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Feb, 2013

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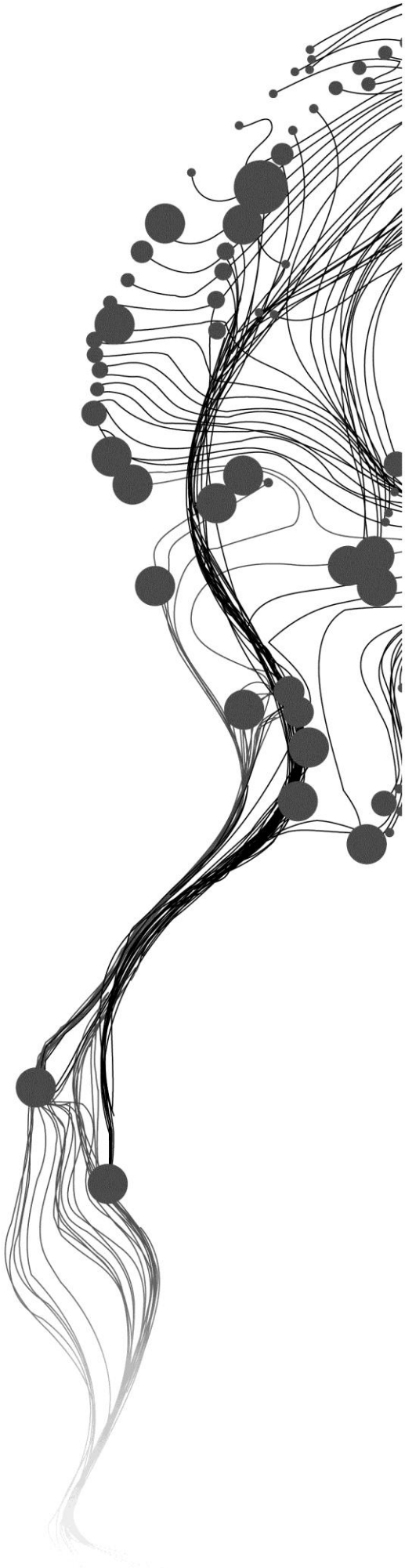

A GIS-based method for bicycle facility planning in Rajkot

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Enschede, The Netherlands, Feb, 2013

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

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ABSTRACT

Carbon emissions being one of the major concerns of today's world, various steps are being taken by almost all the countries for low carbon development. Improving the bicycle infrastructure, to encourage more bicycle users can serve the purpose of low carbon development. Continuing with this line of thought, a GIS based bicycle facility planning method was chosen for research.

The research aims at identifying the existing bicycle infrastructure in Rajkot, which after improvements, can lead to the low carbon transport system. The research was conceded by adopting a method developed in U.S.A which addresses the bicycle demand and supply of infrastructure together, to identify the areas for improvements. The research was carried out on the road segment level as well as the traffic analysis zone (TAZ) level. Demand was analysed by linking the factors generating demand to the nearest road segment, which gave an indication of potential demand on the road segments. The supply of infrastructure was identified by adopting a U.S.A based model. This model compares the perceived safety/comfort by bicycle users with roadway characteristics to identify Bicycle Level of Service (BLOS). BLOS is a performance indicator of quality of bicycle infrastructure in a city. The limited accuracy was identified in the results obtained by adoption of U.S.A based model in case of Rajkot. The results at road segment level were spatially overlaid on the TAZ using the "Spatial Join" technique in ArcGIS. The Global and Local Moran' I technique identified the hotspots of high demand and low supply of infrastructure in Rajkot. The hotspots were taken up to address the future policy making to improve the bicycle facilities, policies in favour of bicycle users and plan land use to have an efficient bicycle system in Rajkot.

The research was able to identify the potential demand and bicycle infrastructure quality (BLOS) on road segments as well as on TAZ's in Rajkot, for improvements, which can further lead to low carbon transport system in Rajkot.

Keywords: Bicycle facility planning, Bicycle Level of Service, Bicycle Infrastructure, Low carbon development, Moran' I technique

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ABBREVIATIONS AND ACCRONYMS

BLOS	:Bicycle Level of Service
BRT	:Bus Rapid Transit
CEPT	:Centre for Environmental Planning and Technology
LMCP	:Low Carbon Mobility Plan
NMT	:Non-Motorized Transport
PT	:Public Transport
TAZ	:Traffic analysis zones
UNEP	:United Nations Environmental Program

1. INTRODUCTION

Today's world is developing rapidly. With this development come issues such as global warming. Global warming is a phenomenon caused by the increased amount of Greenhouse Gases (GHG) in the atmosphere, which is resulting into the heating of earth's surface. This is again causing climate change, sea level rise etc. One of the major challenges faced by the world is reduction of carbon-dioxide emissions, one of the main components leading to global warming. Transport is one of the largest contributors to carbon-dioxide emissions. Countries are therefore trying to keep low in the emissions of carbon-dioxide, while continuing to develop economically, i.e. through low carbon development.

Transportation is one of the key developmental sectors necessary for a countries' economic development. But it is also a major contributor of GHGs in-to the environment. Nearly 23% of total carbon emission can be contributed to the transport system (Shrestha, 2012). Therefore, transport planners are obliged to consider environmental and social factors, while improving mobility and accessibility (Litman & Burwell, 2006). The purpose of planning for low carbon transport is to serve the goal of enhanced mobility for people along with the reduction of carbon emissions into the atmosphere. Conventional approaches adopted by planners are to develop compact cities, improving public transport, non-motorised transport (NMT), reducing the trip lengths by mixed land use etc. (Breithaupt.M, 2010). NMT indeed plays an important role in reduction of carbon-emission as it is a physically powered mode of transport with zero emission. One of the ways of improvement in non-motorised transport is by transforming long and short trips made, currently, by motorized transport into the bicycle trips (Badland & Schofield, 2006). For this purpose, planning of an effective bicycle system is one of the major challenges planners are confronted with. The bicycle is also an economically interesting mode of transport, as it is affordable and accessible to a large group of people. Increases in bicycle usage at the cost of motorized transport would reduce the fuel dependency in transport system (Advani & Tiwari, 2006), amongst others. This research will assist in low carbon development by looking at options for bicycle planning in Rajkot, India.

1.1. Background

The bicycle is one amongst various modes of transport used by people in India. It is cheap, healthy and an easily accessible mode of transport. It is however a slow mode of transport, often plagued by safety issues due to speed differences with other traffic, which is the case in the Indian cities. Bicycle users are part of the normal traffic and have to use the same roads and crossings as the other modes of transport (Pucher et al., 2005). Wee et al. (2011) articulates, the choices of using bicycle depends on the climatic conditions, an individual's professional attire and the travel distances, which discourages the upper and middle class professional to choose bicycle as a replacement for cars. Other issues are topography and slope which make cities like Shillong Aizwal, Jowai etc located in North India, unfriendly towards the bicycle usage (Ahmad & Datta, 2006). In spite of this, bicycle ownership is 30-50% in the Indian cities. The percentage of bicycle users in large cities is 7-15%, while 13-21% in medium and small cities (Interface for Cycling Expertise, 2012). Bicycles users in India are mostly school and university students as they do not possess the licence to use the motorcycles. As the distances to the schools lie within range of 3-4km from the residences, no licences, no fuel is required to travel, makes students attract towards the bicycle.(Interface for Cycling Expertise, 2012). Other users are worker class, slums dwellers who cannot afford other modes of transport. They are not the voluntary users of bicycles. But conditions like poverty, low income force

them to use bicycles. These users are captive users of bicycles.(Jain & Tiwari, 2010). The issues related to bicycle infrastructure are lack of parking space & insufficient racks at public places. Policies in favour of the bicycle users are rare in India (Advani & Tiwari, 2006).

The improvement in bicycle as a mode of transport is possible in Indian cities by improvements in the existing bicycle infrastructure. In The Netherlands, 30% of the people use bicycles for daily commuting (Pucher et al., 1999), due to its superior infrastructure and polices adopted by the government to maintain the bicycle-friendly environment. If separate bicycle lanes, separate crossing, right of the way procedures in favour of cyclists, parking facilities, bicycle repair shops etc. i.e. facilities similar to Netherlands are adopted in India, there is a high chance of a boost in bicycle usage in the Indian cities.

1.2. Justification

This research has a main motivation to develop low carbon mobility in the Rajkot city. For low carbon mobility, it is necessary to improve the status and options for cycling as a mode of transport. In order to improve cycling as a mode of transport this study seeks to understand the existing conditions prevailing in the city. To do so, some basic issues need to be known about the city i.e. current users of the cycle, why are they using the bicycle, how frequent is their usage and the places where the carry out bicycle trips. It is necessary to know the length of the daily trips made by the users. Identifying the above things will help us to understand, what the potential bicycle demand in the city is. It is also necessary to know about the road environment provided to them by the government to know whether, it is making their trips safe and comfortable or not. Their feelings are needed to be understood to give them a better environment to ride the bicycles. In other words we need to know about the supply of infrastructure to the existing bicycle users; so that changes can be introduced for improvements. Lastly the areas where there is a need of improvement i.e. hotspots of bicycle supply and demand need to be identified for improvements. Therefore an approach is necessary to look at both the existing supply and demand for cycling at the same time and identify the place to be improved. From the literature it was identified that a research was carried out by Rybarczyk and Wu (2010) which addresses supply and demand together for improving the bicycle facilities for recreational users in Milwaukee City, WI, U.S.A (details mentioned in chapter 2). Though the conditions in U.S and India are different, an experiment can be undertaken to adopt and adapt the ideas put forward by Rybarczyk and Wu to be implemented in an Indian city for the sake of bicycle facility planning. This research will try to identify the areas for improvement in the bicycle infrastructure and also the credibility of U.S model can be identified in Indian context for further usage in future.

1.3. Selection of study area

For this research, Rajkot was chosen for study, as it was one of the four Indian cities chosen by UNEP, to develop a Low Carbon Mobility Plan (LMCP) (UNEP Risoe Centre, 2010). Rajkot is located in Gujarat state of India. Rajkot municipal corporation (RMC) is comparatively smaller than most other cities in the country as it only occupies area of 105 sq. km (GOPA Consultants & CES, 2011b), which may be positive for cycling. Rajkot is one amongst the cities in India facing urban sprawl. Rapid urbanization is putting stress on the transport system of Rajkot which in-turn is leading to high levels of air pollution in the city (see table 1). According to Rajkot Municipal Corporation (2012), The modal share of bicycle is 3% in Rajkot. Next to this, due to its small area, flat topography and interventions like a ban on heavy vehicles inside the city from 8 am to 8 pm (Gujarat High Court, 2010), Rajkot was considered as a good city for cycling. Details of study area are provided in chapter 3 of this research.

Table 1: Emission of GHG's in Indian cities

City	PM2.5 (tons)	PM10 (tons)	SO2 (tons)	NOx (tons)	CO (tons)	CO2 (million tons)
Pune	16,650	36,600	3,600	127,350	438,200	11.9
Chennai	26,000	56,400	15,100	268,200	857,500	30.6
Indore	9,900	17,900	2,550	146,600	263,300	8.6
Ahmedabad	17,500	35,100	10,500	175,300	510,150	22.4
Surat	12,000	19,950	3,350	146,450	371,400	11.6
Rajkot	7,750	14,000	2,200	91,750	236,700	7.4

Source: (Guttikunda.S & Jawahar.P, 2011)

Below is the map showing study area.

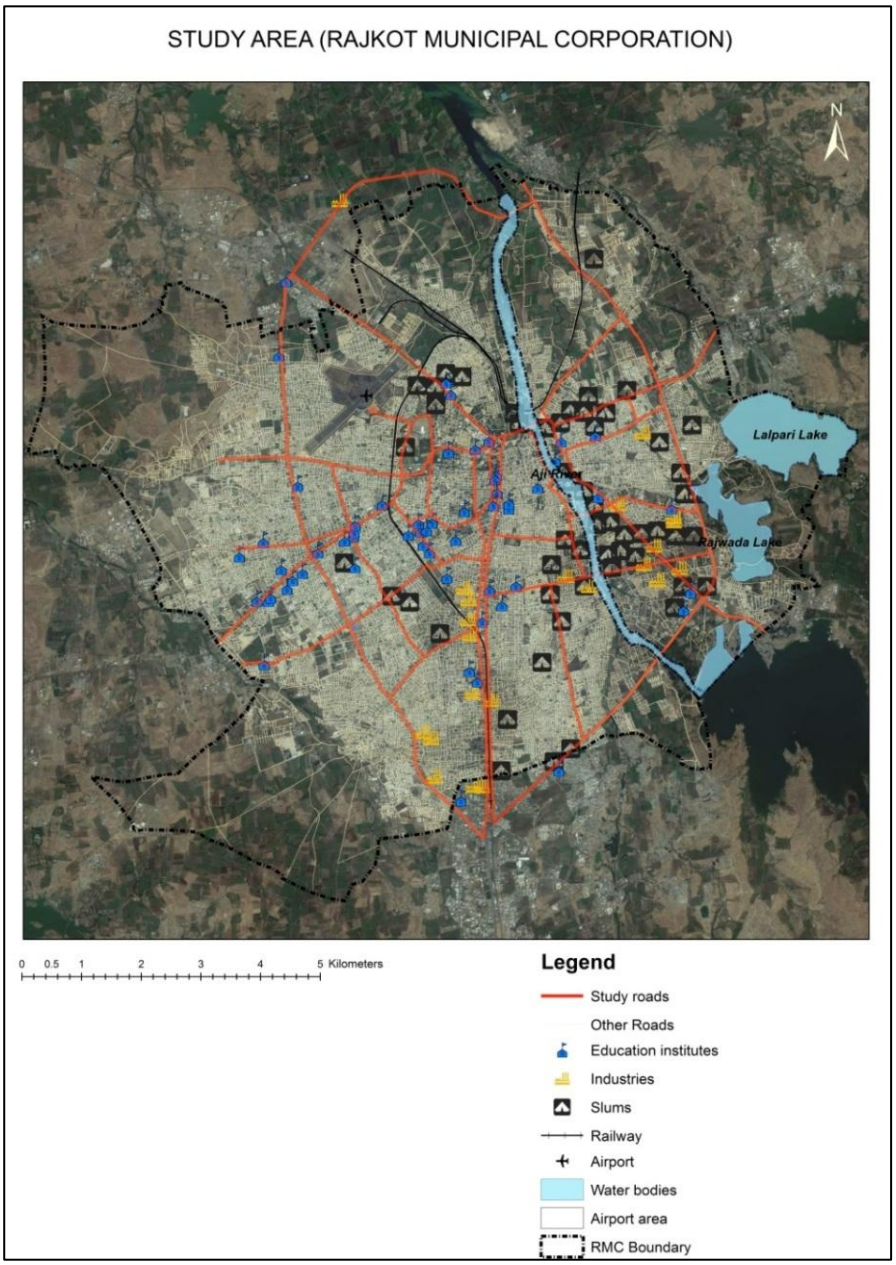


Figure 1: Google image, Data source: (CEPT University), Image source: (ArcGIS Bing map online, 2012)

1.4. Research Problem

Due to the increase in the levels of vehicular emissions, an approach needs to be taken up in order to reduce the carbon-emission by planning sustainable transport system. Therefore, Planning of bicycle system can be an approach which may lead to increase in mobility with reduction of carbon emission. The bicycle system in India is rather weak with lack of infrastructure and policies making the bicycle trips un-safe and un-comfortable. This makes people ignorant towards the bicycle usage. Therefore, an effective bicycle facility planning in the cities may improve the conditions of the existing infrastructure as well as encourage more people to use the bicycles in the city. For the improvement of bicycle facilities, the areas in the city can be identified where more current and potential bicycle trips will be carried out, using GIS techniques. The GIS tools can be effectively used for planning the bicycle facilities, by producing the output maps showing areas of improvements. Strategies can be made by the policy makers in the areas of improvements in order to increase the bicycle usage in the city. This research will investigate the problems related to the existing bicycle facilities and identify areas for improvement in Rajkot, in order to achieve low carbon development.

1.5. Objectives

To adopt and analyze a GIS-based methodology for bicycle facility planning developed by Rybarczyk and Wu (2010) for Rajkot city in the context of low carbon city development. The secondary objective is to test the credibility of this model under Indian conditions.

1.6. Sub-objectives & Research Questions

Sub objective 1: To identify the demand for cycling on road segments in Rajkot, India.
Research Questions:

1. Which are the factors that are generating the bicycle demand?
2. What will be the approach to analyse the demand on the road segments of Rajkot?
3. What modifications are required to adapt and adopt the U.S.A based method for analysing the demand in case of Rajkot?

Sub objective 2: To adopt the supply based model pre-developed in the U.S.A to identify the quality of infrastructure on road segments in Rajkot and test its credibility.

Research Questions:

4. What will be the approach to identify the perception of people towards existing bicycle infrastructure in Rajkot?
5. What are the factors that determine good/bad infrastructure in Rajkot? How can we utilize this information to model the supply based analysis in the study area.
6. What are the modification required to adapt and adopt the supply based model in context of Rajkot
7. What will be the factors that would determine the credibility of the model?

Sub objective 3: To identify hotspots of low supply and high demand.

Research questions

8. What will be the smallest administrative boundary chosen for hotspot analysis?
9. What GIS techniques will be useful for the analysis?

Sub objective 4: Analysis of hotspot identified from the study.

Research question

10. Where in the city are hotspots located and what do they indicating?
11. How can we improve the bicycle conditions upon the hotspots?
12. How will the improvement lead to low carbon development.

1.7. Conceptual framework

The conceptual framework describes the brief process of conceding this research. The main aim is low carbon transport system which can be achieved by effective bicycle planning technique. The bicycle planning process addresses the existing supply and demand for the improvements in the bicycle conditions. The demand based analysis is carried out to identify the places of high bicycle demand in the city. The supply based analysis is carried out to identify the places with poor quality of bicycle infrastructure and unsafe conditions for the bicycle users in the city. This process is carried out in GIS which produced the results in the form of thematic maps. The areas with high demand and low supply are identified at the end of this research and are considered as priority locations for improvements in bicycle conditions.

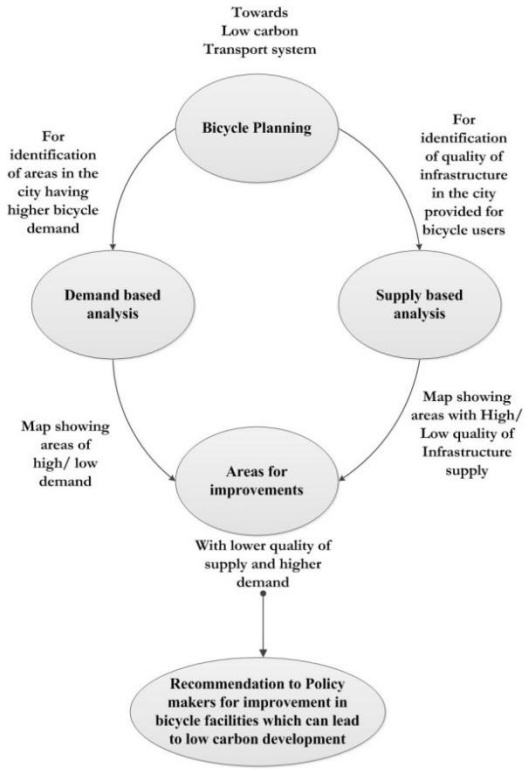


Figure 2: Conceptual diagram of research

1.8. Research design

Table 2: Matrix to address research questions

objective	Research Question	Needed Data	Source Of data	Method of Collection
Sub objective 1: To identify the demand for cycling on road segments in Rajkot, India.	1. Which are the factors generating the bicycle demand in Rajkot?	literature on bicycle users in India Interviews/questionnaire	Scientific Database/ Field work	Survey/ Literature review
	2. What will be the approach to analyse the demand on the road segments of Rajkot?	Literature based Rybarczyk and Wu's method for demand analysis	Scientific Database	Literature review
	3. What modifications are required to adapt and adopt the U.S.A based method for analysing the demand in case of Rajkot	Interviews/ Secondary data on factors generating bicycle demand	Field work/desk work	Semi-structured interviews with the bicycle users/data analysis.
Sub objective 2: To adopt the supply based model pre-developed in the U.S.A to identify the quality of infrastructure on road segments in Rajkot and test its credibility.	4. What will be the approach to identify the perception of people towards existing bicycle infrastructure in Rajkot?	literature based on perception study of bicycle planning /Perceptions on safety and comfort of the bicycle users while making trips(workshop)	Scientific database/ Field work	Literature review/ workshop by hiring 10 people to ride bicycle on 10 road segments of Rajkot, and recording their perceptions
	5. What are the factors that determine good/bad infrastructure in Rajkot?	By field observation and feedback from people hired for the workshop	Field work	From structured feedback form prepared for recording the observations
	6. What are the modification required to adapt and adopt the supply based model in context of Rajkot	Field observations and availability of data. Literature related to study area	Scientific Database /desk work	From study area data /primary data from field inventory/secondary data
	7. What are the major differences in the infrastructure conditions in U.S.A and conditions prevailing in Rajkot which needs to be modified in the model?	Field observation/secondary data	Desk work	Comparison with previous studies.
Sub objective 3: To hotspots of low supply and high demand.	8. What will be the smallest administrative boundary chosen for hotspot analysis?	Secondary information form the on-going project	Field work	Data collection form secondary source (CEPT)
	9. What GIS techniques will be useful for analysis?	GIS software Manuel	ArcGIS search window/ search engines	
Sub objective 4: Analysis of hotspot identified from the study.	10. Where in the city are hotspots located and what do they indicating?	Output of the analysis	Desk work	From the results
	11. How can we improve the bicycle conditions upon the hotspots?	Output of the analysis	Desk work	From the results
	12. How will the improvement lead to low carbon development.	Output of the analysis	Desk work	From the results

1.9. Thesis structure

Chapter 1: Introduction: - This chapter will contain the information about the objectives, problems, concepts and introduction to methods used to carry out the research.

Chapter 2: Literature Review: - This chapter will contain information about the previous studies carried out in the field of bicycle facility planning, and also various techniques used for effective planning.

Chapter 3: Study area and Data collection methods- This chapter will contain information about the study area and the methods used for data collection to carry out the analysis.

Chapter 4: Data analysis and Discussions: This chapter will discuss about the methods used for analysis of the data and will discuss about the results generated from the analysis.

Chapter 5: Conclusion and Recommendations: This chapter this chapter will conclude the research. Recommendations will be provided for the improvement in bicycle conditions and also if required, the improvements in the model for its use in Indian context.

2. LITERATURE REVIEW

This chapter will give some concise details about the ways in which bicycle planning can be carried out. It will discuss the methods to be used in the research for demand and supply analysis in Rajkot. This chapter will answer the research questions 1, 2 and 4 fully or partially as per the requirement in this research.

2.1. Initiatives of planning bicycle system towards low carbon development.

Bicycle planning is an important aspect in transport planning since the last 2 decades (Pucher et al., 1999) as it an healthy and environmental friendly mode of transport and can lead to decarbonizing transport systems. Worldwide urban planners, local NGOs, environmental groups, local activists have developed bicycle traffic policies and bicycle friendly infrastructure (Pucher et al., 1999) which has resulted more safe and comfortable rides for bike users, hence higher shares of bicycle use in the modal split. In countries like the U.S.A, many other countries are striving hard to make a bicycle system efficient by self-restrictions, interventions and policies. European countries already have a higher modal share of bicycle users with 30 % in The Netherlands followed by 20% in Denmark and 12% in Germany (Pucher et al., 1999) . This is due to high investments for the bicycle planning and infrastructure. The question of investment in bicycle planning techniques for stimulating low carbon development was raised by Sælensminde (2004) who carried out cost-benefit analysis in three Norwegian cities. This analysis was done to assess the reduction of insecurity and health benefits for bicycle users. This study also accounted for the reduction of environmental and social (parking, noise) cost after switching modes from cars to bicycles. The results showed that the benefits of investment on bicycle planning were 4-5 times more than the cost required for it, which indicates the worth of investment on bicycle planning for improvements. "Planning for paths, sidewalks, bike lanes, street improvements, road and path maintenance, road safety, personal security, universal access (including features to accommodate people with disabilities), non-motorized traffic law enforcement, education and encouragement programs, and integration with a community's strategic plans and various other programs"(Litman et al., 2009) can be the areas in which cities invest in order to develop bicycle as an efficient mode of transport for daily commuting. Recently, the Indian government has also taken initiatives towards low carbon development in few cities including Rajkot and are in the process of developing innovative strategies with the intention of increasing mobility and accessibility in conjunction with healthy and pollution free environment (UNEP Risoe Centre, 2010). The improvement in bicycle usage by adopting effective bicycle facility planning methods in the city can be one of these strategies. Next section will explore strategies for improvements in the bicycle system.

2.2. Methods used for planning effective bicycle system

This section gives details about the study undertaken by different scientists for the sake of bicycle planning. For planning bicycle system, it is first necessary to identify the bicycle demand in the city. The demand characteristics are based on the users, the route choices which they take for commuting, and the areas which they bike to (Suzuki et al., 2012). One of the aspects which has an influence on demand is the safety feeling while riding the bicycle (Suzuki et al., 2012). Also, route preferences play an important role while analyzing the demand in the city. the preferences depend upon the convenience of people and the bicycle infrastructure provided to them (Caulfield et al., 2012). Route preference, demand characteristics can vary from country to country. In an Indian context, Jain and Tiwari (2010) carried out a research in Pune to identify the bicycle users, in particular factors which generate demand and route preferences. The

research indicates that bicycle users are captive in India. The affordability is one of the issues which are making people use the bicycle. Jain and Tiwari (2010) stress that 50 to 75 % people leaving in slums are users of the bicycles as they cannot even afford the Public transport (PT) for daily usage. The other users are children who don't possess the licenses to use the motorized vehicles. The remaining are the people who belong to lower income class i.e. worker class. The results of research suggest 64% of the school trips and 41% of the work trips are made on bicycles. Only, 12 % of trips made by poor are identified to be bicycle trips may because even bicycles are not affordable to them. Therefore, according to Jain and Tiwari (2010), The bicycle users in Indian are mostly students, workers and the urban poor. For this research we also need to identify the users of bicycle in the study area. We can assume that the bicycle users in Indian cities i.e. Rajkot and Pune are fairly similar, but this needs to be clarified from the fieldwork for purpose of our research. Therefore, the assumption of bicycle users in Rajkot to be fairly similar as Pune indicates the facilities generating bicycle trips are Educational Institutes, Industries and Slums which partly answer the research question 1, though the complete answer would be obtained only from the Rajkot specific data by fieldwork. About the route choice the author articulates that the captive bicycle users consider informal sectors on the side of roads as a security element; they consider arterial roads to be safer than the narrow roads (Jain & Tiwari, 2010). The author also discusses about the problems faced by the bicycle users in India i.e. difficulties for bicyclists in crossing the intersections, tolerance to the pedestrians etc. The factors which have an effect on demand are "*safety; ease of cycling; weather conditions; route conditions; and interactions with motor vehicles"*(Winters et al., 2011). The way to solve the demand problem is by adequate supply of infrastructure to balance the demand in the city. Harkey (1998) indicates that, the supply of infrastructure and services would help in managing the bicycle transport efficiently. But before providing the facilities it is also necessary to understand the perception of people in view of better facilities. To improve the facilities, inventories of the existing quality of infrastructure are necessary. A model to do so is prepared by (Landis et al., 1997) in U.S.A in order to identify the quality of infrastructure i.e. Bicycle level of service (BLOS) on the roads which will give an indication of a good or bad quality of existing infrastructure. *"The Bicycle Level of service model helps in the evaluation of bicyclists' perceived safety with respect to motor vehicle traffic. It identifies the quality of service for bicyclists that currently exists within the roadway environment"(Landis et al., 1997).* The perception of people towards BLOS is essential to understand their feeling of safety and comfort while carrying out day to day trips. BLOS is an indicator for the government and the policy makers for improvement in the bicycle facilities. Kirner and Penha (2011) articulates, BLOS perception of the people depends on the road engineering as well as the traffic characteristics. The factors according to the people which are important to be considered while planning are (1) lane width (2) motor-vehicle speed (3) visibility at intersections (4) presence of intersections; and (5) street trees (shading)(Kirner & Penha, 2011). Landis et al. (1997) specifies that the perception of people can be model using the roadway characteristics to identify the BLOS in the city. The methods stated above indicate that the demand and supply analysis can be considered separately for research purposes. (Rybarczyk & Wu, 2010) experimented a method which dealt with supply and demand together in order to improve the bicycle conditions in Milwaukee City, WI, U.S.A for the recreational users.

(Rybarczyk & Wu, 2010) used a GIS based technique to address the supply and demand for improvement in the bicycle facilities. This method is adopted for Rajkot as it serves three purposes 1) fulfilment research of improvement in bicycle conditions 2) Assessment of credibility of American based method in the Rajkot's context for future use in other cities of India. 3) Fulfilment of M.Sc in urban planning using GIS based techniques. In the next section this method is specified in more detail.

2.3. Rybarczyk and Wu's method

Rybarczyk and Wu (2010) developed a method to analyze the supply and demand of bicycle infrastructure & services in different areas of Milwaukee City, WI, U.S.A., for improving the bicycle facilities for recreational users in the city. The analysis was carried at two different spatial scales i.e. 1) Road segment; 2) Neighborhood level.

The demand side analysis was carried out by identifying the factors which are generating or discouraging the bicycle demand i.e. schools, factories etc. from the secondary sources. These factors were linked to the road segments using GIS technique in a way that the demand generated or discouraged by these factors would be analyze on the nearest road segments used by people to reach these destinations. The information from secondary sources suggested, a recreational bicycles user will not avail a facility which is located 2 blocks i.e. 660 feet off-track and use the nearest facility in his route. Therefore, the factors located in range of 660 feet around the road segment were linked to their relative segment (Rybarczyk & Wu, 2010). After linking the factors to the nearest road segment, they were analyzed using a simple additive weighing technique. This technique considers the counts of the facilities present on particular road segment for analysis. The techniques has three phases 1) value normalization; 2) Ranking with weight normalization; 3) summation of the weighted normalized factors "(Rybarczyk & Wu, 2010). The value normalization function makes the different counts of different factors measurable i.e. the factors are normalized into the scale between 0 -1 for the analysis. The formulae for value normalization is as follow

$V_i' = (V_i - V_{min}) / (V_{max} - V_{min})$ For factors attracting bicycle trips…… (1)
$V_i' = (V_{max} - V_i) / (V_{max} - V_{min})$ For factors discouraging bicycle trips…… (2)

Where V_i' is the normalized counts of the factors, v_i is the original value of that factors, V_{max} and V_{min} are the maximum and minimum value respectively on any of the road segments in the study area" (Rybarczyk & Wu, 2010).

The second part of analysis was ranking of the factors. This is done on the basis of importance of that variable in affecting the demand. For e.g. if a crime has more significance than parks in terms of demand generation, the crime is given higher rank than a park. Rank value is normalized in such a way that the higher weight is given to the higher rank and variables will be assigned with a measurable value for analysis. Below is the formula for weight normalization of ranked variables.

$X_i = n - r_i + 1 / (n(n+1)/2)$…… (3)

Where X_i is the normalized weight of ranked factor; n is the count of factors under consideration; r_i is the rank position of the factor
(Rybarczyk & Wu, 2010).

The demand is calculated on the road segment using the formulae:

$$"\text{Demand} = \sum_i^n XiVi' \quad (i = 1 \ldots . n)$$ ……(4)
(Rybarczyk & Wu, 2010) from the equations (1), (2) & (3)

This process answers research question 2 i.e. an approach for analyzing demand on road segments. This demand is a relative demand which show areas of high and low demand on the road segments in terms of the relativeness with respect to the study area.

For a supply based analysis Rybarczyk and Wu (2010) adopted a method from (Landis et al., 1997) to develop a model suitable for the recreational users in the Milwaukee City, WI, U.S.A. Landis et al. (1997) articulate that the model has to be modified in order to make it suitable for the study area. Therefore, Rybarczyk and Wu changed the few variables and adopted the model for their study.

Landis et al. (1997) developed models to evaluate the performance based indicator for existing bicycle conditions (BLOS) in cities located in U.S.A. He recorded the perceptions of people in terms of safety and comfort while riding the bicycles on different road segments in the city and compared them with the road variables such as

1) Volume of per-lane motor vehicle traffic in 15 minutes

2) Speed limit

3) % of heavy vehicles,

4) Pavement condition of road surface, and

5) Width of outer lane etc. using multiple regression analysis.

The study was carried out to identify perception of people in terms of safety and comfort of bicycle users in Tampa, Florida. The participants with varied ages, genders, experiences in cycling were invited to acquire perceptions in terms of safety and comfort felt on the roads. These people had to ride bicycles on 30 road segments and mark the road in 6 point grading scale i.e. A to F where A signifies most safe/comfortable and F signifies least safe/comfortable. Similarly to this research, the perceptions of people in Rajkot can also be identified by inviting people to ride the bicycles and mark the road segments in the way they perceive the quality of existing infrastructure. This partly answers the research question 4 i.e. a way to identify the perceptions of people in Rajkot, though it need to be confirmed depending upon the availability of participants to assist in identifying perceptions in Rajkot during the fieldwork.

By referring back to the (Landis et al., 1997) method to understand how the recorded perceptions were used to calibrate the model, It was understood that the author used a multiple regression analysis method to compare 4300 observations with the road way characteristics obtained from secondary sources to develop a model which will indicate BLOS on the basis of roadway characteristics. Below is the mathematical representation of method used by Landis et al. (1997)

"BLOS= $f(x_1,x_2,x_3\ldots)$" (Landis et al., 1997)

Where BLOS is recorded perceptions determining the quality of infrastructure and x_1, x_2, $x_{3\ldots}$are the roadway characteristics.

The final regression model produced by Landis et al. (1997) reads

$$BLOS=a_1\ln(Vol_{15}/\ln)+a_2\ln[SPDp(1+\%HV)]+a_3\ln(COM_{15}*NCA)+a_4(PC_5)^{-2}+a_5(W_e)^2+C\ldots\ldots\ldots\quad(5)$$

Where

"BLOS= perception of people

Vol_{15}= Volume of traffic in 15 mins

SP D_p= Posted speed (a surrogate of average speed)

HV= % of heavy vehicles
COM_{15}= Trip generation intensity of the land use
NCA= effective frequency per mile of non-controlled vehicular access
PC_5= 5 point pavement rating
$(W_e)^2$= Effective width of outer lane"(Landis et al., 1997)

The above model produces the BLOS indicators on the basis of roadway characteristics in the entire study area which helps in determining the road segments with good or bad quality of bicycle infrastructure in the study area. This model was successfully adopted by Rybarczyk and Wu along with the other scientists to identify quality of infrastructure in different part of U.S.A.

Our research will check the credibility of this model in the context of Rajkot in India. The successful usage of this model can make it useful for bicycle planning in other cities of India and countries having similar conditions to Rajkot as well.

The third part of Rybarczyk and Wu's research dealt with analyzing the supply and demand at the neighborhood level. For administration, policies and decision making the analysis of the research was also carried out at the neighborhood level. "A neighborhood is considered as a basic unit with urban implications"(Rybarczyk & Wu, 2010). The road segments were overlaid on the neighborhoods to assign values to each neighborhood by using GIS technique. "The mean BLOS was identified on neighborhood polygon by summing the total BLOS values and dividing it by road segments. The mean demand at the different neighborhood was obtained by summarizing and dividing by the area of that neighborhood"(Rybarczyk & Wu, 2010). Moran's I technique was used to identify the autocorrelation amongst the values present in the neighborhoods. The Global Moran's I techniques was used separately for supply and demand. It displayed the value which indicates whether the significant positive auto-correlation exists between the neighborhoods or not. The Local Moran's I displayed the results in scale of High-high, High low, Low-high and Low-low. The high-high and low-low indicated the positive auto-correlation amongst the neighborhoods while the low-high and high-low indicated the negative co-relation (Rybarczyk & Wu, 2010). The results were able to visualize the clusters of high demand and low BLOS areas in the city which were the targets for policy makers for the improvements in the bicycle facilities.

The results identified by (Rybarczyk & Wu, 2010) indicated a spatial mismatch of neighborhoods with high demand and low supply in the Milwaukee City case. But, it was interesting to find these patterns for Rajkot.

Rybarczyk and Wu's methodology can be implemented in Rajkot to analyze the supply and demand of bicycle system in this study. The changes in existing method are essential to address the bicycle service and demand potential in Rajkot by addition of few variables in the Indian context and removal of few existing variables not required in Indian context, which are currently used for Milwaukee City's context. The supply based model developed by (Landis et al., 1997) can be refined and re-used in the context of Rajkot which will indicate its credibility in the Indian conditions and with this answers the research questions 6 i.e. an approach to adapt and adopt the existing model in context of Rajkot.

This research will identify the areas of improvement in Rajkot. The effective improvement in the bicycle systems in Rajkot will improve the conditions for the current users and would also encourage the motorized users to use bicycles. The reduction of motorised usage will lead to reduction of carbon emission which will successfully feed the objective of low carbon mobility in Rajkot.

2.4. Summery

This chapter gave the brief details about the initiatives and methods being used for bicycle planning. It discussed the details of the methods obtained from the main references in this study used to concede the research in Rajkot. The chapter partially answers the research questions 1, 2 and 4

Research question 1: Which is the factors generating the bicycle trips in Rajkot?
Answer: From the previous study carried out in Pune, author articulates that the bicycle users in India are students, workers and slum dweller. This means that the factors generating bicycle trips are educational institutes, Industries and slums. The assumption of conditions in Rajkot being similar to Pune, partly answers the research question, though it needs to be confirmed from the field work.

Research question 2: What will be the approach to analyse the demand on the road segments of Rajkot?
Answer: Once the factors generating/ discouraging demand are identified, they can be linked with the nearest road segment with an intention to identify the bicycle demand generated on the road segments due to the presence of these adjacent factors. This approach will be explained in detail in the data analysis section where the modifications in this approach will be described.

Research question 4: What will be the approach to identify the perception of people towards existing bicycle infrastructure in Rajkot?
Answer: The perceptions of people towards existing bicycle infrastructure can be identified by inviting people to ride bicycle on the road segments of Rajkot and acquiring perception by telling them to mark the road segments in a grading scale, determining high or low quality. The answer of this research question will be answered fully in chapter related to data collection which will give detailed information about the approach used to identify perceptions in this research.

3. STUDY AREA & DATA COLLECTION METHODS

This chapter addresses the data collection methodology and description of the study area. It answers the research question 1 which is already partly answered in the literature review. It also answers the research question 5, 7 and 8 with reference to the collected data.

3.1. Study area

Rajkot is a located in Gujarat state which is in the north-west part of India. It is situated in central part of Saurastra region of Gujarat. Geographical location of Rajkot is 20° 43' North latitude & 70° 51'' East longitude. The city has strong social and cultural background with educational institutes and is well equipped with commercial, economic and political activities. (Consulting Engineering Services (I) Pvt. Ltd, 2004). Rajkot Municipal Corporation (RMC) covers area of about 105 sq. km out of 668 sq.km governed by Rajkot Urban Development Authority (RUDA). The population recorded as per census 2011 is 1,190,000 for RMC and 360,000 for the remaining areas under RUDA. The average increase in population growth is about 79.1% from 1991 till 2001. The recent growth of population is result of immigration from the nearby villages and also due to the extension of administrative boundaries (GOPA Consultants & CES, 2011b). Topographically Rajkot is flat. The slope is identified to be 0-7% (DWDU, 2011). A less to moderate slope in the study area makes it compatible for cycling. The topographic location of Rajkot is about 125m to 158m from south-east to north-west above the sea level. It lies in the semi-arid region. The average annual temperature varies from 6° C to 43.5° C. The average annual rainfall is about 500 mm (GOPA Consultants & CES, 2011a). Due to the moderate temperature and periodic nature of rains, cycling can be effectively done in the city throughout the year. The climate conditions of Rajkot indicate that the city is favourable for cycling.

Rajkot is founded 900 years back by Sasdhar in 1608 AD on the bank of river Aji (UN-HABITAT, 2008). Initially it was a part of princely state Saurastra which later got merged with the state of Gujarat in 1960 (Consulting Engineering Services (I) Pvt. Ltd, 2004). The developed part of old city was popularly known as "Sardar" during the British rule. Later the town and the Sardar regions were simultaneously developed and emerged into one. The city had a population of 36,000 by 19th century. It became the capital of Saurastra which is now part of Gujarat State. The present development in Rajkot is because of its central location in the state and rich culture and socio-economic characteristics (UN-HABITAT, 2008). Previous studies have provided some details of current status of developments observed in Rajkot which is stated below.

Rajkot has various businesses such as textiles, light industries, manufacturing of spare parts of diesel engines etc. The number of enterprises is over 6,000 in the cities which provide employment to around 250,000workers. The average house-hold income is about 4000 USD per year according to GOPA Consultants and CES (2011b). Various industrial estates like Aji Industrial Estate, Bhakti Nagar Industrial Estate have been developed in RMC to improve the Industrial sector of Rajkot (Rajkot municipal Corporation, 2010). Rajkot is also well-equipped with the educational institutes. *"The Saurastra University, a medical college, a pharmaceutical college, six engineering colleges, and two polytechnic colleges"* (GOPA Consultants & CES, 2011a) are present in Rajkot. There are 88 primary schools and 6 highs schools which are operated under the state government financing. Rajkot has various recreational facilities. The race-course, international cricket stadium, an indoor stadium, hockey and football ground are the recreational centres in the city. 82 gardens and dam sites provide open-space for recreational activities. Rajkot is considered as a trade centre of Saurastra. It has more than 33000 shops and various establishments. The increasing rate of shops in the city is approximately 3.05% while growth of commercial establishments is more than 10 %.

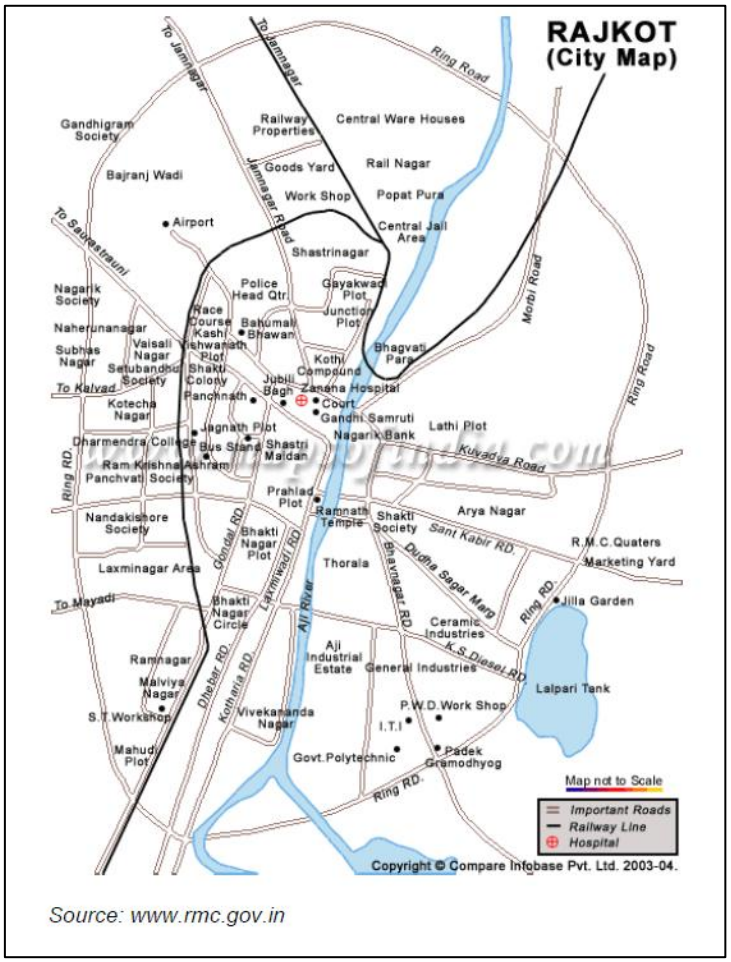


Figure 3: Rajkot Map, Source: (Rajkot Municipal Corporation, 2012)

Table 3: Trade in Rajkot

Details	1999-2000	2000-2001	2001-2002	Avg. Growth Rate
Shops	29980	31411	31825	3.05
Commercial Establishment	2891	3457	3524	10.76
Hotels	49	52	56	6.91
Eating Places	851	927	952	5.81
Cinema Halls	13	13	13	0.00
Total	33784	35860	36370	

Source : (Rajkot municipal Corporation, 2010)

Due to the expansion of the boundary, urban growth in the city, people have to travel to work, educational institutes, shopping, recreation etc. All these activities are located in the smaller area i.e. 105 sq. km. Therefore, if the mobility is improved by bicycle facility planning, the current problems of traffic congestion, air pollutions etc. will be resolved at an extent. Increase in amount of Industries, trade and commerce, quality of education in the city has led to economic growth and emigration from nearby

villages, leading to the over-crowding and slum formation. There is a strain on infrastructure and services due to ever-growing population.

3.1.1. Characteristics of roads in Rajkot

Rajkot is a small and linear city with few major roads. There are roads which carry out the inward and outward movement of the traffic i.e. radial roads; while the roads that cater the east-west and north-south traffic in the city are the city roads. The central roads are the roads which are located in the centre of the city and (GOPA Consultants & CES, 2011a) are most often used by the people in the city. Figure 4 is the map of few roads in the city according to their classification.

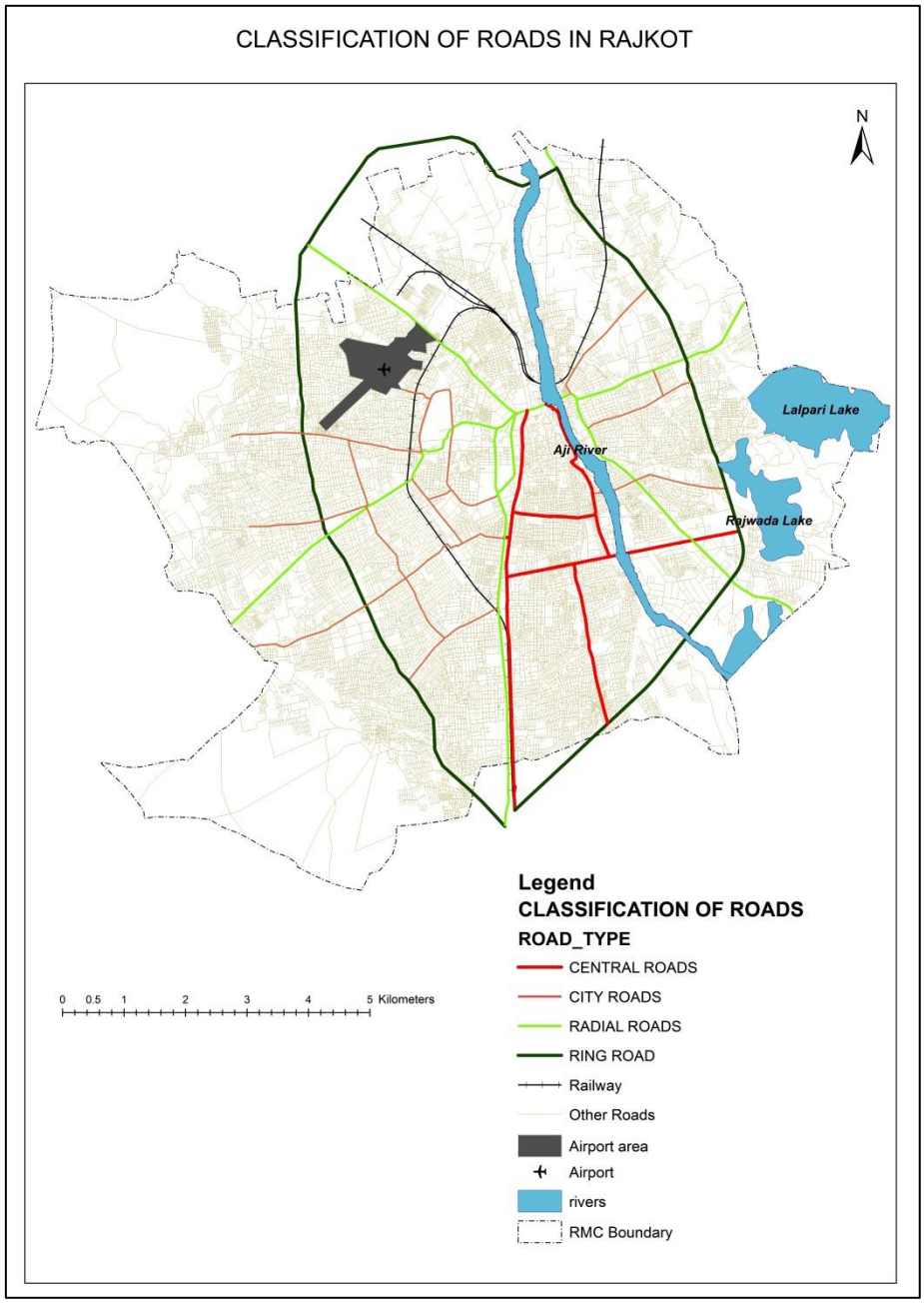


Figure 4: Roads in Rajkot

3.1.2. Modes of transport

Various public and private modes of transport are available in the city. The vehicles registered in year 2001 are 4, 79,017. The average growth recorded from 1991- 2001 is 9.5%

The intra-city public transport is operated by GSRTC (Gujarat State road Transport Corporation). Public transport is supplemented by para transit modes such as (Auto rickshaws and Chakda). Number of buses currently running is 52. Private buses going to other-urban destinations are also available in the city (Consulting Engineering Services (India) Pvt. Ltd, 2002).

Figure 5 is the pie chart showing the modal split of different modes of transport in Rajkot

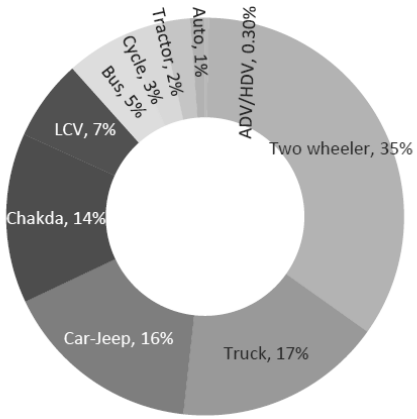


Figure 5: Modal split, Source: (Rajkot Municipal Corporation, 2012)

In order to know the more about the study area, road conditions, bicycle infrastructure etc. to visualize the study area, field work was organized for 3 weeks in Rajkot. The field inventory was carried out for first three days in order to observe the settings in the study area.

3.1.3. Infrastructure and existing condition to understand travel environment for cyclists

From the field inventory it was observed that the city lacks cycling infrastructure and policies for the users. However, cyclists are part of day to day traffic in the city. They have to use same route and crossing for making trips. Separate bicycle tracks have been constructed on the 150' Ring roads but the tracks do not have proper indications and markings, which sometimes mislead people to use bicycle tracks as a service lanes. The awareness of people about the cycling tracks is less; therefore in the adjoining figure, the cycle track on the left is almost invisible with motorbike on it, and a cyclist on the main road which indicates that people still use the same roads with other traffic to carry out their trips instead of using the cycle tracks. A photo in annexes 4 shows a clear picture of cycle track on 150' ring road. The roads in the central part of the city are narrow with single lane, all modes of transport existing on these roads. It is a

Figure 6: 150' Ring road with cycle track

difficult task for a cyclist to find his way out of the traffic and reach the destination. The right of the way policies do not support the bicycle usage in the city. People in the city are ignorant towards bicycle usage. Despite of poor infrastructure and traffic congestions, people were observed to be biking on the roads of Rajkot. A study was carried out in 2011 to analyse the performance for all the modes of transport existing in Rajkot. Performances of different modes were marked in range of 1-4 where 1 signifies best performance and 4 signifies poor performance. The NMT performance indicator in table 4 is 4 which signifies the lack of NMT infrastructure present in the city (GOPA Consultants & CES, 2011a).

Table 4: Performance indicator of transport system (1-4) in Rajkot

Performance indicator	Subsidiary indicator	Rajkot value	LOS	o/a LOS
Public transport facilities	Presence of organised public transport system in urban area	20-40%	3	3
	Availability of public transport (extent)	0.2-0.3	3	
	Service coverage of public transport in the city	0.3-0.7	3	
	Average waiting time for public transport users	>10 min	4	
	Level of comfort in public transport	1.5-2.0	2	
	Percentage of fleet as per *Urban Bus Specification*	< 25	4	
Pedestrian infrastructure facilities	Signalised intersection delay (%)	< 25%	1	2
	Street lighting (LUX)	4 to 6	3	
	Percentage of city covered	<25	4	
Non-motorised transport (NMT) facilities	Percentage of network covered	< 15	4	4
	Encroachment on NMT roads by vehicle parking (%)	> 30	4	
	NMT parking facilities at interchanges	< 25%	4	
Deployment of Intelligent Transport Systems (ITS)	Availability of traffic surveillance	< 25	4	4
	Passenger Information System (PIS)	< 25	4	
	Global Positioning System (GPS) /General Packet Radio Service (GPRS) (%)	< 25	4	
	Signal synchronisation (%)	< 25	4	
	Integrated ticketing system (%)	< 25	4	
Travel speeds (motorised vehicles and public transport)	Average travel speed of personal vehicles (km/h)	15-25	2	3
	Average travel speed of PT (km/h)	10-15	3	
Availability of parking facilities	Availability of on-street paid public parking spaces (%)	< 25	4	4
	Ratio of maximum to minimum parking fees	1	4	
Road safety	Fatality rate per 100,000 people	5	3	3
	Fatality rate for pedestrians and NMT (%)	20-40	2	
Pollution levels	SO_2	0-40	1	2
	Oxides of Nitrogen	0-40	1	
	Solid particulate matter	180-360	2	
	Respiratory solid particulate matter (size less than 10 microns)	40-80	2	
Integration of land use and transport	Population density – gross (persons/developed area in ha)	125-150	3	3

Source :(GOPA Consultants & CES, 2011a)

In order to make a proper bicycle facility planning for the existing users, it is necessary to identify the roads having a higher potential demand of bicycle usage and also the performance indicator on each road segment indicating the quality of supply. Next section will describe the detail process of data collection from field work required for demand and supply analysis in this research.

3.2. Data collection

In order to adapt and adopt the Rybarczyk and Wu's method for bicycle planning there is a requirement of primary as well as secondary data for the analysis. Different types of data sets are required for demand and supply analysis. This data was obtained during the field work in Rajkot.

3.2.1. Data for demand based analysis.

From literature review we know about the process used by Rybarczyk and Wu to identify the demand on the various road segments. A similar method is adopted in Rajkot in order to identify the demand. The variables used in the U.S.A may or may not be suitable in the India context; therefore these variables have to be identified again, which is done below.

The data required in order to carried out a demand based analysis needs to answer the following questions

1. Are the people of Rajkot using bicycles as the mode of transport?
2. If yes, which are the places where they ride the bicycle.

The answer to these two questions helps in identifying the factors generation bicycle trips.

As we have seen in figure 5, the modal split of bicycles in Rajkot is 3 %. A traffic counts survey was conducted by the team working in CEPT University on low carbon mobility plan. The team recorded bicycle traffic counts on roads of Rajkot in 1 hr. This data was readily available to us from project office located in CEPT, Ahmadabad. A map was produced to display the range of traffic counts observed in 1 hr.

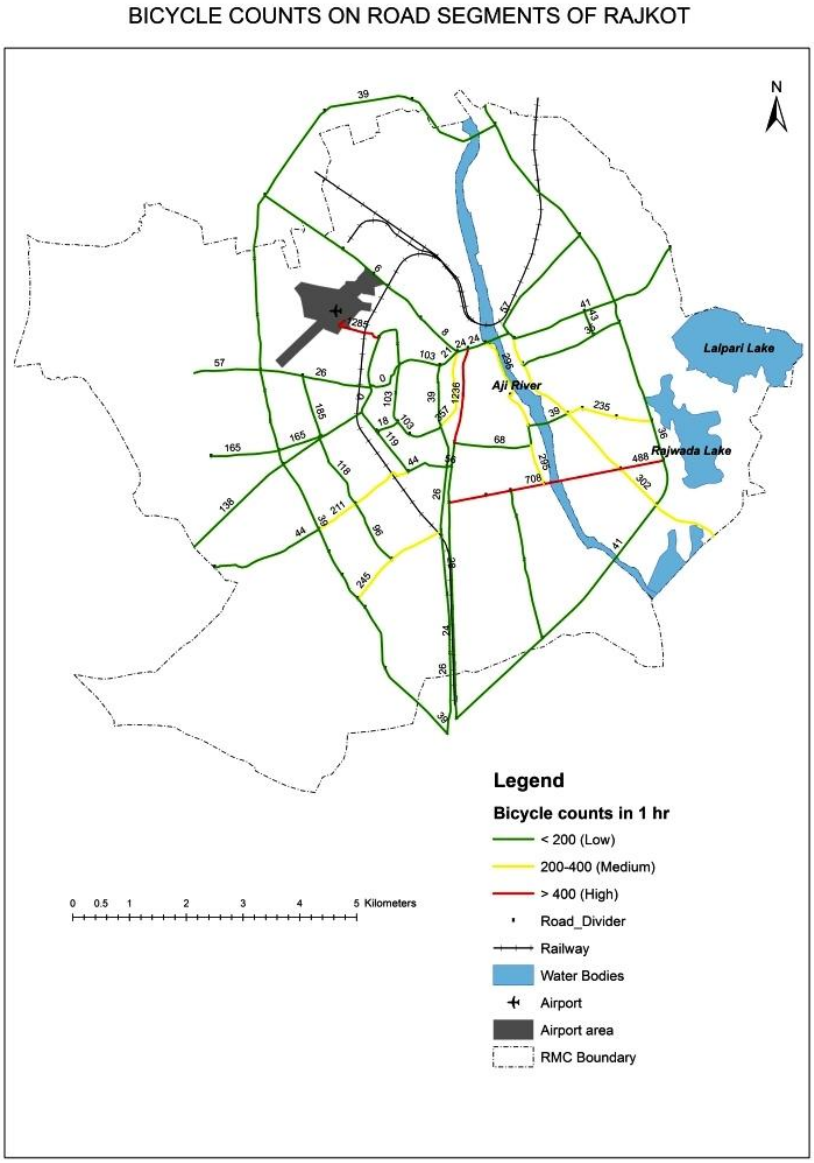


Figure 7: Bicycle counts, Data source: CEPT University

From the previous studies, data obtained and the study inventory, it was confirmed that the bicycle users exist in Rajkot. Next, it was necessary to know the origins and destinations of the bicycle trips in Rajkot, to understand the factors generating bicycle trips. This information was obtained from the survey.

3.2.1.1. Primary data

A survey method was used in order to identify the

- Bicycle users
- Places of bicycle trip attraction.

This survey was conducted by interviewing existing bicycle users on roads of Rajkot. Therefore, theses interviews were conducted by standing at the corner of a chowk ("A chowk is an area between the two junctions of a road in Hindi language" (WordReference.com, 2012)), while stopping the bicycle users for questioning. In other words a chowk it is the junction between the roads for crossing or other purposes. Therefore, this was a best place to conduct the survey. A stratified random sampling technique was used to choose the chowk (junctions) amongst the major chowk in the city in order to carry out the survey. It was decided to interview 10 cyclists on each of the selected 5 chowk. Only 5 chowk were chosen for survey as it was known that the secondary data of bicycle trip origin and destination was to be obtained from CEPT University as it was under process, during the field work. Primary interviews were conducted just for the backup if in case the data was not received from CEPT University. Unfortunately, the data from CEPT was not available at the time of this research, therefore the research had to be conducted based on the 50 interviews only. The interviews were conducted in Gujarati (see annexes 1) for people to understand, and had to be translated in English for me to understand as I am not a Gujarati (see annexe 2). I was assisted in this by friend working in Gujarat forest department, who spared some time to translate the interviews in English for me. No stress was given to conduct more than 50 interviews as it was time consuming to translate them and hope of getting data from CEPT University was alive at that time. A questionnaire showed in Annexes 1 was prepared in a semi-structured way with open-ended questions in order to identify the users of bicycle, the frequency of their usage, distance they travel on bike and modes of

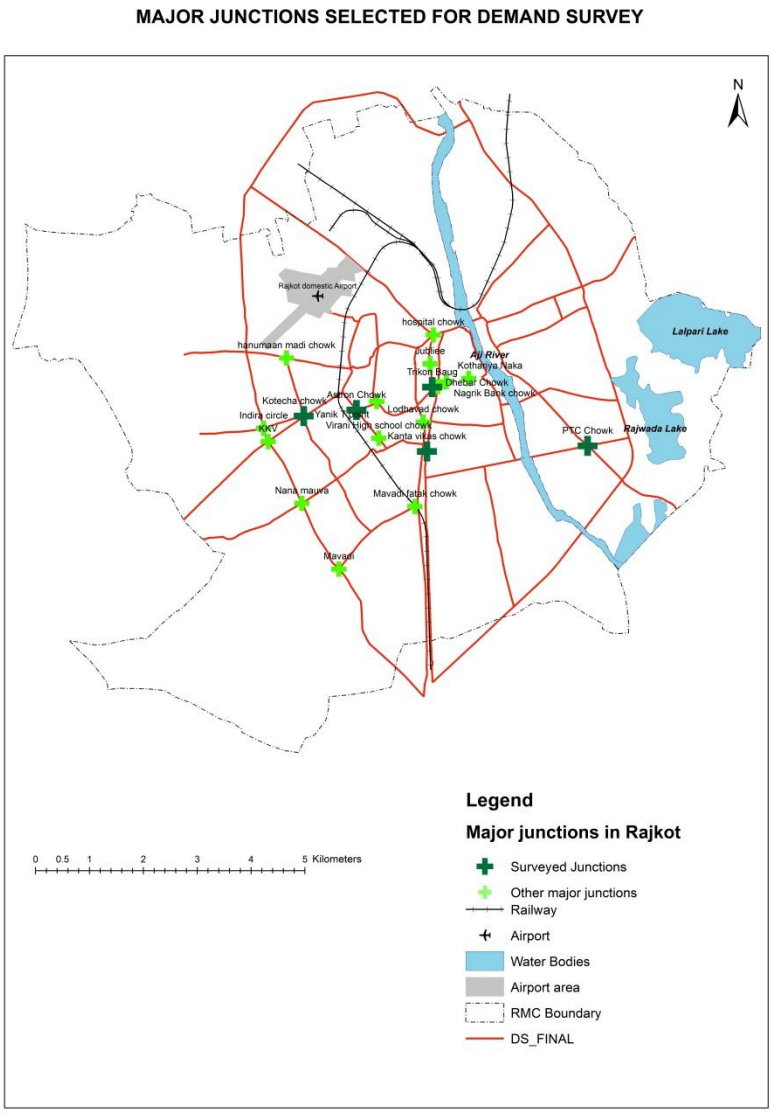


Figure 8: Major junctions in Rajkot, Data source: CEPT University

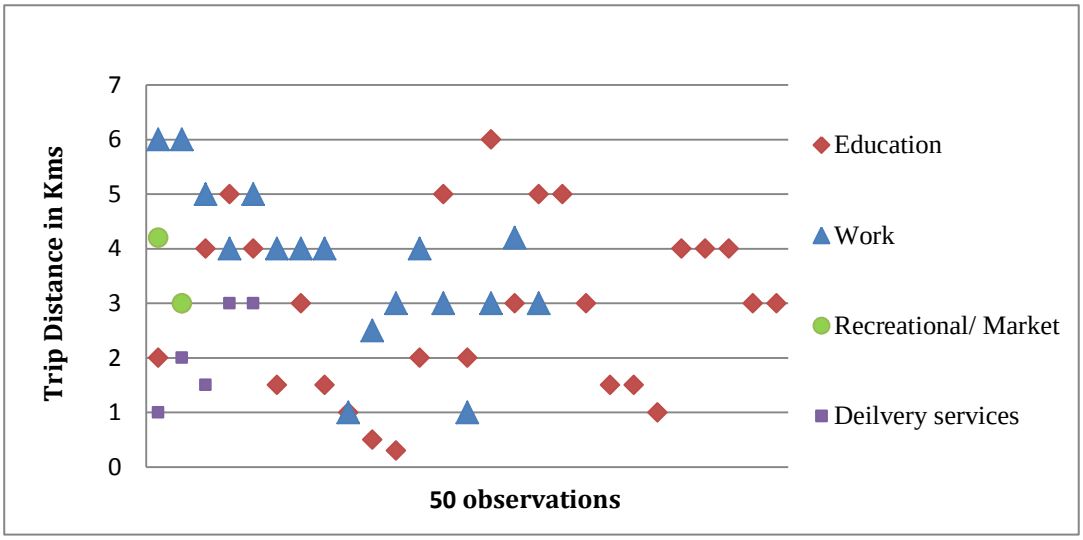
transport used by them other than bicycles. They were also asked about the threat or other factor like crime, extortion, robbery which were discouraging their bicycle usage for their daily usage.

Responses

The responses were in Gujarati and were later translated in English (see annex 3). 16 out of 50 answered that they use bicycle daily for school-home trip, while 11 people used bicycle for college-home trips. 15 said, they use bicycle daily for their work-home trip; 3 used bicycles daily for delivering milk while 2 used the bicycles daily for news-paper delivery. 3 people said that they use bicycles to go to market while remaining 1 said he uses bicycle for recreation. From this analysis it was clear that 27 out of 50 were Educational trips**;** 15 out of 50 were work trips 5 out of 50 used bicycles for delivery services and while rest of the people were not the daily users of the bicycles. It is known to use from the literature that 12 % of bicycle trips made by urban poor. From the limited interviews conducted on the junctions, the poor were not directly identified, but on the basis of local knowledge, I can assume that the some people who delivered newspapers or lower wages workers may be poor and residing in the slums or informal settlements. Though, the 50 samples are not very representative of 1.19 million people in Rajkot, but on the basis of literature, field inventory, local knowledge about the condition in India; and those 50 interviews, the Educational Institutes, Industries and Slums were considered as factors which are generating the demand in Rajkot which answers the research question 1.

From the responses it was identified that the trip journey were in between (< 1) up-to 6 km. Graph below shows the trip lengths identified from the interviews.

Figure 9: Graph showing trip lengths by trip purposes



The graph shows that there is no specific pattern of trip lengths according to the trip purposes.

When students were asked about the reason to use bicycle, the common answers were don't possess a motor-bicycle licences; school bus is expensive, parents refuse to buy a motor-bike; auto-rickshaw is non-affordable; petrol rates are non-affordable or if the trip destination is very close to the house (see annexes 2) Some students answered that they enjoyed going to school on bike with friends than going by a bus. From the above answers most of the bicycle users are forcefully using the bicycles i.e. they are the captive users of the bicycles. This means that the users are either legally dependant (no license) or economically dependent (affordability) on bicycle usage in India. But even then there were 4 people observed who

enjoyed biking to school with friends, while 1 person was observed to be a recreational user. This means that some people prefer biking than using motorized modes. After talking with the people in the tea shops it was also identified that there is a recreational bicycle user group which operates via social networking site (Facebook) and carry out bicycle rides in the city on weekends.

When they were asked about the mode of transport available to them they said use of auto-rickshaw while being with the family (Mostly workers); use cars/motorcycles while being with parents (Mostly school/college students) some of them also used the share rickshaw as it is cheap mode of transport. These answers suggest that the Public transport (PT) mode is very weak in Rajkot and most of the users prefer to take auto-rickshaw and share-rickshaw which are semi-private modes of transports. Other people use their own vehicles for commuting. When people were asked about the threats faced while commuting, they said they use the same route every day and do not find any threat. This may be because of them getting used to those roads. Because of limited interviews, the areas showing any discouraging factors couldn't be identified in the city (see annexes 2).

The survey indicates that most of the trips in Rajkot are Educational, Work trips and affordability being one of the issues can help in assuming that the slums are the areas from where few bicycle trips are being made. Therefore, the trip generating factors used in this research are Educational institutes, Industries and slums.

3.2.1.2. Secondary data

The analysis was to be done in GIS; therefore the GIS point source data set was prepared by digitizing the schools and industries with reference to Wikimapia (Open street map) and verifying it from Google earth. The slum locations were digitized referring to the map from previous study report and were verified from Google earth. A road feature class was received from CEPT University during the field work. The roads chosen for this study had to be defined based on the attribute information present in the road feature class; importance of the road from previous studies and by confirmation from Google earth and Wikimapia

3.2.2. Data to carry out supply based analysis.

Based on the literature, it was identified that the supply based analysis can be done by checking the quality of infrastructure existing in Rajkot. The quality can be checked by various methods i.e. by asking the local people about the existing infrastructure, field observations etc. But for this research, it was decided to use the U.S.A based method to identify the quality of infrastructure in Rajkot. The U.S.A based method is based on perception of people towards the infrastructure. For instances, the perceptions of people are acquired and compared with the characteristics of the road. Landis et al. (1997) articulates bicycle level of service (BLOS) is the function of roadway characteristics i.e. the conditions prevailing on the road i.e. traffic, road width, speeds of vehicles etc. can determine the BLOS in the city. Therefore, this study requires perceptions of the people which would indicate the BLOS on some of the road segments in the city. By recording BLOS perceptions and comparing them with the road way conditions using multiple regression analysis, a model can be prepared which would identify the BLOS in the road segments in entire study area. Therefore, the primary data requirement of this research to carry out supply based analysis is the perception of people on the road segments of Rajkot.

3.2.2.1. Primary data

From the literature, we known that the approach taken by (Landis et al., 1997) to acquire the perceptions from the people was, by inviting people to ride bicycles on the road segments and grading the segments as per BLOS perceived on the segments. For this research, workshop was conducted in order to identify the perceptions of the people in Rajkot. For the participation in the workshop, it was necessary to have as many people as possible. In order to get the participants, a message was sent to the "Rajkot Bicycle Group" which is a volunteer bicycle group on a social networking site (Facebook). But, appropriate responses was not gained from the group as only few people replied that they were busy with their daily schedule and were not able to attend the workshop. Others who may not be frequent users of social networking sites didn't reply to the message. After waiting for three days without any response, it was concluded that there would not be any participation from the volunteer user group, a secondary approach of hiring people was used. After consultation with organisation who was responsible for household survey (hired by CEPT for Low carbon mobility plan), an arrangement was made to meet 9 university students who know how to ride the bicycles. I and a colleague from CEPT University working on Low Carbon Mobility Plan also participated in the workshop so that the total amount of participants would be 11. These university students had ages varying form 18-22. The statistics of the samples is as follow

Table 5: Statistics of the participants

Participant No	Occupation	Age	Frequency of biking	Reason for Biking/ Not biking
1	student	18	daily	affordability
2	student	19	occasionally	possess motorbike
3	student	19	daily	don't have a motorbike
4	student	18	was daily user during school days	possess motorbike
5	student	20	daily	share rickshaw is time consuming
6	student	20	not much	possess motorbike
7	student	19	not required to use	possess motorbike
8	student	18	daily	college is nearby
9	Student/part-time survey for LMCP project	22	occasionally	possess motorbike
10	CEPT employee	25		
Myself	ITC student	26		

The participants agreed on spending 2-3 hours per day for the workshop as they had to attend the college for the rest of the hours in the days. The workshop was conducted on week days as the students refused to work on weekends. The students spoke Gujarati, little Hindi. They said they read and understand English but were not fluent in speaking. To carry out the workshop a detailed plan was made. Participants, myself and the employee from CEPT, we sat together to discuss about how to carry out the workshop. The questions rose in the discussion were.

1) What are the factors, which make people feel unsafe and uncomfortable?
2) How to grade these factors
3) Which roads need to be to be chosen for the perception study?

During the discussion a list of factors was made which makes the trips unsafe and uncomfortable so that these factors will be graded individually on the particular road segment. It was decided to segregate the road way traffic in-to Motorbikes, Auto Rickshaw and cars as perception can be identified based on each

of the modes prevailing on the road segment. This was because of the point raised in the discussion, about the routes in Rajkot with less Auto Rickshaws frequency and some of the road had fewer amounts of cars due the road width. Road width, pavement conditions and gradient was chosen for perception of comfort of riding the bicycle. Other factors which make bicycle rides un-safe were street vendors, on-street parking and animals as they are the main causes of accidents. The last factor was tree shading on the roads, it was chosen as few participants insisted on it due to the sunny weather experienced by them. Grading Form was prepared which had all the factors printed on it, while the participants just had to grade the factors on basis of what they perceive. Regarding the grading, it was decided to choose the 5 point grading scheme, 1 best performance of the factor while riding and 5 is least performance causing trouble to the riders.

Table 6: Grading scale

1 is Best condition	best implies when the performance of the factor is optimum for bicycle ride
2 is Good condition	Good implies when the performance of the factor is good but can be improved further
3 is Neutral condition	Neutral implies when the performance of the factor is nether good not bad
4 is Bad condition	Bad implies when the performance of the factor is bad and need an improvement
5 is Worst condition	The worst condition implies when there is a serious issue of threat by a factor while biking.

The grade given to factor indicates good/bad performance of that factor in terms of cycling on a particular road segment.

The selection of roads was done on the basis of their importance in the city. In total 11 roads having various characteristics i.e. high traffic counts, traffic congestions, adjoining bus or railway stations, higher bicycle counts, recreational centres, universities, schools, slums etc. were chosen for the analysis. Amongst these some were the radial roads showing the characteristics of inward-outward traffic, some were central roads frequently used by the people and some were the city roads catering east-west and north south traffic in the city. 150' ring road shown in figure 5 (section 3.1.3) was also chosen for the analysis as it has an existing bicycle track, but people are still not making use of it. It also has a newly developed Bus rapid transit (BRT) line running from the centre of the road. The BRT corridor and the cycle track have reduced road-width. The analysis was carried out on the main road and not on the track as the cyclists are still using the main road for commuting. Adjoining figure 10 show the road segments selected for study. The segments had

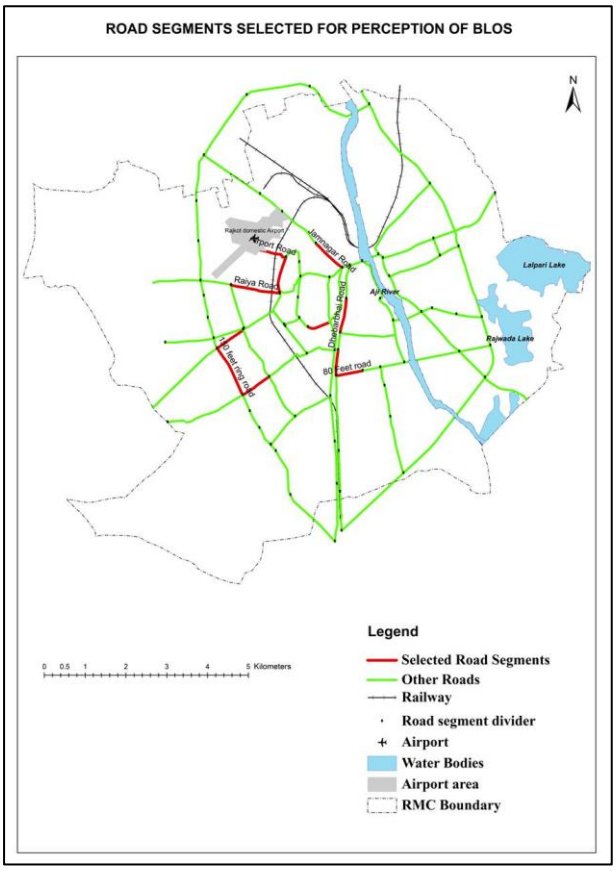


Figure 10: Selection of Road segments

variations in the lengths.

Table 7: Road segments for acquiring perceptions

Road name	Segment length in KM.
Kalavad road (Kotecha Chawk to KKV Chawk)	0.7 kms
150' Ring Road (KKV Chawk to Nanamuva Chawk)	0.9 kms
Race course road (From Race course Garden to Airport road)	0.9 kms
Dhebarbhai Road (From VV complex to Dharti Bank Chawk)	0.36 kms
Dhebarbhai Road 2 (Dharti Bank Chawk to Nagrik Bank Chawk)	0.5 kms
Raiya road (From Kalyan High School Chawk to Railway crossing)	0.9 kms
Dr Yagnik road (Raj Kumar College to Kotak Mahindra Chawk)	0.8 kms
Airport road (From Race course to Sivnandan Society)	0.3 kms
Jamnagar Road (GT Seth eye hospital to Mochi Bazar circle)	0.7 kms
Nanamuva road (Nanamuva chawk to Laxmi Nagar underpass)	0.5 kms

Last part of the discussion was the drill which was to be carried out by the participants during the workshop. Participants were told to come at 9 am in the morning so as to acquire perceptions during peak hours. The participants had to ride the bicycle on the selected road segments and register their perception on a grading form. They were told to grade the factors occurring only on the segments and not on the junction present at the starting/end of the segment. The drill was to stop at the end junction of the every selected road segment and write down the perceptions. The group of 11 people was divided in-to 3 parts to avoid chaos as the traffic counts on the roads are high during the peak hours. One group was led by me; other group was led by the colleague from CEPT University and the 3rd group was led by a part-time surveyor (from organisation outsourced by CEPT of survey).Three groups used to go in different directions for the analysis of the road segments. The workshop was organised for 3 days (but took 5 days because of political visit of a minister in Rajkot) considering the 2 hours of time decided with the participants dedicated to the workshop. Every day one group had to cover 3- 4 roads. Each and every group had to cover all the roads which were decided. On each day, after the workshop, a meeting point was fixed and the forms were collected from the participants. The sample of grading form on one of the road segments is in (annex 4). Every participant had to cover all the 11 selected road segment and grade all the factors present in the grading form as per the table 6. See (annexes 4) for the table of data recorded. Landis et al. (1997) suggest, there should be one quality indicator for 1 road segment by one observer. But in this study different factors were graded differently in order to identify the importance of these factors from the perspective of the users. The significant factors showing higher grades i.e. 2 wheelers, auto-rickshaw, cars, on-street parking, street vendors and pavement conditions were summarised and an average of these grades was taken as a 1 observation by 1 participant which made it similar to the previous study.

Table 8: Perception data conversion into 1 observation

Factors	Grades
2 wheelers –	Grade 4
3 Wheeler -	Grade 4
4 Wheeler –	Grade 3
Road width –	Grade 4
On-street parking-	Grade 3
Street vendors-	Grade 4
Pavement conditions-	Grade 3

1 quality indicator on 1 segment = (∑grades)/no of variables.
Factors like tree shading were omitted as no road in the city had considerable amount of tree-shading and all were graded as 5 in terms of tree shading. The animal obstruction was omitted as road segment was observed to have animal obstruction during the peak hours due to the limited observations. 11 such observation on each of the 11 road segments comprises to 110 observations for this study with quality grades ranging from 1 to 5. This answers the research question 5 i.e. factors determining good or bad infrastructure in Rajkot.

Summary of the survey
From the field observation it was identified that there is a lot of variation in the variables chosen in the U.S.A for analysis and the factors prevailing in Rajkot.

- The existing model doesn't take into consideration the factors like On-street parking, street vendors, tree shading and animals which are essential for identifying the performance of BLOS in India.
- Other than that the factor like road width has a lot of variation in context of Rajkot. One model will not be able to adjust the varied lengths on different roads of Rajkot. The traffic counts observed on the roads had lot of variation, and there was no specific pattern of traffic depending upon the road type. Cyclist were struggling on the roads with less width as there was very less space left for them to travel.
- The roads identified in Rajkot were single lane (single carriageway), double lane (single/duel carriageway) and four lanes (duel carriageway). The speed limits were not defined on the roads; it was dependent on the amount of traffic present on that road. The model developed by (Landis et al., 1997) depends on the outer lane width which does not exist on some of the road. The cyclists are found on all the lanes of the road wherever they find the place to travel.
- Another issue was auto-rickshaw parking. There were few legal auto-rickshaw stands observed in the city, but most of the rickshaws were parked in illegal places which were creating traffic congestion and problem for the cyclists.
- Model uses % of heavy vehicles which is non-existent in Rajkot as the vehicles are banned to enter the city for 8 am to 8 pm.

3.2.2.2. Secondary data

It is necessary to have the data related to the roadway characteristics in order to compare with the perceptions to run the model. This data was collected from the CEPT University office. The secondary data available was digitized road network with road names, road type, carriageway width (road width considering more than one lane separated by a painted lines)(The Alliance of British Drivers, 2011)), number of lanes and average speeds calculated for all the modes. Traffic counts were available in Excel format which were collected on the major junctions of the city. This traffic counts were latter put in in the attributes of the road using editing functions to manage databases in ArcGIS.

The only road way factors available for this study were Traffic counts/lane in 15 mins, Carriageway width and average speeds. From the U.S.A based method, we know that these factors would have an influence of the Perceptions. Therefore Pearson's co-relation analysis was chosen to identify the co-relation of the factors with perceptions. The traffic counts were bigger values which had to be normalized using Natural log to make it comparable with the perceptions which are in range of (1-5), as done in previous studies. The results of Pearson's co-relation are shown in table 7.

Table 9: Pearson correlation results

Correlations

Correlations		observed values	15 mins traffic/lane	speeds	width in meters
observed values	Pearson Correlation	1	.378**	.233*	-.105
	Sig. (2-tailed)		.000	.011	.255
	N	120	120	120	120
15 mins traffic/lane	Pearson Correlation	.378**	1	.264**	-.670**
	Sig. (2-tailed)	.000		.004	.000
	N	120	120	120	120
speeds	Pearson Correlation	.233*	.264**	1	-.422**
	Sig. (2-tailed)	.011	.004		.000
	N	120	120	120	120
width in meters	Pearson Correlation	-.105	-.670**	-.422**	1
	Sig. (2-tailed)	.255	.000	.000	
	N	120	120	120	120

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

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

The results show that the Perceptions (observed values) have positive co-relation with the traffic and speeds in km. This means that if the average speeds and traffic counts on the road are high, the Perceptions value is high i.e. bad condition. But it is negatively co-related with the width i.e. less the width more is the Perception value i.e. bad condition. Due to the limitations in the quality of data received, which showed large amount of variation in speeds, traffic counts and width; it was able to show less accurate co-relations of the variables with the perceptions. Despite, the analysis helped in determining that these factors can be chosen to model the BLOS by using the method by (Landis et al., 1997). The other variables chosen in the U.S based model were % of heavy vehicles which was non-existent in Rajkot and the data related to the pavement condition was not available. From the availability of primary and secondary, multiple regression analysis can identify the co-efficient to run the model in case of Rajkot, to identify BLOS on roads segments of Rajkot and also check the credibility of the model (details explained in chapter 4).

3.2.3. Data for analysis on of demand and supply on the smallest administrative boundary

From the method used by Rybarczyk and Wu, the analysis is carried out on road segment level as well as the neighbourhood level. The data at the neighbourhood level is not available in case of Rajkot. For the on-going project related to the low- carbon mobility plan, the city is divided in-to traffic analysis zones (TAZ). "A traffic analysis zone (TAZ) is a special area delineated by state and/or local transportation officials for tabulating traffic-related data- especially journey-to-work and place-of-work statistics"(U.S. Department of Commerce, 2012). The city is divided into 183 traffic analysis zones to analysis and improvement in mobility. This (TAZ) data is available for the CEPT University for the analysis of this research. Therefore, (TAZ) are used instead of neighbourhoods to identify the spatial clusters of high demand and low supply in the study area. The TAZ is the lowest administrative boundary to be used for this research which answers the research question 8.

3.3. Summary

This chapter gave a brief idea about the settings in the study area. It describes the methods used and collected data in order to identify the supply and demand in Rajkot. This chapter answers research question 1, 5 and 7.

Research question 1: Which are the factors generating the bicycle demand in Rajkot?
Answer: From the literature review this question was answered partly, which was confirmed in this chapter by a survey technique to identify the factors generating bicycle demand. The bicycle demand generators in Rajkot are educational institutes, industries and slums.

Research question 5: What are the factors that determine good/bad infrastructure in Rajkot?
Answer: The good/bad infrastructure conditions are determined by grading the factors observed on the road in 5 point grading scale i.e. 1 signifies good condition and 5 signifies bad condition. 2 wheelers, 3 Wheeler, 4 Wheeler, Road width, On-street parking, and Street vendors are the factors used to analyse the quality of infrastructure in this research.

Research question 7: What are the major differences in infrastructure conditions in U.S.A and conditions prevailing in Rajkot which needs to be modified in the model?
Answer: The major factors which are different in Rajkot than American infrastructure are roadway width. The roads in U.S.A have outer through lane for bicycles but in Rajkot, the bicycle users are part of traffic and they have to utilize the carriageway width as roads of Rajkot are identified to be single lane, double lane with undivided carriageway. The other factors are street vendors, on-street parking which are non-existent in U.S but exist in Rajkot. The % of heavy vehicles is non-existent in Rajkot as there is a ban on heavy vehicles to enter the city.

Research question 8: What is the smallest administrative boundary that will be used for study?
Answer: The smallest administrative boundary which is used for the study is Traffic analysis zones (TAZ

4. DATA ANALYSIS AND DISCUSSION

From the previous chapters we know about the method to carry out the analysis of the research and the data available. This chapter will help in understanding the actual method used in this research to carry out the demand and supply based analysis. It also discussed about the modifications in the Rybarczyk and Wu and Landis et al. method for demand and supply based analysis respectively to make it suitable for the context of Rajkot. This chapter will answer the research questions 3, 6,9,10, 11 and 12 which will fulfil the objectives of the research

4.1. Demand based analysis

The demand based analysis was carried out to identify the demand on the road segments of Rajkot, by linking the trip destinations with the nearest roads. From the literature it was identified, if the areas attracting bicycle trips are linked with the road, the potential demand on that road can be identified. This method is adopted by Rybarczyk and Wu in his analysis, which is further adopted in this research with modifications.

From the survey, Educational Institutes, Industries and Slum locations were identify to be the demand generating factors, also with reference to the literature which confirms, 64% of the trips are made for educational purposes, 41 % by low income group i.e. workers and 12 % are made by the poor i.e. slum dwellers (Jain & Tiwari, 2010) which helps in choosing these variables for analysis. From chapter 3, we know that the about secondary data in GIS format i.e. point source files of educational institutes, industries and slums to be used in this research. The method explained in literature review for demand analysis consist of 3 phases 1) normalization of variable counts ; 2) Ranking and normalization of rank value ; 3) summation of the weighted normalized factors "(Rybarczyk & Wu, 2010*)* which will be adopted by modifications in context of Rajkot.

4.1.1. Modifications in Rybarczyk & Wu's method and method used in Rajkot

- Rybarczyk & Wu used 5 variables i.e. Crime, Businesses, Schools, Recreational areas, Parks, Population as these were the factors affecting the bicycle demand in Milwaukee City for recreational users only. In the context of Rajkot, the Educational Institutes, Industries & Slum locations are the factors generating bicycle demand. A technique used for normalization of the variable counts was same as the previous study.
- As Rybarczyk & Wu's study addresses the recreational users, higher ranking was given to crime, then to businesses, schools, recreational areas, parks and population consequentially according to their importance in generating the bicycle demand. In case of Rajkot, the study addresses the captive users. The educational institutes were given a higher rank because highest numbers of bicycle trips are the educational trips, as students being legally dependant on the usage of the bicycles. Despite to affordability of other modes, they use bicycles to go to school as use of bicycles being legal and most convenient mode of transport to make independent trips. Industries were given second rank as the industrial works are economically dependent on bicycle usage. For e.g. if a person gets a salary hike, he may switch to motorized modes of transport. Hence, they are not completely dependent on bicycle usage. The slums were ranked 3rd as the poor people who are un-employed and can't even afford food, wouldn't be able to afford and maintain a bicycle for traveling. As the study in Pune says, 50-75% of slum dwellers are the bicycle users therefore slums were considered with a lower rank.

- In U.S.A specific blocks have been developed in the city for planning. The literature says that the recreational bicycle users don't deviate more than 2 blocks i.e. 660 feet. Therefore, the variables falling in the range of 660 feet were linked with the road segments to identify demand at the road segment level. But in case of Rajkot, neither specific block have been developed nor is the data available which indicates the deviation of bicycles from the main road. Apart from that the users are captive; so they don't have much choice but to avail the facility. To solve this problem, "NEAR" function was used in ArcGIS to identify distances of facilities to their nearest road segment. The 'NEAR" function gave the distances of all the facilities and indicated the road segment located nearest to them. The result obtained after applying 'NEAR" function identified that all the facilities available for this study lie in the range of 400m from the road segment nearest to them. Therefore, 400m buffer was created along the road segment and the variables i.e. Schools, Industries and Slums were overlaid using a "SPATIAL JOIN" function in ArcGIS. In this way, the variables lying in the buffer areas were linked to their nearest road segments. The process resulted in identifying the variable counts existing on every road segment. These counts were utilized for the demand analysis.
- The variable counts were normalized using the below formulae

  $V_i' = (V_I - V_{min}) / (V_{max} - V_{min})$ for factors attracting bicycle trips…… (1)

  Where V_i' is the normalized counts of the factors, v_i is the original value of that factors, v_{max} and V_{min} are the maximum and minimum value respectively on any of the road segments in the study area" (Rybarczyk & Wu, 2010).

  After ranking the variables, the ranked values were normalized using the below formula

  $X_i = n - r_i + 1 / (n (n+1)/2)$…… (3)

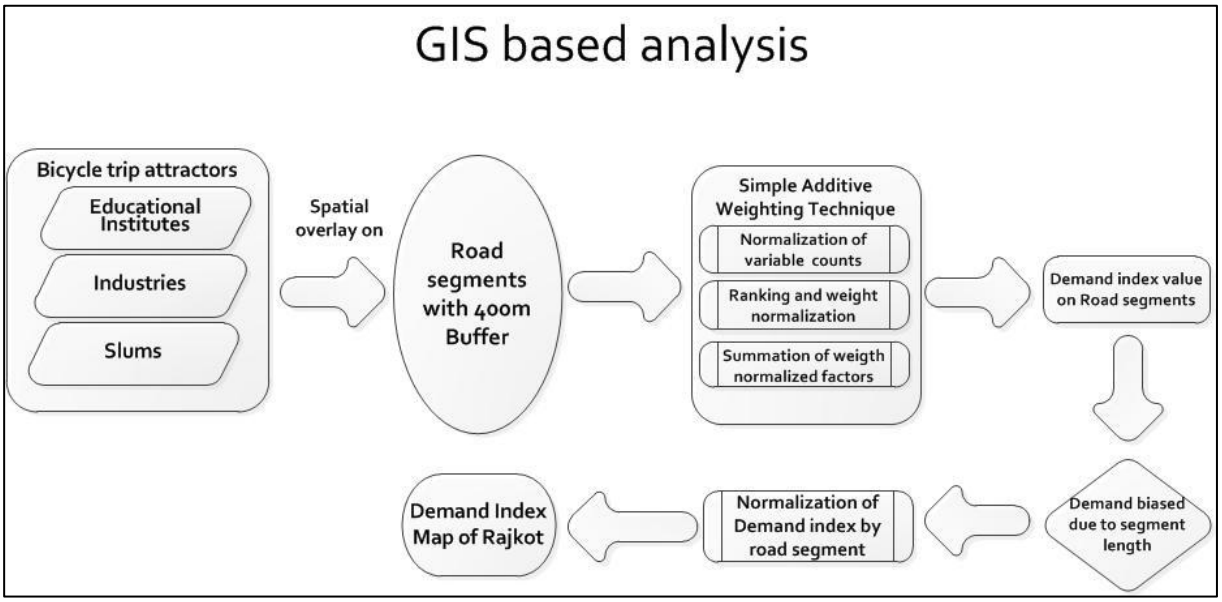
  Where X_i is the normalized weight of ranked factor; n is the count of factors under consideration; r_i is the rank position of the factor
  (Rybarczyk & Wu, 2010).

  The demand is calculated on the road segment using the formulae:
  $\text{"Demand} = \sum_i^n XiVi'$…… (4)
  $(i = 1 \ldots . n)$ (Rybarczyk & Wu, 2010) from the equations (1) & (3)

- From above equations, demand index on the road segments of Rajkot was calculated. This demand is latent demand in the study with values ranging between 0 and 1. The potential demand on a particular segment is high when the value is close to 1
- In case of U.S.A the roads segments are divided in equal length and follow specific grids. In case of Rajkot, the segments had variables lengths and were creating bias results i.e. long length segments were having more counts of the variables than shorter segments which was leading to higher demand on long length segments. This issue was resolved by normalizing the demand index by segment length. The normalization function in ArcGIS divides the demand index by segment length to eradicate the bias caused due to segment lengths. Thus the un-biased demand index was calculated on the road segments of Rajkot. The process of demand identification answers the research question 3 i.e. modification to adapt and adopt the demand based analysis in Rajkot. Below is the thematic representation of the process followed to identify the demand index on road segments of Rajkot.

Figure 11 shows the GIS based process used to identify the demand index on the road segments of Rajkot

Figure 11: Process to identify the demand index on Road segments of Rajkot



The adaption and adopting of U.S.A based method to carry out the demand based analysis in this chapter answer the fully research question 2 i.e. utilization of demand generating factors for identifying potential demand on road segments of Rajkot. From the literature review, modifications methods for its adaption in Rajkot, and the above diagram; we know the process of identifying potential demand in Rajkot. Figure 12 is the map showing the results of the analysis.

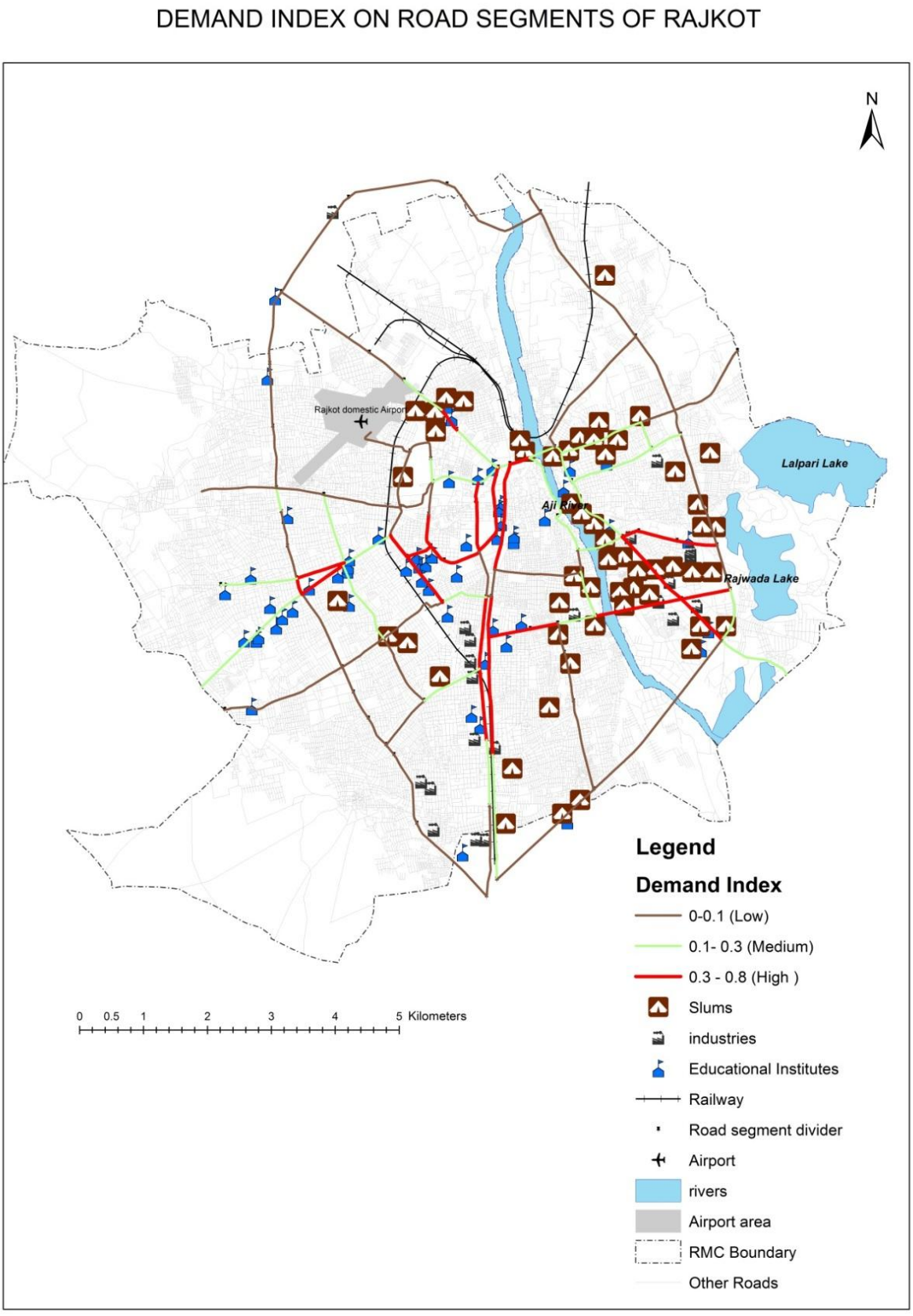


Figure 12: Demand Index map of Rajkot

4.1.2. Discussion on demand analysis

The above map shows the potential demand on road segments in Rajkot. The brown colour indicates the segments with low demand, green indicated segments of medium demand while the red colour indicates the segments showing high demand. The segments with high demand are mostly located in the centre of the city as most of the schools, Industries and slums are present in those areas. This demand is a relative demand i.e. the segments of high and low demand are specific to the context of Rajkot. Though this method has some limitations as it addresses the demand on the basis of ranking of variables and not the magnitude of the variables, for e.g. a big industry can have higher demand than a primary school or a slum would have more bicycle users than people going to school or an Industry. Overlooking the limitations, this method was successful in identifying the demands on the road segments of Rajkot which can be targeted for the improvements. It can also help in land use planning as new school and industries can be placed in the areas having lower bicycle demand. Next section will discuss about the analysis carried out to identify the quality of infrastructure provided for bicycle users in Rajkot.

4.2. Supply based analysis

As discussed in the literature review chapter, BLOS is the function of roadway characteristics. Continuing with the line of thought, the supply based analysis is carried out by adopting the model by (Landis et al., 1997) which compares the perceptions with the roadway characterstics to identify the quality of infrastructure (BLOS) in Rajkot. This model was adopted with some modification in the variables used for the analysis. The detailed process of aquiring perceptions is discussed in chapter 3 which indicates 110 perceptions acquired for this study. The availablity of secondary data is traffic counts/lane in 15 mins, speeds and the carriageway width in meters; for this research.

U.S.A based model reads

$$BLOS = x_1 \ln (Vol_{15}/lane) + x_2 Spt (1 + \% HV) + x_3 (1/PR_5) + x_4 We^2 + C$$

Where

"Vol_{15} = volume of directional traffic in 15 min,

Lane = number of directional through lanes,

Spt = speed limit, the posted speed limit determined by the Wisconsin Department of Transportation, U.S.A;

HV = percentage of heavy vehicles;

PR_5 = Federal Highway Administration, U.S (FHWA)'s 5-point pavement surface condition rating (e.g. 5 represents the best),

We^2 = average effective width of outside through lane" (Rybarczyk & Wu, 2010). From the availability of the data and considering the conditions in Rajkot the model developed in this research is below.

Model in context of Rajkot reads

$BLOS = x_1 \ln (Vol_{15}/lane) + x_2 S (1 + \% HV) + x_3 W + c$ ..... (7)

↕ ↕ ↕ ↕

Setting Variable Co-efficient Constant

BLOS is the recorded perception; Vol_{15}/lane is the 15 traffic of volume per lane in 15 mins, S is the average speed in Km/hr and W is the carriageway width in meters.

The multiple regression analysis was used to compare the BLOS with the roadway variables, in order to identify the coefficients i.e. x_1, x_2, x_3..... and the constant of regression. Figure 13 show the process of calibration and validation of the model

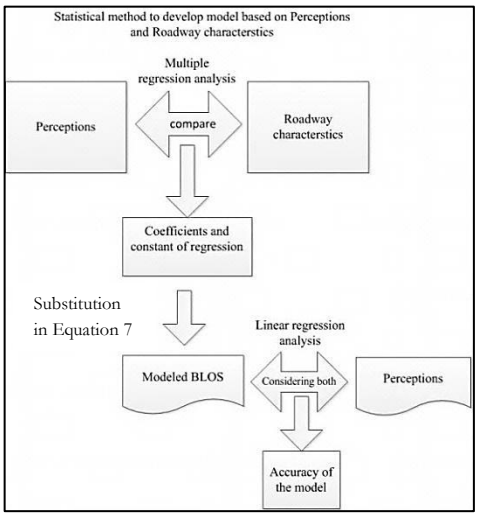


Figure 13: Multiple regression method to develop BLOS model

The perceptions and the roadway characteristic were entered in SPSS software. The perceptions were selected as dependant variables while the roadway characteristics were selected as independent variables. The multiple regression analysis was run in order to obtain the co-relation between the Perceptions and the roadway characteristics. Below is the result of multiple regression analysis.

Table 10: Results of Multiple regression analysis for 110 observations

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.481[a]	.231	.211	.7846571

a. Predictors: (Constant), speeds, 15 mins traffic/lane , width in meters

The results indicate the multiple regressions co-efficient is 0.481 which indicates that the positive co-relation exists between the variables and the perceptions. This multiple regression co-efficient value lies between 0 and 1 which indicated 1 as strong co-relation and value obtained from this analysis is moderate. R square is 0.231, while in U.S.A it was 0.73. This indicates that only 23% of variables of Roadway can be predicted the perceptions to identify BLOS in study area.. This means that there are other variables which

have an influence over the perceptions other than the variables used for the study. Even though the accuracy was weak, the analysis was able to identify the co-efficient and constant in order to identify BLOS in the entire study area. Below is the table that shows the significance of the model; co-efficient and the constant obtained from the multiple regression analysis to identify BLOS in Rajkot.

Table 11: Significance test

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	21.492	3	7.164	11.636	.000[b]
Residual	71.420	116	.616		
Total	92.912	119			

a. Dependent Variable: observed values

b. Predictors: (Constant), speeds, 15 mins traffic/lane , width in meters

The above result indicates that model is well fit, as it has to be less than 0.05 i.e. 95 % confident level

Table 12: Coefficient obtained from multiple regression analysis

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-3.648	1.297		-2.812	.006
15 mins traffic/lane	.704	.136	.567	5.170	.000
width in meters	.158	.049	.378	3.235	.002
speeds	.076	.028	.243	2.701	.008

Dependent Variable: observed values

Table 12 gave the coefficients and the constant for the model. The unstandardized coefficients were used in the analysis as the variables don't possess a standard scale. The sig. indicates that accuracy with 95% confidant level. These co-efficient were used in (equation 7) to obtain the BLOS from the model. The expected BLOS values are calculated based on the 110 observations and multiple regression technique. The expected values from the model were compared with the observed values (perceptions) in Microsoft Excel. Figure14 showing the results of comparison.

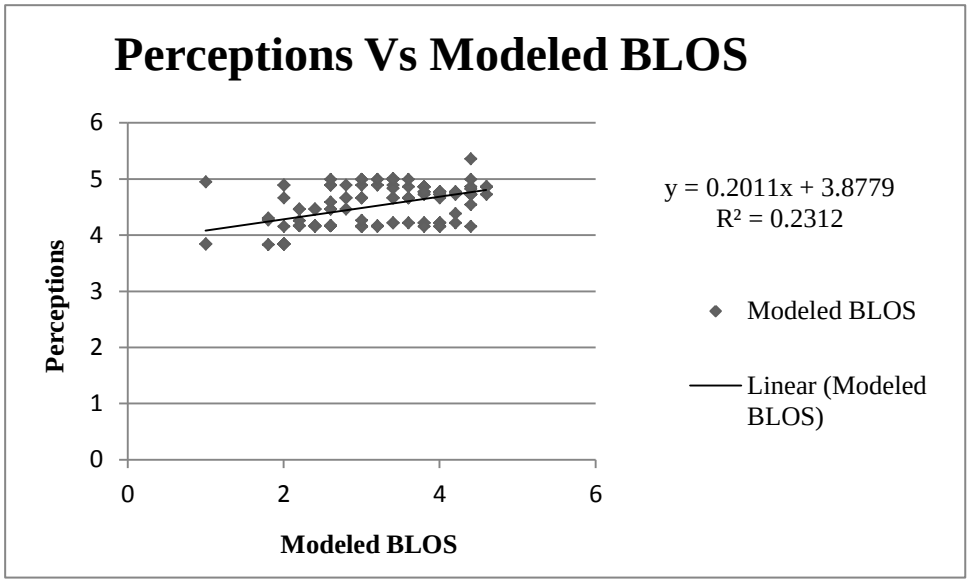


Figure 14: Model Accuracy

From figure 14 we can say that the comparison between the observed value and the predicted values shows 23% accuracy. From this, we can conclude that the result of the model is relatively poor for Rajkot. The values obtained from the model show variation due to uneven traffic counts on various roads, variation in carriageway width of 1 lane and 4 lane roads while the speed on the different roads are different. This model can only give a blur idea about the existing bicycle level of service in Rajkot. This answers the research question 6 i.e. method to run model based on perceptions

Even though the model accuracy was weak, it showed a positive co-relation amongst the variables and the perceptions. Hence it was used to predict the BLOS in the entire study area. Figure 15 is the map which is generated from the model that indicates the bicycle level of service in Rajkot.

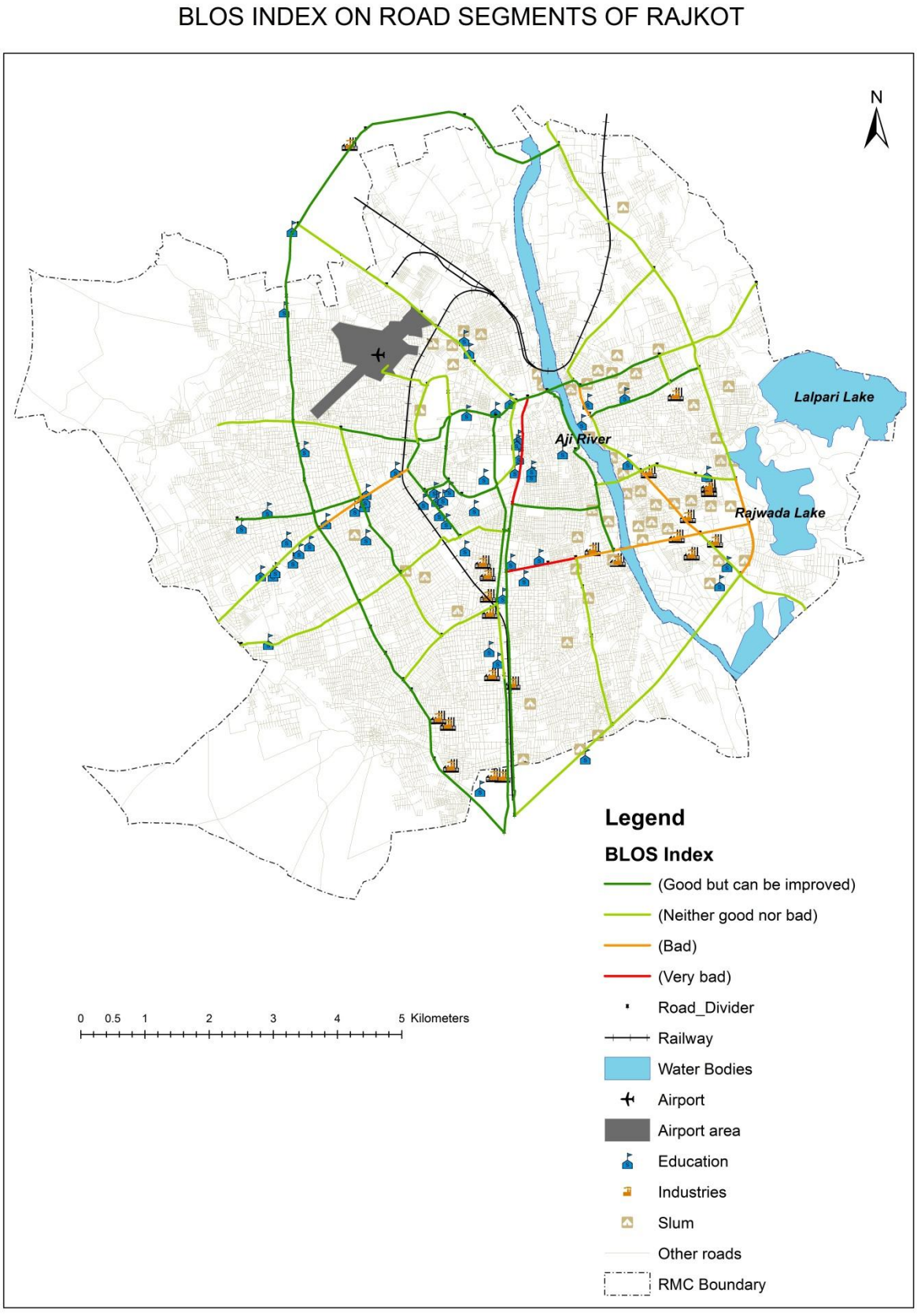


Figure 15: BLOS map of Rajkot

4.2.1. Discussion of Supply based analysis

The map in figure15 shows the bicycle level of service on the segments of Rajkot along with the significance differentiated by colours. In order to analyse the BLOS in a scale on the basis of grading which was done on the roads during the time of data collection i.e. grading from (1-5), same scale was used to analyse the results of bicycle level of services predicted from the model. The values of BLOS in the study were varying between 2 to 5. The values between 2 and 2.9 were considered as grade 2 i.e. (good but can be improved), 2.9 to 3.9 were considered as grade 3 i.e. (Neither good nor bad), 3.9 to 4.9 were considered as grade 4 (Bad) and values above 4.9 were considered as 5 i.e. (very bad). The values only till 0.9 were clipped in one grading scale because for e.g. the values between 2.9 and 3 would predict the condition which is similar to the 3 scale. This would adjust some ± error as the model show only 23% accuracy.

Reasons for the meagre results in the model may be

- The variables other than the used once have an effect on the perceptions.
- The accuracy in the collected data can affect the results
- The time of observation may be different from the time of data collected by the CEPT University.
- The differences in traffic at that particular moment of observation and data collection.
- The traffic counts at the time of collection may be high compare to the normal day.

4.3. Analysis over the Traffic analysis zones (TAZ)

Up till now the research was carried out on the road segment level. But as mentioned in the literature, the Rybarczyk and Wu (2010) carried out the research on road segment as well as neighbourhood level. From the data collection chapter we know that the replacements for neighbourhoods are the TAZs in case of Rajkot. The supply and demand analysis on the road segment was overlaid on the TAZ using the spatial join function in ARCGIS. "The mean BLOS at the TAZ was identified by summing the values in the TAZ and dividing by the number of road segments. The mean Demand was identified by summarising the values and dividing by the TAZ area" (Rybarczyk & Wu, 2010). Each TAZ polygon was assigned a supply and demand value by the above method. A Global Moran's I technique was used to identify the strength of auto-correlation between the TAZ, while the local Moran's I was used to identify the areas showing similar values i.e. spatial clusters of supply and demand. The Global and Local Moran's I was identified for supply and demand separately. Below is the thematic representation of the method used for analysis at the TAZ level.

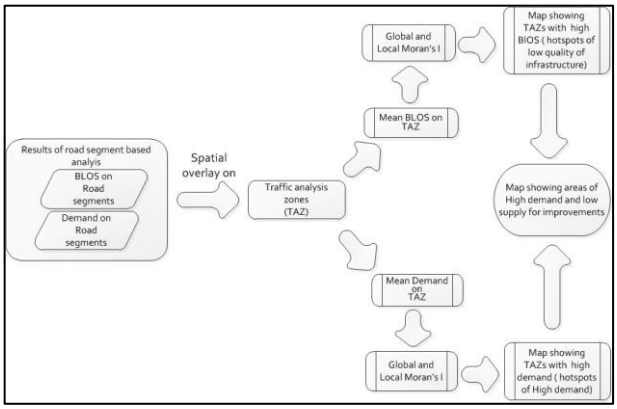


Figure 16: Moran' I technique

4.3.1. Results of Global Moran' I

An automated results is generated by ArcGIS software to analyse the Global Moran's I. Below are the results of both supply and demand side of the analysis.

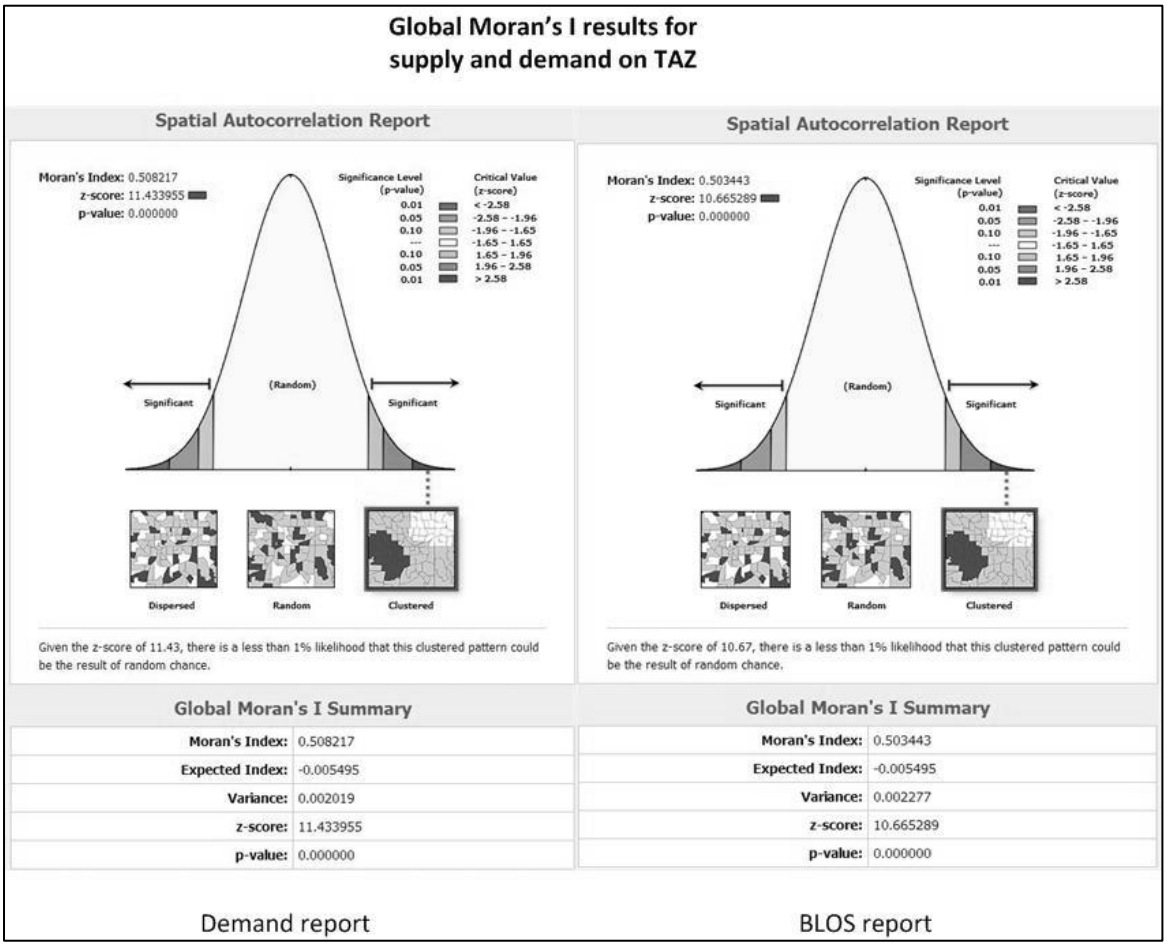


Figure 17: Global Moran's I results

The Moran's I value for demand is 0.50 which indicates a good overall positive spatial autocorrelation exists amongst the neighbourhoods. The z-score is 11.43 which indicate high significance of the areas with high demand being clustered together in the study area. The Moran's I value for BLOS is 0.50 with z-score 10.66 which also indicates the areas of low supply in the study area are clustered together.

4.3.2. Results of Local Moran' I

The local Moran's I is represented in the form of Maps prepared in ArcGIS. The maps show values i.e. High-high, High-low, low-High, Low-Low. High-high and Low-Low indicates the positive auto-correlation amongst the neighbourhoods, while the High-Low and Low-High indicates the negative co-relation amongst the neighbourhoods. This Local Moran's I helped in identifying the spatial clusters (hotspots) of areas with High demand and low bicycle infrastructure (BLOS). The maps below show the areas with hotspots of high demand, low supply and the combination of both, which can to be the areas of interest for policy makers to improve bicycle conditions in Rajkot.

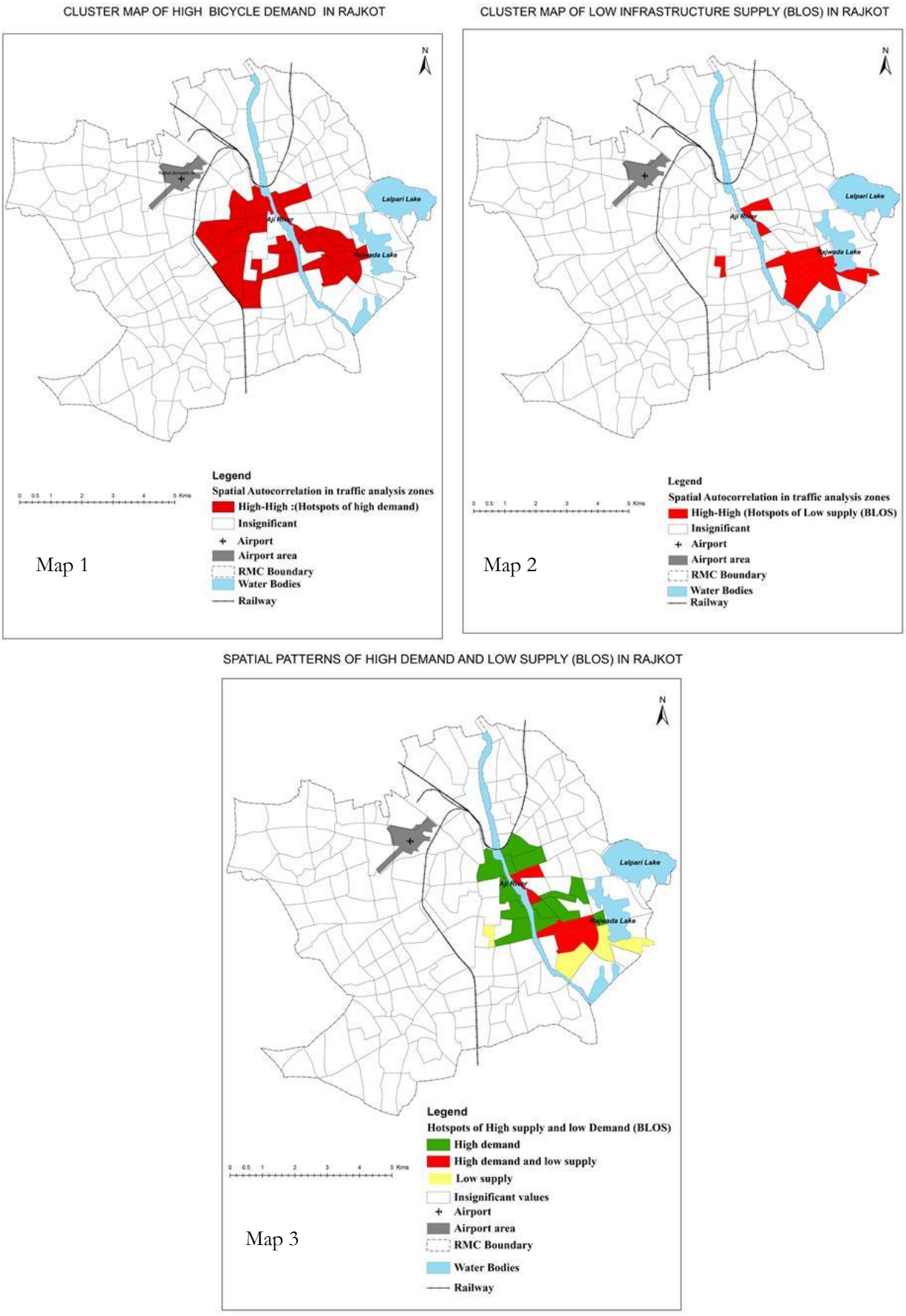


Figure 18: Hotspots of Low supply and High Demand

4.3.3. Discussion

Hotspot analysis of High demand

In figure 17, Map 1 shows the hotspots of high demand areas. From the study, we know that the areas with high demand were identified by linking the Educational Institutes, Slums and Industries with the road segment. This means that the road segments linked to maximum number of schools, Industries and slums will have higher demand. The demand analysis was taken further but overlaying the road segments over the traffic analysis zones using GIS technique, which exported the demand index values in the traffic analysis zones. Therefore, looking at the above map we can say that the hotspots with high demand have more number of Educational Institutes, Industries and slum location, which generate the bicycle trips in these areas.

Hotspot analysis of Low supply

Map 2 shows, the hotspots with low bicycle infrastructure quality (BLOS) in Rajkot. BLOS is a perception of an individual, about road segment, based on traffic, road width, street vendors, on-street parking, and pavement conditions. This perception, was modelled using the secondary information i.e. traffic, averages speed and road widths on the road segments chosen for study in Rajkot. The research is based on adapting and adopting the U.S.A model in context of Rajkot. In spite of the limited accuracy, model was able to generate BLOS values to indicating low infrastructure areas in Rajkot. BLOS values were exported in the traffic analysis zones and hotspots were identified. These hotspots are the areas with narrow roads. The other factors prevailing in these areas are high traffic, on-street parking, and street vendors. These areas can be taken up by policy makers to improve the bicycle infrastructure, which will encourage more bicycle trips in the city.

Low supply and High Demand

Map 3 shows the combination of areas with high demand and low supply in Rajkot. These are the areas which need to be improved in order to improve the travel conditions of the existing bicycle users in Rajkot.

From discussion we know about the locations of hotspots and how do they contribute to the improvement; which answers research question 10.

4.4. Policies to improve bicycle facilities in Rajkot

From the analysis, we have identified the areas for improvement in Rajkot. These areas are located in the centre of the city. Considering the ever growing population, increase in number of schools, industries there are chances of increase in bicycle demand in these areas. But if bicycle infrastructure does not improve in the coming years the areas will be completely congested and there will be absolutely no room for further bicycle usage. This will lead to discouragement in bicycle usage and increase in motorised transport which will add to the already existing high vehicular emission. Therefore, for low carbon development, the hotspots of high demand can be converted into bicycle zones by restricting the motorised traffic in these areas. On-street parking and street vendors can be restricted on the road and road width can be increased to create space for the bicycle users. Separate lanes and crossings with proper marking can be provided in order to segregate the bicycle user from the regular traffic. Right of the way procedures can be improved with 1st priority to the bicycle users, which will discourage the use of

motorbikes in the city. Animal should not be allowed on the roads. Increase in tree plantation will create a shade for bicycle users during summer.

The hotspot analysis can also help the policy makers in land-use planning. The locations for new schools, industries can be in the areas where less bicycle demand is identified, which would balance the bicycle demand in Rajkot; and thus, lead to the answers of the research question 11. As the city occupies only 105 sq. km of area, improvement in the bicycle facilities, right of the way policies, and increase in the road width with restriction on street vendors and on-street parking will considerably cut down the motorized usage in Rajkot. The decrease in motorized usage will lead to reduction in carbon emissions which will contribute to the low carbon development serving the main objective of this research, and answers the research question 12.

4.5. Summery

This chapter discusses about the methods used to analyse the supply and demand on the road segments as well as TAZ in Rajkot. The research question 2 and 6 which were partially answered from the literature review are fully answered in this chapter by the analysis process. Answers of research questions 3, 6, 9 and 10, 11 and 12 are as follow

Research question 3: What modifications are required to adapt and adopt the U.S.A based method for analysing the demand in case of Rajkot?
Answer: The modifications required to adapt and adopt the U.S.A based model for demand analysis were

1) Variables chosen were in context of Rajkot.
2) The distance of factors to be linked with the road segment was considered with respect to Rajkot as no specific blocks are identified in Rajkot, which determines travel behaviour of people like the way it is in U.S.A
3) The road segments in Rajkot were variable unlike U.S.A, therefore the demand index had to be normalized using the segment length

Research question 6: What are the modifications required to adapt and adopt the supply based model in context of Rajkot
Answer: The modifications required for adaption and adoption of supply based model are as follow

1) Variables were chosen in context of Rajkot
2) Carriageway width was be considered instead of outer lane width as outer lane doesn't exist on some of the roads in Rajkot
3) Average speeds were considered instead of effective speed limits as no data is available which determines the speed limits on roads of Rajkot.

Research question 9: What GIS techniques will be useful for the analysis?
Answer: Various GIS techniques were used for the analysis.

1) A "near" function was used to identify the distances of variables form the nearest road segment to create a "buffer" in the demand based analysis.
2) For TAZ analysis "spatial join" was use to overlay the data on road segments over the neighbourhoods.
3) The "Global and Local Moran's I" technique was used to identify the strength of autocorrelation and identification of hotspots of high demand and low supply respectively in Rajkot.

Research question 10: Where in the city are hotspots located and what do they indicating?
Answer: The hotspots are identified to be located in the central part of the study. The hotspots indicate the areas with high demand and low supply which can be taken up for improvements in bicycle facilities in Rajkot

Research question 11: How can we improve the bicycle conditions upon the hotspots?
Answer: The bicycle conditions can be improved by implementation of following things

1) Creating bicycle zones
2) Increase road width, restrict on-street parking and street vendors
3) Construction of bicycle lane.
4) Right of the way policies

Research question 12: How will the improvement lead to low carbon development.
Answer: The improvement in bicycle facilities in small area i.e. 105 sq. km will lead to increase in the bicycle usage leading to decrease in motorized usage. The decrease in motorized usage will lead to the reduction of carbon emission leading to low carbon development.

5. CONCLUSION AND RECOMMENDATIONS

This chapter will conclude the research. It will also provide some recommendations for improvement in the bicycle conditions in Rajkot.

5.1. Conclusion

In order to develop a low carbon transport system, a GIS based approach was used, which would improve the bicycle facilities in Rajkot. This research aims to increase the mobility in Rajkot by bicycle usage and reduces the usage of motorized transport in the city. The approach addressed demand of bicycle usage as well as the existing supply of infrastructure provided to the bicycle users in Rajkot. Despite only 3 % people using bicycles in Rajkot, the infrastructure system is identified to be rather weak. A U.S.A based approach was used to identify road segments with high potential demand in Rajkot considering the Educational institutes, Industries and Slums as demand generators. The quality of infrastructure (BLOS) was identified on the road segments of Rajkot by adopting the model developed in U.S.A. The accuracy of the adopted model in Rajkot was rather weak i.e. 23 % and needs modifications for its usage in future. This analysis was further taken on the traffic analysis zones to identify the hotspots of high demand and low supply in the city. The hotspots are the areas which needs improvement. The policy makers can take advantage of this hotspot analysis for the following actions (a) improvement in existing facilities. (b) Policy implications and (c) land use planning to the encouragement of more people to use bicycles in Rajkot. The increase in the bicycle usage with the reduction of motorized vehicles will lead to the reduction in carbon emissions, thus leading to the low carbon transport system in Rajkot.

5.2. Recommendations

The recommendations to improve the bicycle infrastructure, based on the problems identified in this research are as follow

- Road width needs to be increased with divided carriageway to make space for bicycle users
- Separate bicycle tracks, crossing and right of the way needs to be implemented
- Restriction on road vendors, on-street parking which are creating obstruction to bicycle users
- Cattles on the roads should be discouraged.
- Plantation of trees on the sides of roads to provide shade during summer.
- The city central roads are mostly single lane roads with less width. An experiment can be taken up to ban cars and Auto-Rickshaw on one of the days in the week to check if there is increase in number of bicycle users with such kind of provision (From discussion it was identified that the municipal Commissioner of Rajkot has made a similar provision for pedestrians on race course road. Every Sunday morning from 6 pm to 8 pm, traffic is banned on race course road).
- People should be made aware of the pollution caused by the motorized traffic and should be encouraged to use bicycles by rallies and awareness camps.
- Improvements in public transport and its link with bicycles will lead to considerable amount of reduction in motorized vehicles usage in Rajkot.

5.3. Future research

In future, if similar research has to be carried out, some steps need to be taken.

For demand analysis

- This research only considers educational institutes, industries and slums as factors attracting demand whereas there may be other factors which are generating bicycle demand, needs to be identified.
- The information about deviation of bicycle users off the main roads need to be known, which would help in identifying more accurate results of potential demand prevailing on particular road segments.
- The data related to the residences of the bicycle users will considerably enhance the results.

For supply analysis

- The observed perceptions had considered the on-street parking, street vendors while the secondary variable data for the comparison was not available.
- Repetitive readings of traffic counts are necessary for the improvement in results as lot of variation was seen in the traffic on different roads of the city.
- An extensive study of at least 3 months is required on the field for close analysis of all the factors affecting the bicycle level of services.
- GPS markings are necessary to identify the spots where road surface conditions are bad and require maintain ace.
- Rajkot has different variety of roads i.e. Single lane undivided, double lane (undivided/divided) and 4 lane divided roads. A single model cannot address all types of roads hence different models are required to address different types of roads.
- It is necessary to know the roads in the city where cattle is frequently identified so that the factor can be included in the model
- All the roads having/ not having tree shades need to be marked for the analysis.

Addition of the above steps in future would be able to generate very accurate and reliable results for the policy makers to improve the bicycle facilities in Indian cities.

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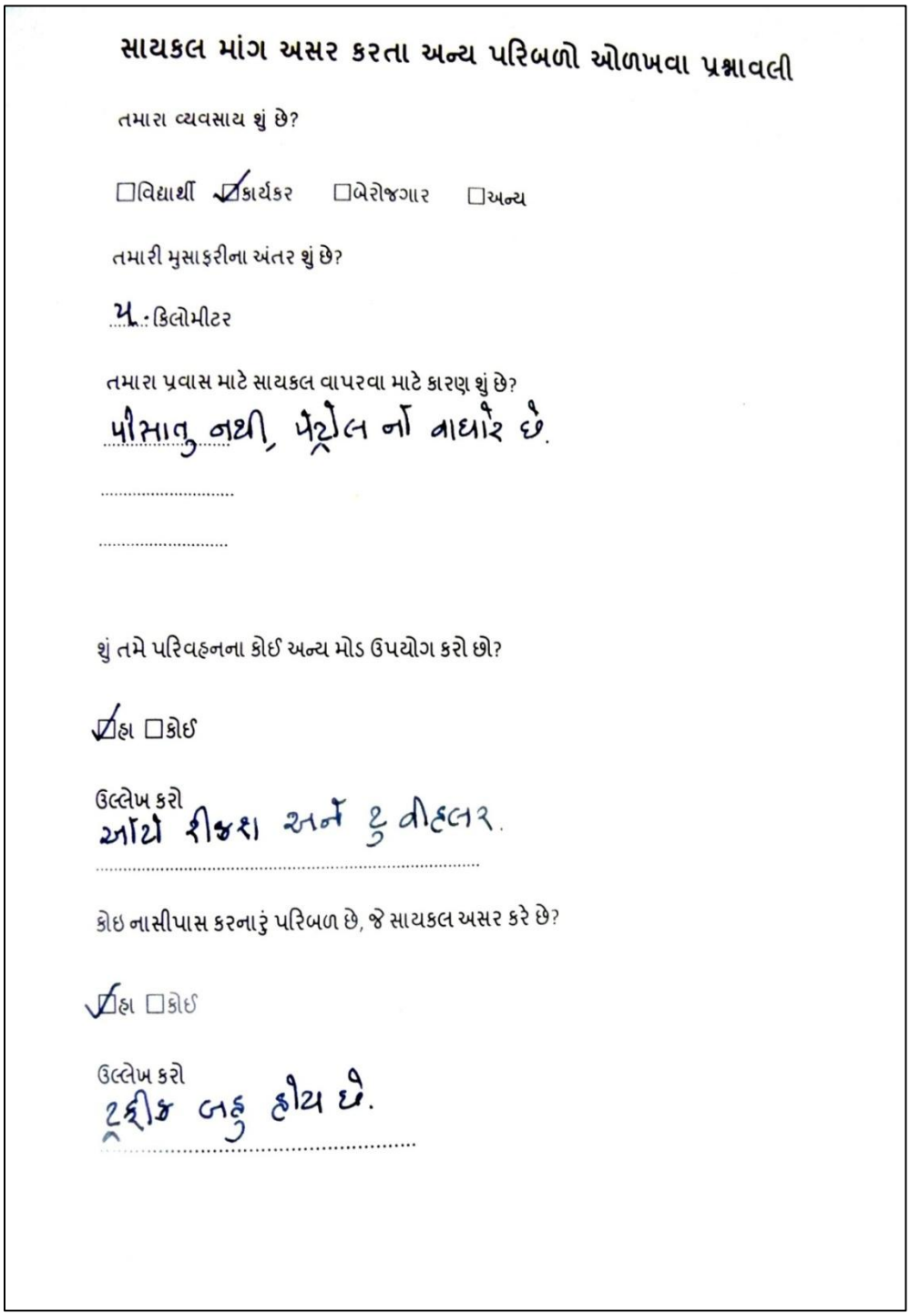
LIST OF ANNEXES



સાયકલ માંગ અસર કરતા અન્ય પરિબળો ઓળખવા પ્રશ્નાવલી

તમારા વ્યવસાય શું છે?

☐વિદ્યાર્થી ☑કાર્યકર ☐બેરોજગાર ☐અન્ય

તમારી મુસાફરીના અંતર શું છે?

૫ : કિલોમીટર

તમારા પ્રવાસ માટે સાયકલ વાપરવા માટે કારણ શું છે?

પૈસાનુ નથી, પેટ્રોલ નો બાધારૂ છે.

.....

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શું તમે પરિવહનના કોઈ અન્ય મોડ ઉપયોગ કરો છો?

☑હા ☐કોઈ

ઉલ્લેખ કરો

ઓટો રીક્ષા અને ટુ વીહલર.

.....

કોઇ નાસીપાસ કરનારું પરિબળ છે, જે સાયકલ અસર કરે છે?

☑હા ☐કોઈ

ઉલ્લેખ કરો

ટ્રાફીક બહુ હોય છે.

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1: Sample interview from prepared in Gujarati

Questionnaire to identify other factors affecting the demand for bicycles

What is your occupation?
□Student □Worker □Unemployed □Other

What is the distance you travel?
Kilometres .....
What is the reason to use a bicycle for your tour?
.....
.....
.....

Do you have any other mode of transportation you use?
□ Yes □ No
Mention
.....
There is a discouraging factor, which affects the cycle?
□ Yes □ No
Mention
……

2: Interview from translated in English

Chowk for survey	Trip destination	Distance (km)	Trip frequency	Reason to use bicycles	Other modes	Discouraging factors
Astron chowk	Recreational	2.5	on weekends	Recreation	Motorbike	none
Astron chowk	Educational	2.5	daily	enjoy biking with friend	auto, motorbike (with family)	none
Astron chowk	Educational	4	daily	school bus not affordable	share rickshaw	traffic
Astron chowk	Educational	3	daily	enjoy biking with friend	car, motorbike (with family)	none
Astron chowk	Educational	5	daily	auto-rickshaw not affordable	motorbike (with family)	none
Astron chowk	Educational	1	daily	school close to house	motorbike (with family)	none
Astron chowk	Educational	5	daily	school bus not affordable	auto, motorbike (with family)	none
Astron chowk	Delivery service	5	daily	other modes not affordable	auto (with family)	none
Astron chowk	Delivery service	6	daily	convenient to enter small lanes	share rickshaw, Chakda	none
Astron chowk	Delivery service	6	daily	other modes not affordable	auto (with family), Chakda	none
Kanti vikas	Market	4	once	enjoy biking	car, motorbike (with family)	none
Kanti vikas	Work	3	daily	other modes not affordable	auto rickshaw (with family)	traffic
Kanti vikas	Work	3	daily	high petrol rates	motorbike (with family)	none
Kanti vikas	Work	3	daily	other modes not affordable	auto rickshaw (with family)	none
Kanti vikas	Work	2.5	daily	other modes not affordable	auto rickshaw(with family)	none
Kanti vikas	Market	4	daily	easy to put bags in carrier	motorbike	none
Kanti vikas	Educational	4	daily	parents refuse to buy bike	father's bike	none
Kanti vikas	Educational	3	daily	no licence	car, motorbike (with family)	traffic
Kanti vikas	Educational	1	daily	school close to house	car, motorbike (with family)	none
Kanti vikas	Delivery service	5	daily	other modes not affordable	Auto rickshaw, share rickshaw	none
Kotecha	Work	2	daily	high petrol rates	motorbike	none
Kotecha	Educational	0.3	daily	school close to house	motorbike (with family)	none

Kotecha	Educational	1	daily	school bus not affordable	auto rickshaw (with family)	none
Kotecha	Educational	2	daily	enjoy biking with friend	car, motorbike (with family)	none
Kotecha	Educational	3	daily	enjoy biking with friend	auto, motorbike (with family)	none
Kotecha	Educational	1	daily	school close to house	walking, motorbike	none
Kotecha	Educational	3	daily	Enjoy biking with friends	walking, car, motorbike (with	none
Kotecha	Educational	5	daily	No licence	share rickshaw, Chakda	none
Kotecha	Educational	1.5	daily	school close to house	auto rickshaw	traffic
Kotecha	Educational	4	daily	parents refuse to buy bike	share rickshaw, Chakda	none
PTC	Work	5	daily	other modes not affordable	auto rickshaw (with family)	traffic
PTC	Work	1	daily	factory close to house	auto	none
PTC	Work	3	daily	high petrol rates	motorbike	none
PTC	Work	1.5	daily	factory close to house	bus , auto rickshaw	none
PTC	Work	6	daily	other modes not affordable	share rickshaw Chakda	none
PTC	Work	1	daily	factory close to house	motorbike, walking	none
PTC	Work	5	daily	other modes not affordable	bus , auto rickshaw	none
PTC	Work	2	daily	factory close to house	walking, motorbike	none
PTC	Educational	5	not regularly	when parents are busy to drop to	car, motorbike (with family)	none
PTC	Educational	2	daily	enjoy biking with friend	motorbike, car (with family)	none
Trikon Baug	Work	3	daily	other modes not affordable	share rickshaw	none
Trikon Baug	Work	3	daily	other modes not affordable	bus, auto rickshaw	none
Trikon Baug	Educational	3	daily	parents refuse to buy bike	auto rickshaw, share rickshaw, Chakda	traffic
Trikon Baug	Educational	4	daily	no licence	bus, share rickshaw	none
Trikon Baug	Educational	2	daily	parents refuse to buy bike	auto rickshaw	none
Trikon Baug	Educational	1.5	daily	college is close to house	bus, walking	none

Trikon Baug	Educational	4	daily	no licence	bus, motorbike	none
Trikon Baug	Educational	1	daily	no licence	auto rickshaw (with family)	none
Trikon Baug	Educational	1	daily	no licence	motorbike (with family)	none
Trikon Baug	Delivery service	4	daily	other modes not affordable	Chakda	none

3: Frequency table from Interview

Road Name	Participant	Road Conditions (1-5)	Two wheelers (1-5)	Auto Rickshaw (1-5)	Cars (1-5)	On-street parking (1-5)	Road vendors (1-5)	Road width (1-5)	Gradient (1-5)	Trees (1-5)	Animals (1-5)
Dhebarbhai 1	1	4	5	5	5	5	5	4	1	4	1
	2	3	4	4	4	5	3	4	2	4	1
	3	4	4	5	5	3	5	5	1	3	1
	4	3	5	4	5	4	4	5	2	4	1
	5	3	4	3	5	3	3	4	1	5	1
	6	4	4	4	4	4	3	3	1	4	2
	7	5	5	5	3	5	4	5	2	3	1
	8	3	3	4	4	4	5	3	3	4	2
	9	4	4	5	3	5	3	4	2	5	1
	10	3	4	4	4	4	5	3	1	4	2
	11	5	5	5	5	3	4	4	3	4	1

4: Grading of road segment

Existing cycle track

Same crossings for all modes

On-street parking

Animals on road

Undivided Roads

5: Photos showing road conditions in Rajkot