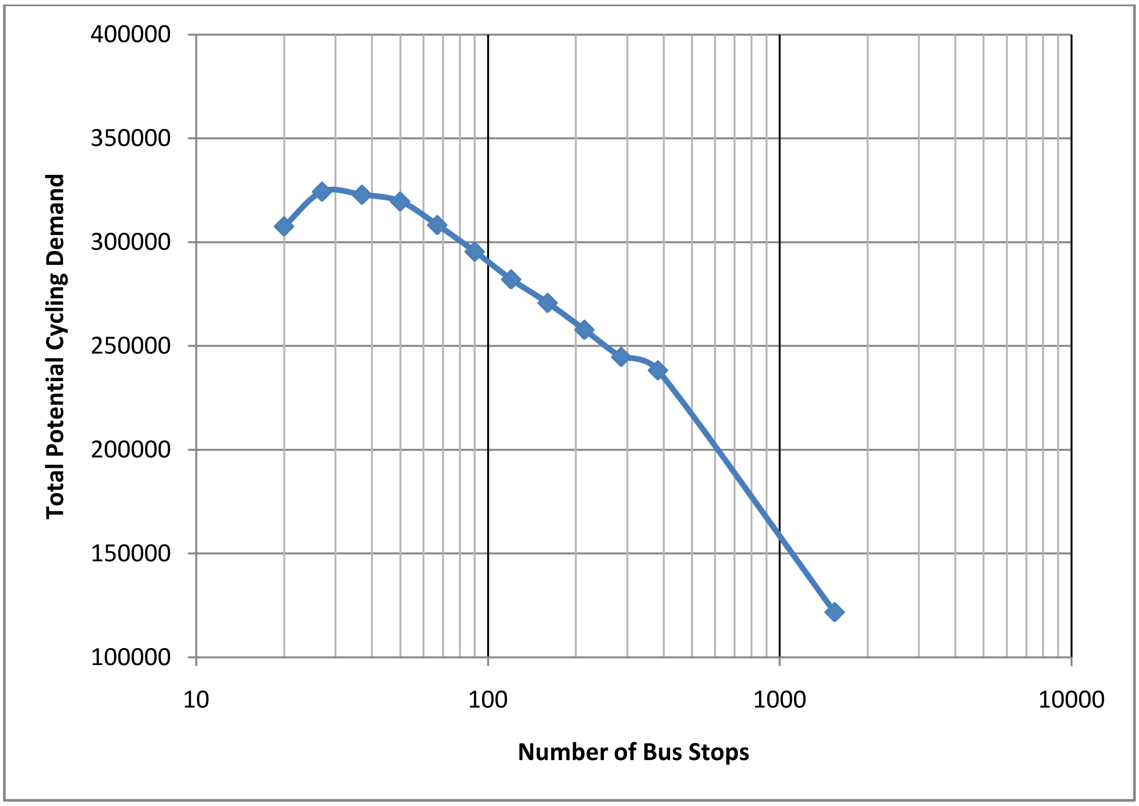

Figure 5-6: Total Potential Cycling Demand using Reduction by Demand

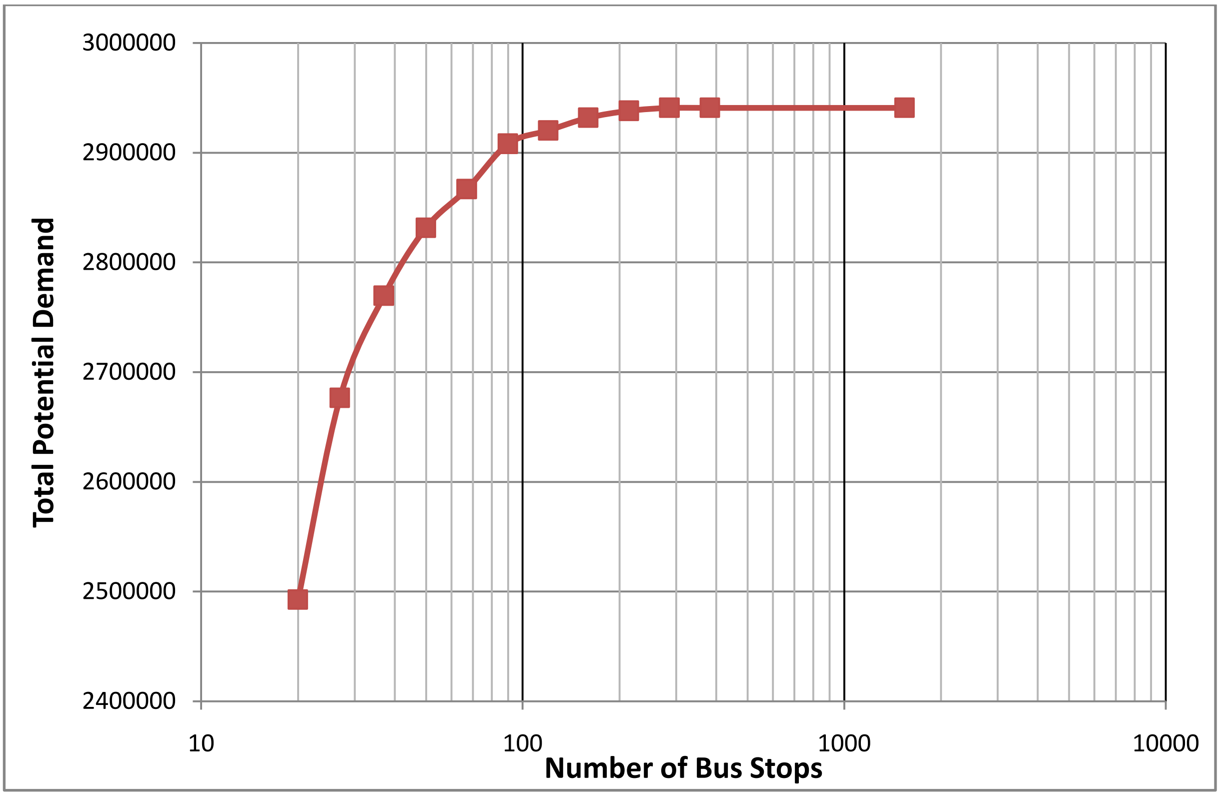

Figure 5-7: Total Population Covered using Reduction by Demand

Using a three dimensional scatter diagram, the total population served and total potential cycling demand was plotted against number of bus stops (figure 5-8). Two optimal points were realised depending on the policy used. An increase of total potential cyclists was observed with an increase in total potential population served as the number of bus stops reduces till the 3rd iteration indicating maximum spatial coverage. Beyond this point, the total population covered started to decrease even though the total number of potential cyclists was increasing until after iteration 11 after which the total potential cyclist also started to decrease. In considering both policies, iteration three would be considered the optimal. However reduced bus stops were not going to be demolished and as such the spatial coverage of all bus stops are going to remain constant. Because of this, the maximal spatial coverage could be ignored and increasing bicycle-bus commuters focused on. This would therefore result in 27 bus stops serving as transfer stations for about 324,300 bicycle-bus commuters been the optimal bus stops.

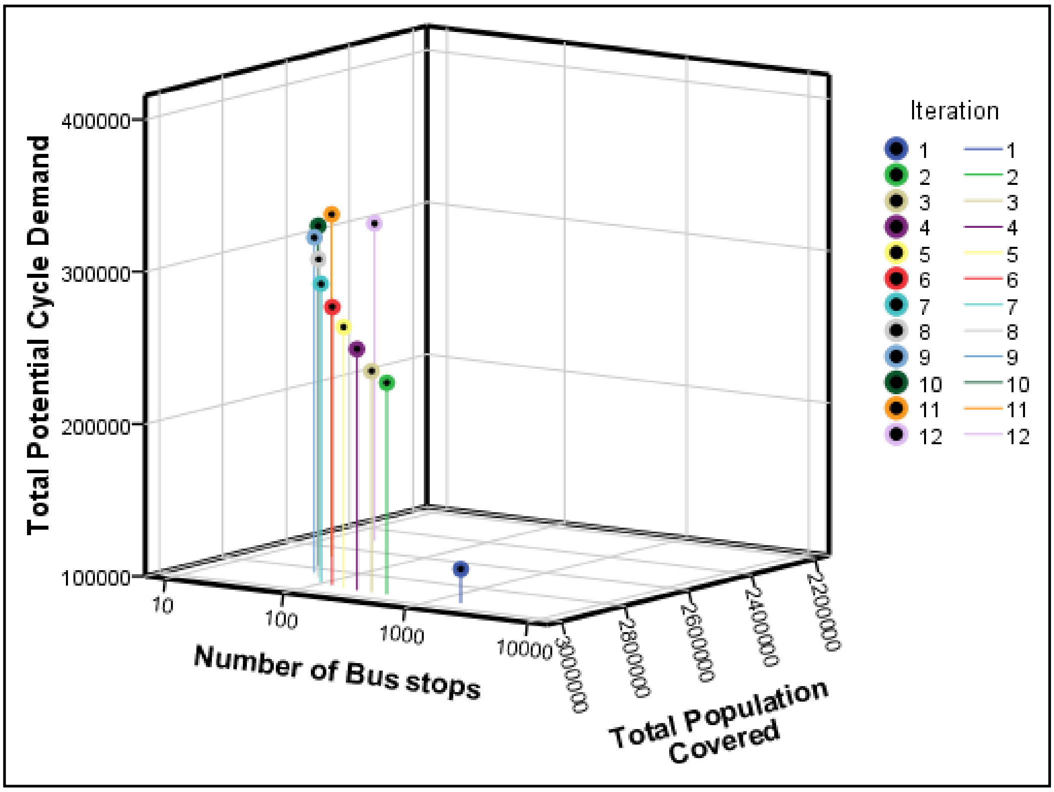

Figure 5-8: 3D Scatter plot (Reduction by Demand)

5.5.2.2. Reduction Using Distance

With the large difference between the number of bus stops with the maximum spatial coverage and that for the maximum bicycle-bus commuters served, the reduction by distance which was to keep the spatial coverage constant as initial was done. The distance from each demand point to the closest bus stop was calculated. The potential demand was also calculated to keep a check on the maximal coverage point. From the demand points assigned to each bus stop, the farthest demand point was determined. The distance to that demand point was recorded and attributed to that bus stop. A quartile classification of four classes was then made of the farthest distance attribute. The bus stops falling below the 25th percentile was removed and the rest of the bus stops used in the next iteration. It was assumed that if bus stops are close to each other, the potential coverage per each bus stop is going to be reduced due to the assumption that commuters use the closest bus stop. This may result in redundant bus stops and can be removed from the prioritization for non-motorized infrastructures.

The number of bus stops, total potential walking demand and the total potential bicycle-bus commuters and total population covered were recorded after each run (table 5-5). Once again the maximum number of bus stops, even though yielding the highest non-motorised transport commuters, could not induce the highest bicycle-bus commuters. From the table, reductions in the total number of non-motorised commuters as the number of bus stops reduced were observed even though bicycle-bus commuters were increasing. To know the number of bus stops providing maximal bicycle-bus commuters served and maximal coverage, the number of bus stops, total potential cyclist and the total population covered were plotted.
After the ninth iteration, the total number of potential cyclist served started decreasing when plotted against the number of bus stops (figure 5-10). Total bicycle-bus commuters of about 356,000 potential

cyclists were served with 47 bus stops serving as transfer stations. However this was not the number of bus stops with the largest spatial coverage, thus covering the highest population. The sixth iteration with 114 bus stops was seen to be the turning point after which the spatial coverage started reducing (figure 5-11).

Table 5-5: Reduction results using Distance Criterion

Iteration	Number of Bus stops	Total Potential Demand Covered			
		Bicycle	Walking	NMT	Population
1	1,540	121,814	1,707,786	1,829,600	2,940,963
2	382	238,279	755,278	993,557	2,940,963
3	286	249,484	673,024	922,508	2,940,963
4	211	271,255	523,205	794,460	2,940,963
5	154	290,790	423,953	714,743	2,940,963
6	114	311,919	316,325	628,244	2,940,963
7	84	336,478	208,792	545,270	2,917,887
8	63	346,697	162,131	508,828	2,905,389
9	47	356,425	129,921	486,346	2,869,223
10	33	353,947	90,564	444,511	2,737,662
11	22	313,818	64,591	378,409	2,360,969

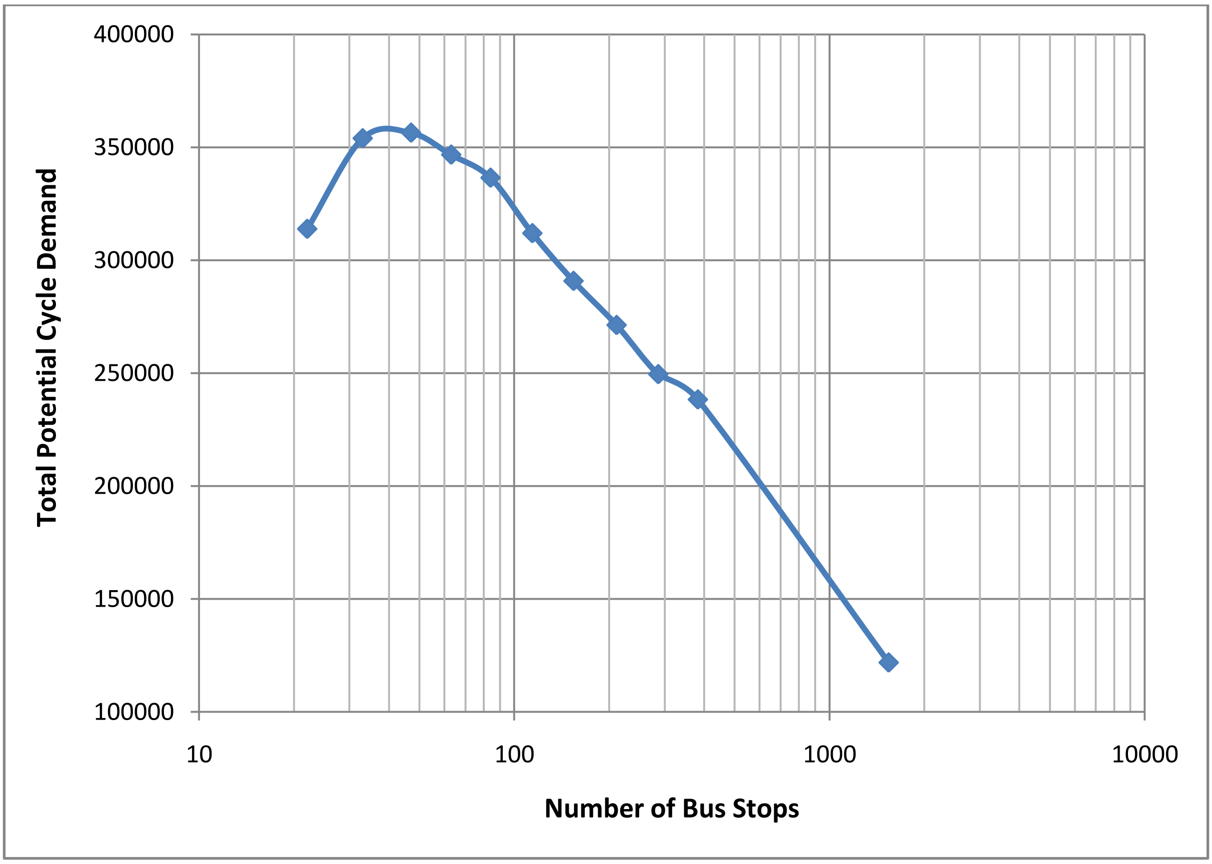

Figure 5-9: Total Potential Cycling Demand using Reduction by Distance

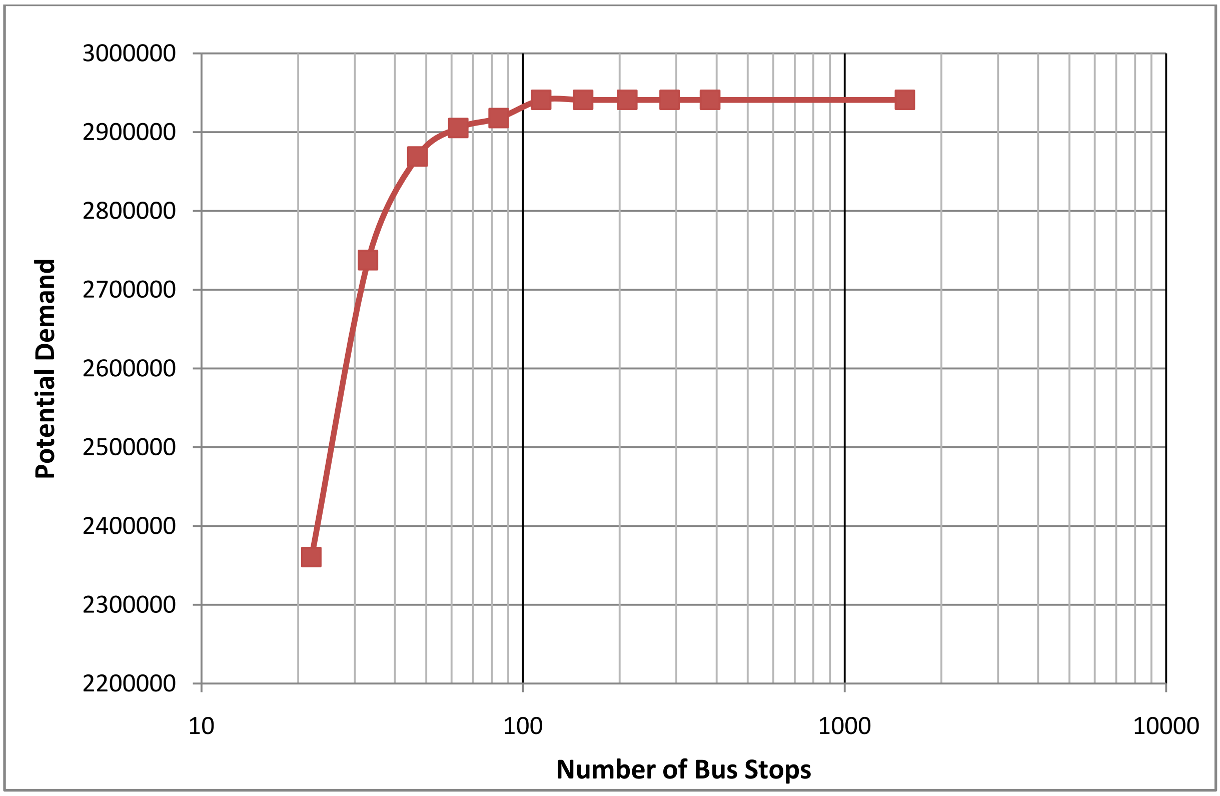

Figure 5-10: Total Population Covered using Reduction by Distance

A 3D scatter plot of the number of bus stops, total population covered and total number of potential bicycle-bus commuters served (figure 5-12) was done as a comparison. The plot shows an increase in both total number of potential bicycle-bus commuters served and the total population covered till the 6th iteration. After this point, the number of population covered started decreasing while the total potential bicycle-bus commuters was still on the increase till the 9th iteration after which both started decreasing. Iteration six was considered to be the turning point when considering both the demand points and total cyclist served. Thus 114 bus stops were considered to be optimal covering about 2,940,900 of the population and serving about 311,900 bicycle-bus commuters. With the reality that the reduced bus stops are not going to be demolished, this spatial coverage is going to be maintained and could be ignored in determining the optimal number of bus stops. Focusing on inducing the highest bicycle-bus commuters, the 9th iteration would be considered optimal. This had 47 bus stops serving about 347,000 potential bicycle-bus commuters.

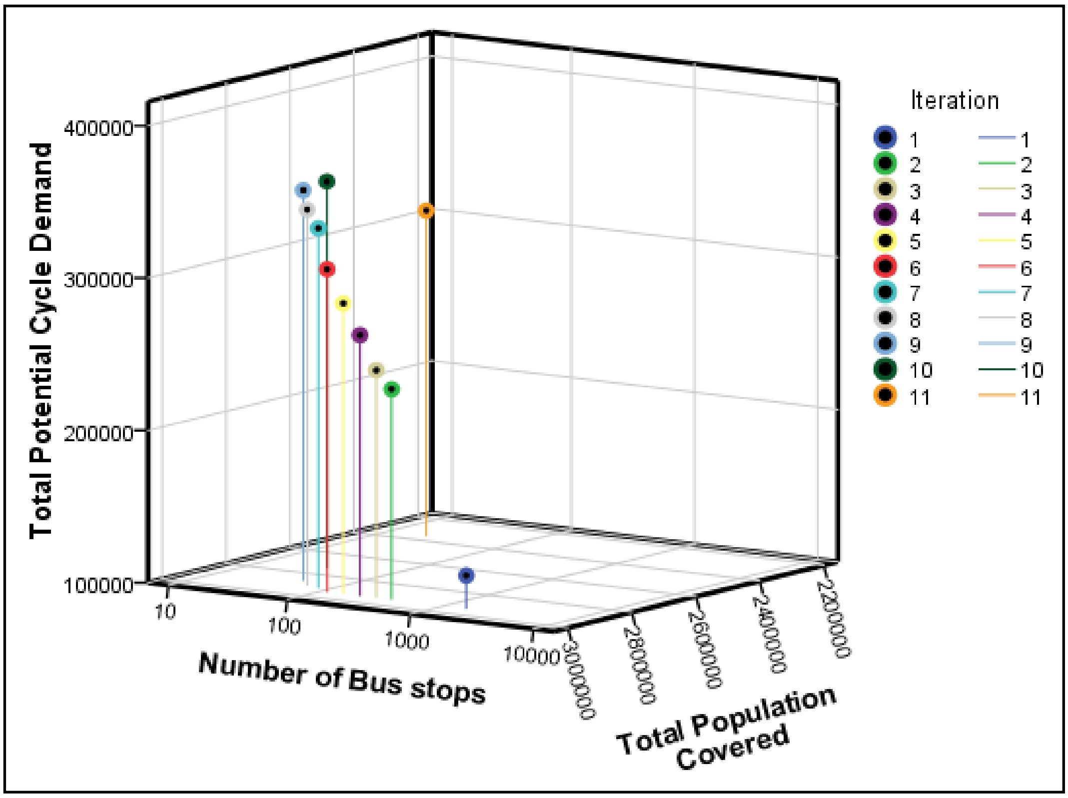

Figure 5-11: 3D Scatter Plot (Reduction by Distance)

In comparing the two reduction criteria, the total potential bicycle-bus commuters served was plotted against the number of bus stops for both criteria (figure5-13). The reduction by farthest distance criteria was seen to serve the highest number of bicycle-bus commuters of about 356,000 with 47 bus stops. The reduction by demand criterion produced 27 bus stops serving about 324,000 bicycle-bus commuters. Even when 27 bus stops which were the optimal for the demand reduction criterion was considered, the reduction by distance criterion serves higher potential bicycle-bus commuters. It was therefore clear that the reduction by farthest distance produces a much better reduction model than the reduction by demand.

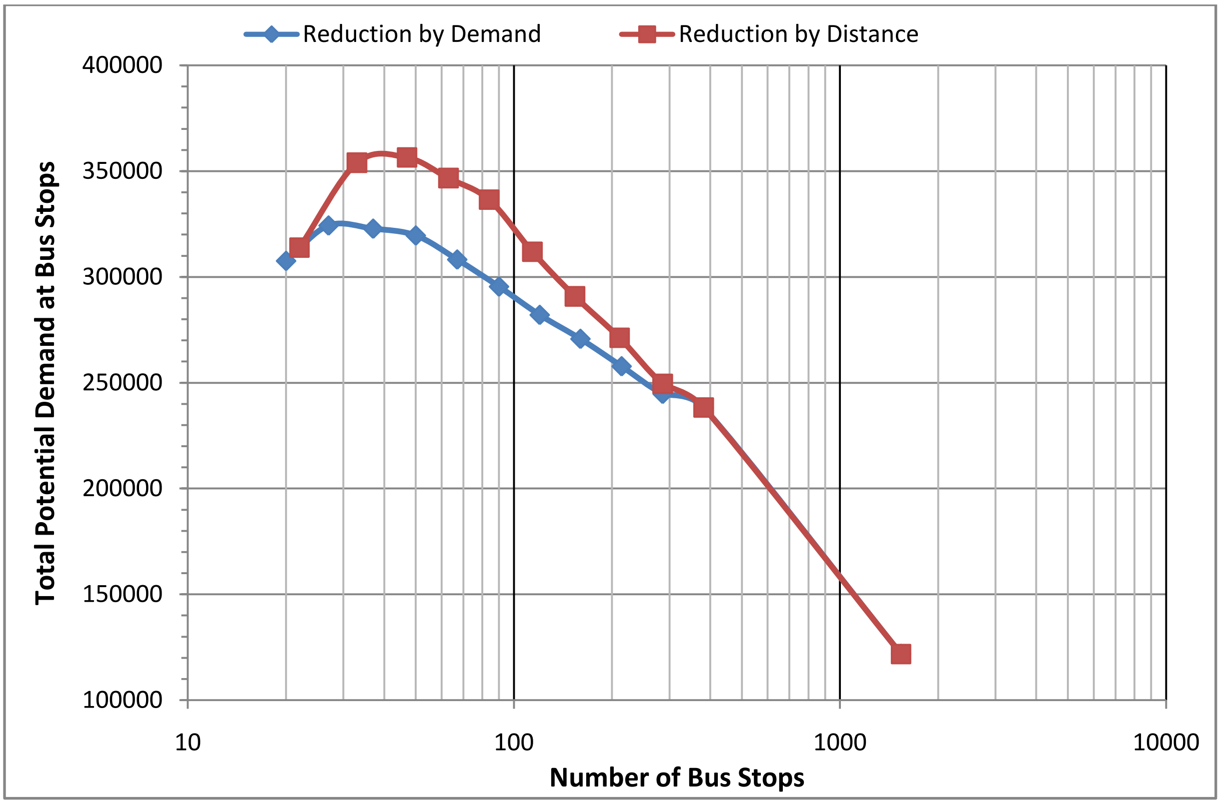

Figure 5-12: Comparison plot between reduction criteria

The 47 bus stops which were seen to be optimal serving the highest potential bicycle-bus commuters, were seen to be well distributed spatially (figure 5-14). They were spatially distributed over the whole city. Most of these bus stops were found in the medium to low densely populated areas. Using the potential bicycle-bus commuters at each bus stop, they could be prioritized for the provision of bicycle parking facilities. Again a quartile classification with four classes was used in the classification of the potential demand served by each bus stop. A detailed demand is presented in table 5-6. Most of the highly prioritized bus stops were located around the central part of the city where demand is high with the low prioritized bus stops found on the fringes of the city.

A coverage map of the optimal number of bus stops (figure 5-15) was produced to identify the areas served and compared to the coverage map of the initial condition (figure 5-16). From the two maps, a substantial increase in areas theoretically transformed from walking distance to cycling distance was observed. Also evident is an increase in the area beyond the cycling threshold even though they are small as compared to those transformed to cycling distances.

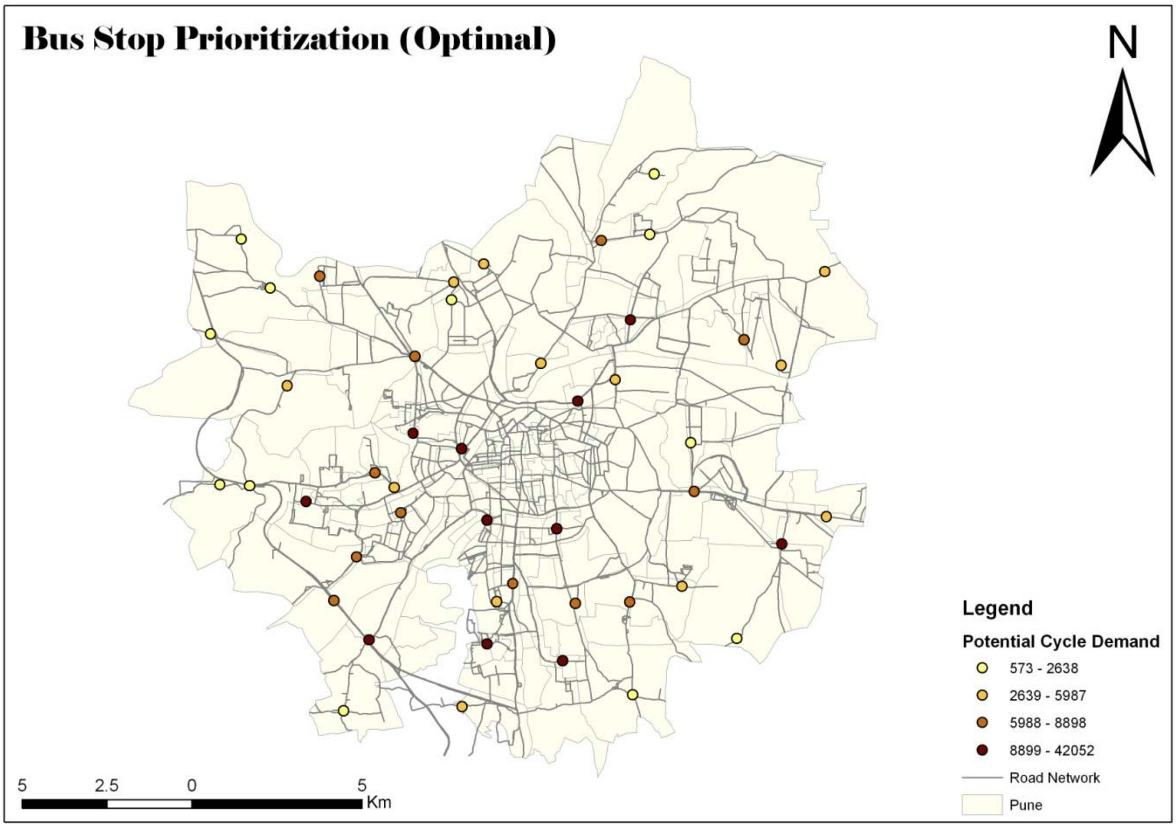

Figure 5-13: Bus Stop Prioritization (Optimal Case)

Table 5-6: Potential Demand at Bus Stops (Optimal)

Priority	Name of Bus Stop	Potential Bicycle-Bus Commuters	Total Population Covered
1	Gultekadi Bus Stop	42,052	313,153
2	Parvati Payatha	25,200	205,200
3	Prayag Hospital	23,022	175,445
4	Sohrab Hall Bus Stop	21,879	163,337
5	Netaji Subhashchandra School Bus Stop	18,396	147,564
6	Dhankawadi Last Stop	13,065	108,179
7	Upper Indira Nagar Last Bus Stop	12,451	98,155
8	Symbiosis Bus Stop	11,782	93,281
9	Ganesh Nagar Bus Stop	9,774	81,241
10	Sasane Nagar Bus Stop	9,464	75,432
11	Vadagaon Budruk Bus Stop	9,036	69,504
12	Kalubai Mandir	8,898	72,443
13	Kasturba Wadi / Vasahat Bus Stop	8,714	69,606
14	Karve Nagar Bus Stop	8,392	77,720
15	Natu Baug	7,823	64,992
16	Datta Mandir	7,770	62,799
17	University Bus Stop	7,767	59,701
18	Ganesh Nagar Bus Stop	7,596	62,422
19	Sant Gadge Baba Bus Stop	7,177	58,996
20	Ganga Dham Last Bus Stop	7,085	53,832
21	Warje Malwadi Bus Stop	6,992	58,899
22	Ideal Colony Bus Stop	6,367	54,434
23	Laxmi Mandir Bus Stop	6,301	49,012
24	St Meera College / Blue Diamond Bus Stop	5,987	46,574
25	Paud Phata Bus Stop	5,688	50,781
26	Salunke Vihar Last Bus Stop	5,133	44,215
27	Ravi Darshan Bus Stop	4,489	45,391
28	Ramyanagri Bus Stop	4,018	29,279
29	Power House Bus Stop	3,687	32,383
30	Sangamwadi Bus Stop	3,669	28,886
31	Sainath Nagar	3,602	29,604
32	Janak Baba Darga Bus Stop	3,492	27,332
33	B & C Colony Bus Stop	3,381	33,364
34	Khadaki Station Bus Stop	3,198	31,350
35	Dehgaon Yearwada Station 329 Bus Stop	2,708	19,151
36	Kalashankar Bus Stop	2,638	20,872
37	Baner Gaon Bus Stop	2,304	17,883
38	Teccan Bus Stop	2,205	28,319
39	Munjaba Vasti Last Bus Stop	2,190	18,249
40	Chandani Chowk Bus Stop	2,026	16,278
41	Khadi Machine Bus Stop	1,915	14,845
42	Dhayari Gaon Bus Stop	1,681	13,983
43	Sub Bridge Bus Stop	1,675	13,571
44	Regional Office Bus Stop	1,475	11,808
45	Mahamdvadi Last Bus Stop	857	7,417
46	Laxmi Mata Mandir Bus Stop	830	7,028
47	Athashree Foundation Bus Stop	573	5,313

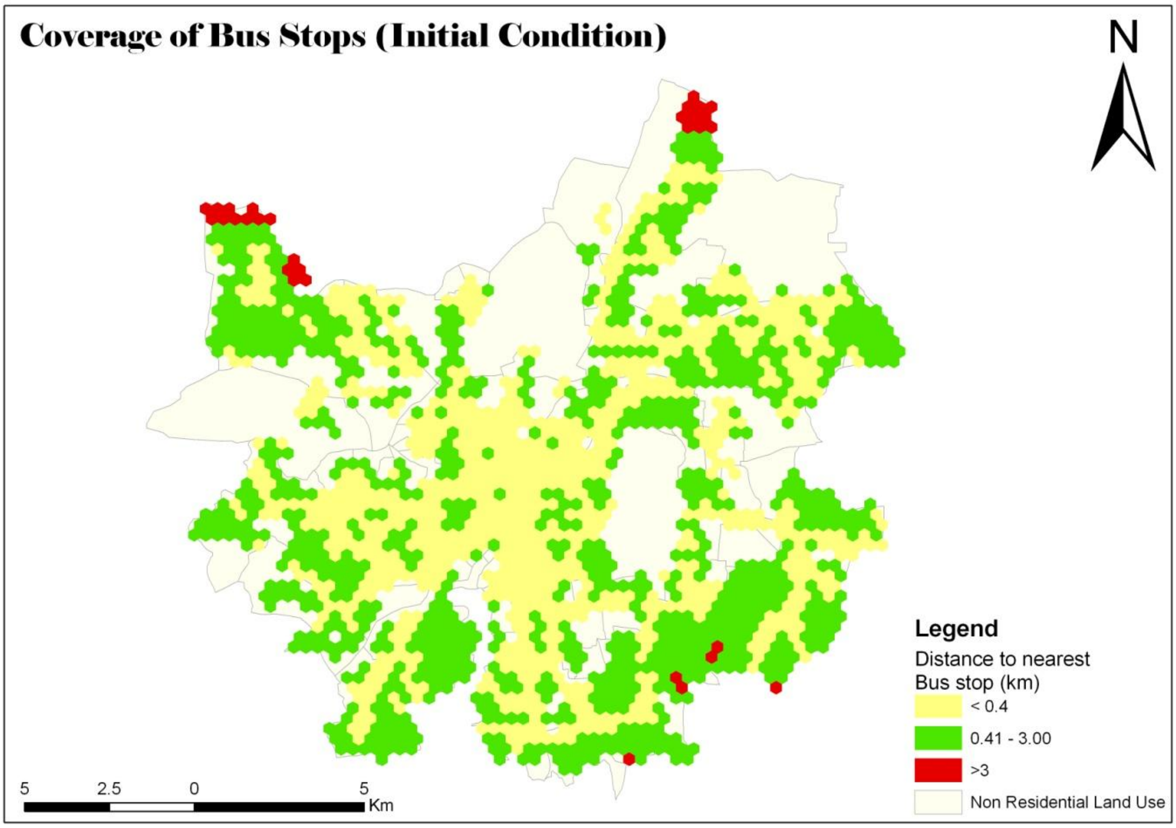

Figure 5-14: Initial Coverage of Bus Stops

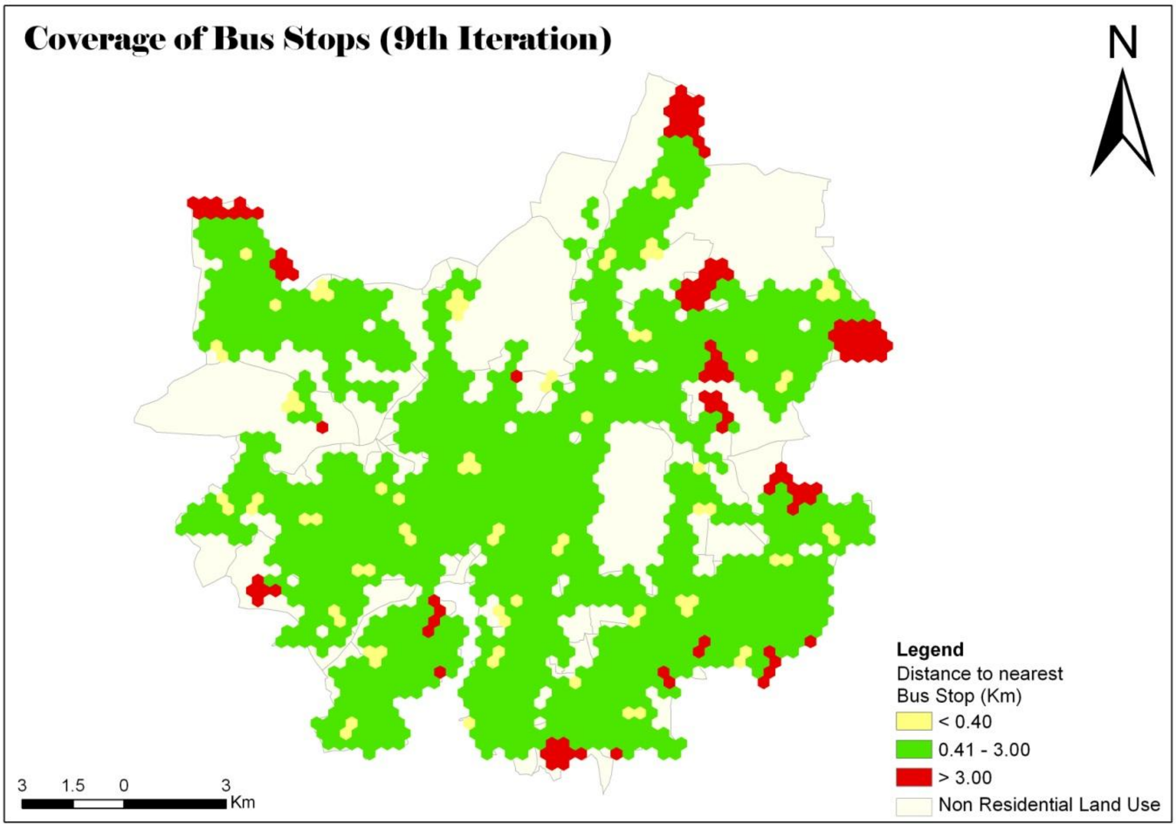

Figure 5-15: Coverage of Bus Stop (Optimal)

5.5.3. Route Prioritization

After knowing the number of bus stops for optimal results and their location, bicycle access needed to be provided to them. With financial constraints still a factor, these access roads might not all be upgraded and as such needed to be prioritized for the provision of bicycle infrastructures. The entire road network was used in the route prioritization process. The bus stops producing the optimal solution was used in this prioritization.

The distance from each demand point to the closest bus stop was calculated using the closest facility tool with the road network. The potential number of cyclist in each hexagon was calculated using the modal function for cycling based on the calculated distances. This resulted in the potential bicycle-bus commuters in each hexagon its closest bus stop.

The hexagon layer was then intersected with the road layer to get the potential cyclist in each hexagon onto the road passing through it. A network dataset was then built using the resulting road network. The task was to pick the route leading to the bus stops with the highest cyclist demand along the route. With the closest facility algorithm in ArcGIS picking the route with the least cost, using the potential demand as a cost of using the road segment in the network was going to yield a route having the least demand along it. The multiplication inverse of the potential cyclist was then used as the cost of traversing a road segment. In this case, the closest facility would be choosing the route with the highest cyclist demand on route to the bus stops whiles using the least cost algorithm.

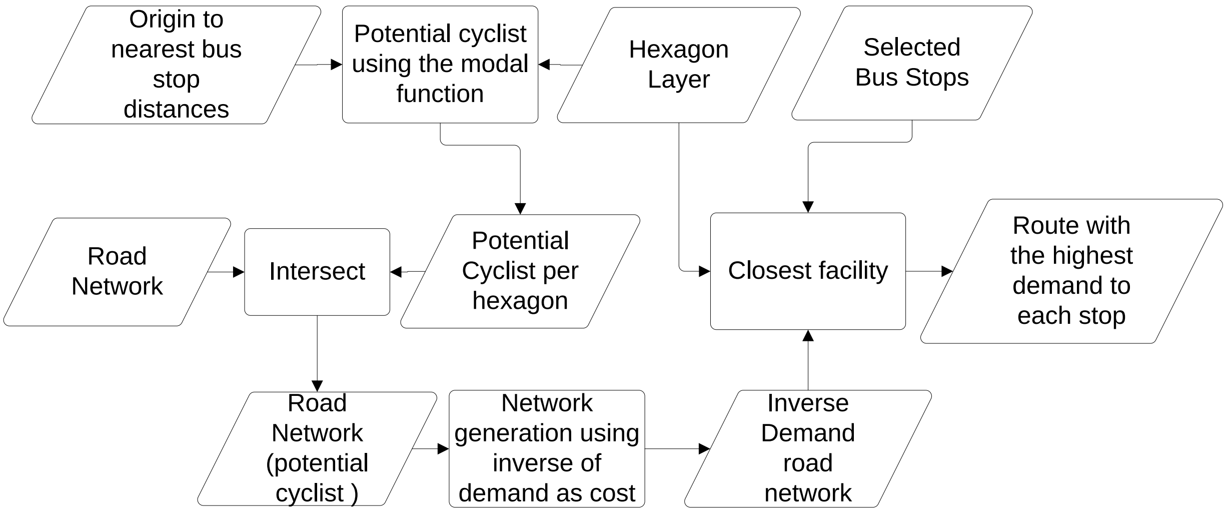

Figure 5-16: Route Prioritization flowchart

Most of the highly prioritized routes for upgrading were found in the south-western part of the city with those in the central parts within medium prioritization (figure 5-15). From the prioritization, it could be seen that most of the routes close to bus stops were classified as medium to low priority roads for non-motorised infrastructures. This was because of the assumption that all commuters with distance below 0.4 km to bus stops were predominantly walking mode and was ignored. However, the provision of bicycle lanes and paths must be continuous up to the each bus stop in order to encourage bicycle-bus commuters. These could therefore be ignored when providing bicycle lanes and paths.

Also most of the roads on the outskirts of the city were classified as low priority roads because of the low potential bicycle-bus commuters in these areas.
It must also be noted that, these routes might not necessarily be the shortest routes from these demand areas to the bus stops but it accrues the highest potential commuters.

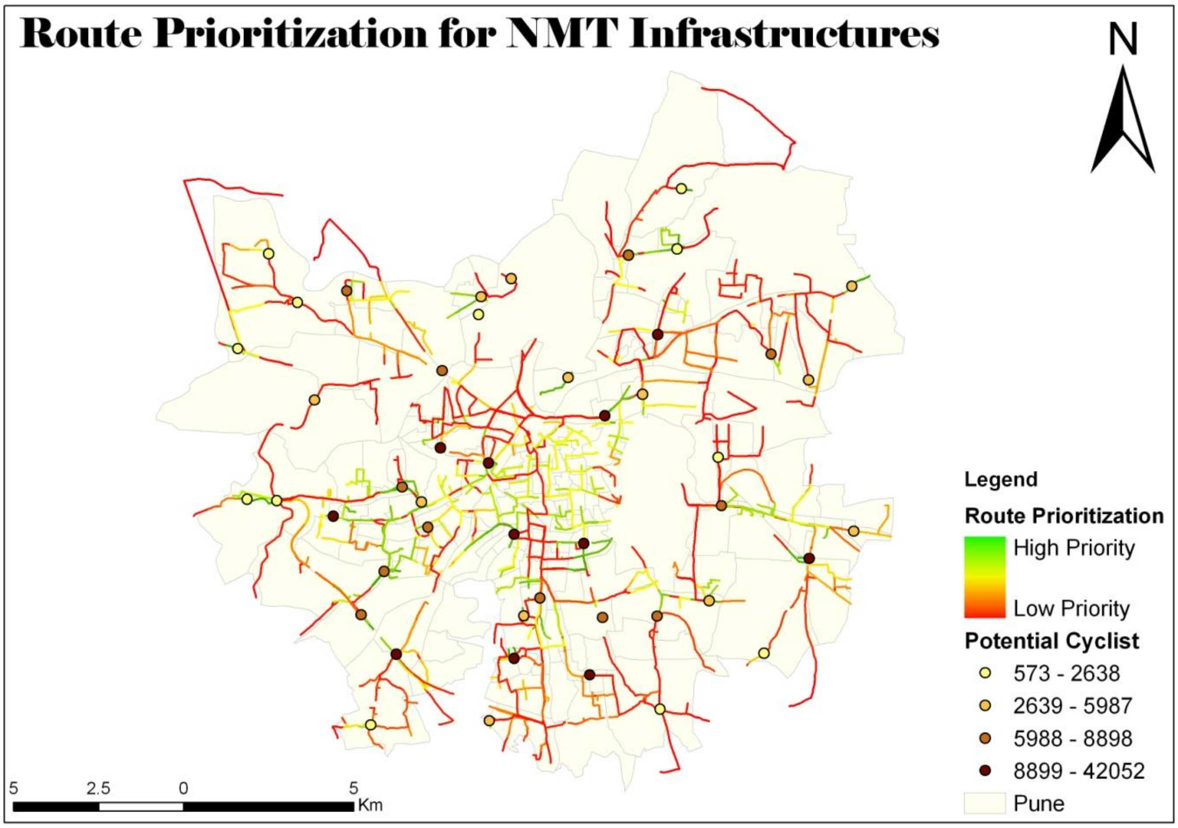

Figure 5-17: Route Prioritization for NMT Infrastructures

6. Discussions

6.1. Introduction

In the previous chapter, a detailed analysis and results for prioritizing bus stops and access routes for the provision of non-motorised infrastructures were done. In order to do this, a modal distribution curve was formulated to aid in the determination of potential bicycle-bus commuters from each origin point. This was then used in prioritizing the bus stops. Considering the number of bus stops, a heuristic reduction model was developed to determine to number and spatial location of bus stops serving the highest bicycle-bus commuters. After the determination of these bus stops, the access routes were also prioritized.

This chapter now discusses critically the outcomes of the analysis considering some literatures. Explanations to these outcomes were going to be sought to the findings resulting from the analysis.

6.2. Modal Distribution

The modal curve was done for modes including; walking, cycling, cycle rickshaws, scooters and motor-cycles, private cars, and public transports including auto rickshaw, bus, taxis, and trains. These were seen to be the various modes of transport for the people of Pune. However, the two modes of focus were walking and cycling and are discussed here.

As expected most of the trips less than one kilometer were predominantly made by walking with a sharp decrease in modal share as the distance becomes longer. From the curve, it was observed that commuters were willing to walk for about 6.5 kilometers from their origin to their destination.

The bicycle modal curve also followed an expected curve. Increasing over some few kilometers and decreasing gradually as the distance become longer. A distance of about 9.5 kilometers was observed to be the allowable distance commuters were willing to cycle from their origin to their destination.

These trips were not trips made in access bus stops but rather general origin-destination trips. In considering trips made in accessing bus stops, these distances of 6.5 and 9.5 kilometers for walking and cycling were considered to be very long as compared to the generalized distance of 0.4 and 3 kilometers for walking and cycling respectively (Ontario Ministry of Transportation and Ontario Ministry of Municipal Affairs 1992; O'Sullivan and Morrall 1996) for accessing bus stops. It was considered to be for the captive riders in the society and was not used in the integration model.

These observed distances for walking and cycling could however be possible when considering a general origin-destination trips. These may be as a resultant of the cultural and economic condition of individuals coupled with the topography and climate conditions of the city (Scheiner 2009). With a developing nation where most of the people are considered to be poor, economic reasons may be a big contributing factor to these long distances obtained. Walking and cycling may be the only mode of transport accessible to most of the citizens. The other modes of transport may be financially or physically inaccessible to them. With the city located on top of a plateau, depicting its relatively flat topography, these long distance thresholds could be realised.

However if public transport is made accessible to everyone in terms of both physical proximity and bus transport fare, these distance thresholds could be reduced. Because of this the generalized distances of 0.4 and 3 kilometers for walking and cycling to bus stops respectively were used in the bus stop prioritization model for the calculation of the potential demands.

6.3. Bus Stop Prioritization

Now using these distance thresholds, the bus stops were prioritized for the provision of non-motorised facilities using the maximal coverage algorithm. The modal function resulting from the modal curve estimation was incorporated for a better determination of the potential commuters.

Two reduction processes were used in removing redundant bus stops and for the prioritization. In both cases an increase in the number of potential bicycle-bus commuters served as the number of bus stops reduced was observed until a certain number of bus stops (turning point) after which it started to decrease. The resultant number of bus stops was considered to be the optimal number serving the highest potential bicycle-bus commuters. This low number of potential bicycle-bus commuters served at the beginning of the analysis was due to the large numbers of bus stops in the city. This made most of the demand points having their closest bus stops within 400 meters reach. Walking mode was assumed to be the predominant mode of transport for residents below 400 meters to bus stops and as such, they were not considered to cycle and were removed from the model. As the number of bus stops reduced, the number of demand points with distance to closest bus stops falling below 400 meters reduces, increasing the number of potential bicycle-bus commuters served. However there was a point beyond which potential bicycle-bus commuters started reducing. This was considered to be the optimal number of bus stops serving the highest bicycle-bus commuters but not necessarily having the maximal spatial coverage.

For the maximal spatial coverage, the total number of the population covered was used in finding the optimal number of bus stops. In both cases, the population covered remained constant as the number of bus stops reduced until a certain number, after which the number of population covered started to reduce. This results in the optimal number of bus stops for maximum spatial coverage. After the third iteration, this spatial coverage for the reduction by demand started decreasing. Demand areas at the fringes of the city were made inaccessible because of their low population resulting in low potential bicycle-bus commuters. A total of 286 bus stops were realised. The reduction by the farthest distance criterion resulted in about 114 bus stops (less than 50%) having the same spatial coverage. This was expected as the stops were to retain their spatial coverage as they were reduced because the farthest demand area was still to be served. However this did result in the highest number of bicycle-bus commuters served as was expected. Even though the bus stops serving the farthest demand area were kept, the removal of some bus stops having the farthest area served been the smallest (thus below 25th percentile) could leave some of the areas to be beyond the cycling distance threshold to a nearest bus stop. This caused a reduction in the total population covered. The bicycle-bus commuters in these areas may not be as high as compared to those converted from walking distance to bicycle distance resulting in an increase in the potential bicycle-bus commuters even as the spatial coverage was reducing. The ninth iteration was seen to produce the highest potential bicycle-bus commuters (about 356,000) with 47 bus stops.

This number of bus stops was considered to be the optimal number of bus stops even though they did not have the maximal spatial coverage. Without the demolishing of the reduced bus stops, it was deemed that the maximal spatial coverage was going to be maintained even as the number to be upgraded for bicycle parking facilities reduced. Because of this the number of bus stops which were able to induce the highest bicycle-bus commuters was considered optimal.

Comparing the two criteria for reducing the bus stops, the reduction by distance was seen to be better. This provided 47 bus stops serving a total of about 356,000 potential bicycle-bus commuters as compared to the reduction by demand resulting in 27 bus stops serving about 324,000 potential bicycle-bus commuters.

6.4. Route Prioritization

Using the number of bus stops serving the highest potential bicycle-bus commuters, the routes leading to them were prioritized for the provision of non-motorized transport infrastructures such as bicycle lanes, bicycle phase in traffic lights etc.

Most of the roads closed to the bus stops were not classified as high priority roads for the provision of non-motorised transport infrastructures. This may be because of the exclusion of all living below 400 meters from their closest bus stops. It was considered that these people would dominantly walk to bus stops and as such they were excluded in the prioritization model. This resulted in no potential cyclist in these areas resulting in the low prioritization of roads closest to bus stops. However for commuters to use bicycle, lanes should be connected to bus stops and not be hanging. The upgrade of access roads should therefore cover these roads as well. Most of the roads following 3 kilometers from bus stops were also classified as roads with low priority. At these points, commuters were not expected to use bicycle as feeder modes to bus transports. The construction of bicycle lanes and paths in integrating bicycle to bus transport was therefore not deemed to be of priority.

7. Conclusion and Recommendations

7.1. General Conclusion

The use of bicycle as a feeder mode of transport to bus stop transport has been seen to increase its coverage. Commuters are however willing to make bicycle trips when non-motorised infrastructures are provided on access routes to bus stops. Financial constraints do not make the provision of non-motorised transport infrastructures at all bus stops and access routes viable. Little has however been done in prioritizing bus stops and access routes.

Using CommunityViz, the maximal coverage algorithm was used in prioritizing bus stops. A modal function was used in calculating the demand at each bus stop. The main goal of prioritizing bus stops and access routes for non-motorised infrastructure was attained using CommunityViz and GIS-based spatial analysis through a heuristic reduction model.

7.2. Results against research objectives

In drawing conclusion of this research, the research objectives and research questions stated in the first chapter were evaluated against the findings and observations.

- **To understand the travel behaviour of the people of Pune.**

  Through literatures and secondary data, nine main modes of transport were identified. These included walking, cycling, cycle rickshaw, auto rickshaw, scooters and motorcycles, private automobile, taxi, public transport and train. Among these modes of transport, the non-motorized modes of transport and the public bus transports were of interest. A hypothetical multi-modal distribution curve was developed.

- **Establish (hypothetical) multi-modal distribution curves for trip makers in Pune**

  Through curve fitting using Microsoft Excel, a modal function was developed, yielding distances of 6.5 and 9.5 kilometers as walking and cycling thresholds for non-motorised commuters of Pune. Although economic and topological factors could explain these results, they were considered very long compared to generalized distances of 0.4 and 3 kilometers for walking and cycling to bus stops. They were considered to be the distance thresholds for captive riders. These generalized distances were therefore used in determining the potential coverage of each bus stop in the prioritization processes.

- **Prioritize bus stops to be upgraded with a bicycle parking facility**

  Two heuristic reduction models were used in removing redundant bus stops considering two types of policies, thus maximizing spatial coverage and bicycle-bus commuters. Reduction by farthest distance was seen to provide a much optimal result than the reduction by demand at bus stops. This resulted in 47 bus stops serving a maximal number potential bicycle-bus commuters of about

356,000 as compared 324,000 potential bicycle-bus commuters served by 27 bus stops resulting from the reduction by total demand.

Maximising the potential bicycle-bus commuters would provide a better optimisation when compare to maximising the spatial coverage. This is because the reduced bus stops were not going to be demolished and upgrading these bus stops together with those not upgraded were going to maintain the maximal coverage.

- **Prioritize access routes to bus stops for the provision of bicycle infrastructure**

Using the optimal number of bus stops and a combination of spatial analysis and network analysis tools, the routes leading to these bus stops yielding the highest demand points served were prioritized. From the results, most of the roads close (within 400 meters) and farther away (above 3 kilometer) from the bus stops were classified as of low priority for non-motorised infrastructure. This was as a result of taking only commuters within a distance threshold of 0.4 to 3 kilometers into consideration in the model. However it is the provision of a continuous bicycle lane or path that encourage commuters in using bicycles. As such provision of these infrastructures should also cover road close to these bus stops.

In total, through a heuristic reduction model based on CommunityViz, bus stops and access routes were prioritised for the provision of non-motorised infrastructures such as bicycle parking facilities, bicycle lanes and bicycle phase in traffic light along access routes. It is hoped that the findings of this research go a long way in helping transportation planners and decision makers in the integration of bicycle and public transport planning in Pune city and elsewhere.

7.3. Study area recommendations

- Using bicycles as feeder mode of transports to public bus transport has the potential for expanding its coverage. To encourage commuters in making bicycle trips to bus stops, non-motorised infrastructures need to be in place. About 47 bus stops were identified to be upgraded with bicycle parking facilities providing about 356,000 potential bicycle-bus commuters services. Using the number of potential cyclist attracted to each bus stop, bus stops have been prioritized.
- Access routes to these bus stops need to be upgraded with bicycle lanes and bicycle phases in traffic light along the routes. These have been seen to induce commuters into making bicycle trips. Access routes have also been prioritized for this provision using the number of potential cyclist along each route.

7.4. Further research recommendations

During this research, some assumptions were made due to the lack of time and fieldwork limitations. Recommendations are therefore been made for future improvement of this model.

- **Data acquisition**

With the lack of data on trips made in accessing bus stops, a generalized origin-destination multi-modal distribution was used in estimating the potential cyclist to a bus stop. This may be misleading as commuters may make longer trips as observed. Improvement can be made by using a multi-modal distribution curve estimated from trips made in accessing bus stops. The need in collecting trips made in access bus stops would therefore be a major contribution in the improvement of the model.

The lack of local road network also had an effect on the calculation of total distances from each origin point to the bus stops. The detour factor of the road network in Pune had to be estimated and multiplied by the Euclidean distances from each origin to the closest road network. Even though this error was reduced, the availability of very local road networks could help in a better estimation of these distances

- **Reduction Procedure**

A heuristic reduction model was used due to lack of time and the requisite software knowledge. This reduction model was setup in CommunityViz and manually operated. Bus stops falling below the 25^{th} quartile of the criteria were removed from the next iteration. The resultant number of bus stops may not be the optimal as more than one bus stop are removed each time. For a much optimal results, only one bus stop should have been removed and its effect on the number of demand points served assessed each time. An automated reduction model could therefore be setup for a better estimation of the optimal number of bus stops.

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