Modelling of Bicycle Activity on Midsized City Road Segments in Indian Context

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology

In

Transportation Engineering

By

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DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Under The Guidance of
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ROURKELA, ODISHA-769008

CERTIFICATE

This is to certify that the thesis entitled, "**Modelling of Bicycle Activity on Urban Street Segments in Indian Context**" submitted by **Chellapilla Haritha** in partial fulfilment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Transportation Engineering** at the National Institute of Technology Rourkela for the academic year 2013-2015 is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Date**:**

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ABSTRACT

Bicycle comfort level rating (BCLR) is a qualitative measure that characterizes operational conditions of bicyclists and their level of comfort within the geometric and traffic flow conditions of a road. Most of the widely accepted international BLOS models are proposed for homogeneous traffic and cannot be adopted to measure the service quality of roads under the influence of heterogeneous traffic flow. Due attention was paid in this research on heterogeneous traffic flow conditions and a Bicycle Comfort Level Rating (BCLR) model was developed which can be adopted in midsize cities under the influence of highly mixed traffic flow conditions. Several factors (based on road features, traffic flow characteristics, on-street parking, driveways and land use of adjoining area etc.) affecting the comfort level of cyclists were considered while developing the model. Required data set were collected form 60 segments of three Indian midsize cities namely; Bhubaneswar, Rourkela and Kottayam. In perception survey participants with a good cross-section of age, experience level, sex and education were participated. Relationship was established between the factors which contribute to the comfort level of bicyclists and perceived comfort level of users in the modeling process. The model was developed by stepwise multiple linear regression in SPSS V20.0. The model tested and satisfied the significance criteria with correlation coefficient (R square = 0.757). The model satisfied the un-correlation assumption of residuals very well with a Durbin-Watson value of 2.064. The *t*-tests of the predictors are highly significant ($p < 0.05$) and the *F*-ratio for the model is also significant ($p < 0.001$). The tolerance values are far above 0.2 and average Variance Inflation Factor (VIF) value is 1.516 which concludes there is no collinearity in the data set considered in this study. The standardized residuals of the regression are normally distributed. The slope of the

trend line in the graph plotted for observed BCLR indices vs. predicted BCLR indices was 44.97 degree which indicates that the model is well validated. Four clustering techniques namely; FCM, HAC, K-Means and K-Medoid were applied to classify the BCLR model output into six categories (A-F) and K-medoid clustering was found to be the most applicable one in the present context. The service categories predicted by the model was also compared with the perceived service categories and the matching was approximately 93.33%. BCLR model was compared with HCM BLOS model (for link) and two other widely accepted models namely, Bicycle Compatibility Index (BCI) model and FDOT BLOS model; and BCLR model was found to provide far better results than other models in Indian conditions.

Key words: Midsized city segments, Bicycle comfort level rating, Heterogeneous traffic flow, Fuzzy C-Means Clustering, Hierarchical Agglomerative Clustering, *K*-Means Clustering, *K*-Medoid Clustering, Average Silhouette Width and Service categories

.

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ABBREVIATIONS

ASW	Average Silhouette Width
BCLR	Bicycle Comfort Level Rating
BCI	Bicycle Compatibility Index
BLOS	Bicycle Level of Service
BSIR	Bicycle Safety Index Rating
BSR	Bicycle Suitability Rating
FCM	Fuzzy C-Means
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HAC	Hierarchical Agglomerative Clustering
HCM	Highway Capacity Manual
IBPT	Interruption by Public Transits
IEI	Intersection Evaluation Index
HIS	Interaction Hazard Score
ISI	Intersection Safety Index
Kmph	Kilometer Per Hour
L	No. of Lanes
LOS	Level of Service
LU	Land Use
NMV	Non-Motorized Vehicle Volume
PBL	Presence of Bicycle Lane
PCI	Pavement Condition Index
PCU	Passenger Car Units
PHV	Peak Hour Volume
PHMV	Peak Hour Motorized Vehicle Volume
PV	Pedestrian Volume

QOS	Quality of Service
RCI	Roadway Condition Index
RSI	Roadway Segment Index
RW	Road Width
SPD	85^{th} Percentile Speed
SW	Silhouette width
TRB	Transportation Research Board
VIF	Variance Inflation Factor
%HV	Percentage Heavy Vehicle

CHAPTER 1

INTRODUCTION

1.1 General

India is the second most populous country in the world next to china. From past few decades there is a tremendous increase in the population which has resulted in escalations of travel demand and hence leaded to traffic congestions, accidents, pollutions, shortage in petroleum fuel and several other issues. So the essential needs of green mode of transport like bicycle is highly felt today. But due to urbanization and industrialization in urban India, a large attention is paid on motorized vehicles and on the other hand, non-motorized modes of travel are highly neglected. However, there always exits a substantial section of population in India who use bicycle as their major mode of transport.

Form the past statistics it is known that, bicycle ownership is about 30 to 50 percent in India. The bicycle use also ranges from 7 to 15 percent in large cities and 13 to 21 percent in midsized cities. Moreover, in most of the cities about 56 to 72 percent of population make short trips (trip length below five kilometers) which offers a huge potential for bicycle use if proper facilities are provided. Easy ridership, no license requirement and no fuel requirement also encourage cycling to be an attractive mode of travel for short trips. The conversion to cycle trips from other modes is highly likely, if a favorable cycling infrastructure is made available. Hence transportation engineers and planners should make available of required facilities for the comfort and convenience of cyclists and should aim to promote this green mode of transportation.

In India about 20 to 30 percentage of severe bicycle crashes occurred in last few decades. For the safety of cyclists bicycle-inclusive planning should be carried out focusing on equitable allocation of road space and emphasizing the non-motorized transport. Measurement of bicycle comfort level a road is able to provide is also highly essential as it describes the operational conditions and level of satisfaction of bicyclists within the geometric and traffic flow conditions of a road.

The traffic flow on urban Indian roads is highly heterogeneous which results in complex interaction between various kinds of vehicles. The geometric characteristics and behavior of people also differs from other countries. Hence the models developed for homogeneous traffic flow conditions cannot be adopted directly in Indian conditions to evaluate the service quality offered by the facilities for bicycle use. As no appropriate methodology is available, new methodologies should be developed for this perspective, which is the aim of this research. A Bicycle Comfort Level Rating (BCLR) model is proposed in this study for the evaluation of service qualities offered by roads segments for bicycle use in midsized Indian cities. However, the generalization of this model towards big cities is the future scope of this research. Relationship was established between the factors which contribute to the comfort level of bicyclists and perceived comfort level of users in the modeling process. The statistical significance of the model was tested and the model was compared with the existing models developed in the other parts of the world. The ranges of service categories were also properly defined by application of suitable classification techniques.

1.2 Problem Statement

In most of the large and midsized cities of India, about 56% to 72% of people make short trips having trip lengths less than 5km, which offers a huge potential for bicycle use. The conversion to cycle trips is highly likely if cycling infrastructure is made available. But in the present scenario facilities for bicycle mode such as separate bicycle lanes, zigzag pavement marking at the junctions etc. hardly exists in urban Indian context and there is also no specific laws for bicyclists. The presence of bicyclists is often ignored by the policy makers, planers and engineers, and bicyclists are forced to share carriageway with motor vehicles which results conflicts of bicycles with motor vehicles. So bicycle accident rate is increased and subsequently comfort level of bicyclists is decreased. Hence for safe and convenient traffic flow, it is necessary to measure the level of comfort provided by urban Indian roads.

1.3 Objective

The objectives of this study are as follows:

- To access the influencing factors those contribute to the service quality provided by the facilities for bicycle use
- To develop a suitable methodology which can be used to determine bicycle comfort level provided by midsized city segments under the influence of heterogeneous traffic flow in Indian context
- To test the significance of the proposed model and compare it with existing widely accepted models

- To define the ranges of service categories (A-F) through the applications of several classification techniques and to select the most applicable one in present context

1.4 Organization of the Report

This report contains six chapters. The first chapter presents the topic, addresses the problems existing in the Indian scenario and the need of the work, and provides the objectives and scope of the work. In the second chapter a detailed discussion on different literatures regarding the Bicycle Level of Service (BLOS) models, BLOS for arterials and intersections, perception based BLOS, benefits of providing bicycle facilities are done. Chapter three presents the study area and data collection procedure that has been carried out in the present study. In fourth chapter, a detailed description on the model development is given. Fifth chapter represents the results and analysis in which statistical significance of the model are discussed and the ranges of service categories (A-F) are defined through the applications of suitable classification techniques. Chapter six presents summery, conclusion and future scope.

CHAPTER 2

LITERATURE REVIEW

2.1 General

One of the most supportable, environmental friendly and green transportation modes is cycling. This mode of transport can increase physical activities and decrease externalities like congestion and pollution etc. Hence it is essential to define the bicycle level of service criteria for the street segments. Bicycle level of service (BLOS) is a qualitative measure which characterizes the operational conditions of bicyclists and their level of satisfaction within the geometric and traffic flow conditions of a road. Several factors such as vehicle speed, travel time, maneuverability, delay, safety and comfort level etc. affects the level of satisfaction of bicyclists. The BLOS of road is usually represented through a letter-grade scale 'A' to 'F', where 'A' represents the best operating conditions and 'F' represents the worst. Several models have been developed in recent years to relate the roadway geometric and operational characteristics to the level of satisfaction of bicyclists.

2.2 Bicycle Level of Service Concepts in Highway Capacity Manual (HCM)

The initial attention on bicyclists was reflected in the 1985 version of HCM. The focus was mainly on bicycle impacts on motorized vehicle capacity. BLOS criteria were introduced in HCM (2000) which are based on the factors such as; average travel speed, average delay and hindrance. Recent version of HCM (2010) considers a broad range of factors for BLOS analysis. In this version, BLOS on both road link and intersection are considered for evaluation of BLOS of road segments. Many models are proposed in recent years to define level of service criteria for intersections and segments of roadways.

2.3 Bicycle Level of service models

Several models have been proposed in recent years to relate the roadway geometric and traffic flow conditions with operational characteristics of bicyclists. Davis (1987) developed the first model named as, Bicycle safety Index Rating (BSIR) model for determining BLOS. The purpose of the model was to relate bicycle safety to the physical and operational features of the roadway. BSIR model includes, Roadway Segment Index (RSI) and Intersection Evaluation Index (IEI). Epperson (1994) made changes to RSI model and proposed Modified Roadway Condition Index (RCI) model, also called Epperson-Davis model. Landis (1994) proposed Bicycle Interaction Hazard score (IHS) model. Sorton and Walsh (1994) introduced a simple model called, Bicycle Stress Level (BSL). Harkey et al. (1998) and Bicycle Compatibility Index (BCI) model was proposed. Mozer (1994) developed a model to evaluated BLOS. Landis et al. (1997 validated IHS model and a BLOS model was proposed. FDOT (2009) suggested this model as the best model for determining BLOS. Petritsch et al. (2007) further simplified this model. Eddy (1996) adopted RCI model to evaluate BLOS criteria in urban areas. Factors considered in these models are, traffic volume, number of lanes, speed limit, width of outside traffic lane, pavement factors and location factors, Land use intensity adjoining the road segment and Curb cut frequency, peak hour non-motorized volume and pedestrian volume factors, Frequency of non-controlled vehicular access, motor vehicle peak hour volume, kerb-lane speed and kerb-lane width etc.

2.4 BLOS on Road Segments and Arterials

Matters and Cechvala (2014) evaluated BLOS of urban streets by using the methodology described in HCM (2010). The authors used multimodal LOS score ranges to find the appropriate letter grade of LOS, i.e. ‘A’ through ‘F’. Bicycle LOS sensitive analysis was also carried out on scenario based LOS data, i.e. numerical values of some factors affecting BLOS were changed and then the change in letter grade of base LOS was examined. Most of the data required for analysis purposes, such as: traffic volume, number lanes in through direction, traffic speed, heavy vehicle volume, and pavement surface condition etc. were collected from aerial photographs and some other data sources. But the directional component is not considered in the model.

2.5 BLOS on Intersection

Yang and He (2004) explored the application of most widely used simulation software, CORSIM in simulating the signalized intersections on china. The delay and average queue length were considered as the measure of effectiveness (MOE) in model calibration and used in comparison analysis between field and simulation. The author prepared a base model with auto mobile data and calibrated the model by varying the parameters embedded in CORSIM. By using the base model the selected the signalized intersections were simulated and the applicability of this calibrated base model in simulating the intersections was observed. It was found that CORSIM can be applied to simulate the signalized intersection when the combined flow of bicycle and pedestrian is under 1200 bicycles per hour.

Being diverted from conventional methodologies which evaluate the quality of each transport mode separately, Hunter et al. (2011) focused on multimodal assessment of signalized intersections. A unique LOS methodology was proposed which considers all transport modes and the numbers of travelers of the different modes were considered in order to access the efficiency of different modes. A route importance factor was introduced to consider the differing importance of each transport mode for the intersection. For model development, the numerical value of LOS for each mode was calculated and were weighted according to number of travelers. The poor LOS were squared to give importance to them and then, the modal LOS was further weighted by a factor accounting for the intersection function.

2.6 Perceived BLOS

Kang and Lee (2011) introduced a Bicycle level of service model from user's perspective for the evaluation and improvement of existing bicycle roads. User's level of satisfaction and multiple factors that affect the bicycle LOS were considered for development of that model. Bicyclists of South Korea were interviewed on the road by the surveyors to collect the data about their perception or level of satisfaction. An ordered probit method was employed to develop the bicycle LOS model. Correlation coefficient or R^2 value for the model was calculated and found to be lying closer to one; which indicates that the data fits to the model well. The factors affecting LOS criteria were found to be width of the road (most important variable), road type, total number of lanes on the approach to the intersection, and number of encounters (travelers and bicyclists moving in the opposite direction). In this research a three letter graded LOS system (A-C) was introduced for the perception based LOS. The authors justified it as, the conventional six-level LOS of HCM considers average bicycle speed and average control delay etc.; but bicyclists can actually distinguish only 2 or 3 levels of service. This model represents an alternative solution for encouraging bicycling. The only drawback of this model is that, all possible factors affecting the bicycle LOS criteria are not considered.

2.7 Benefits of Bicycle Facilities

2.7.1 Effects

Barnes et al. (2006) reported the changes in bicycle commute mode shares and the impact of new bicycle facilities created between 1990 and 2000 in the Minneapolis Paul-St. Paul, MN area. The authors compared same locations before after the facilities were built; and found an increase in mode share from 1.7% to 2.0%. Significant increase in bicycle trips was also found on Mississippi River Bridge in this decade. Large increase in the bicycle trips was found in downtown Minneapolis and the University of Minnesota areas. The areas where no facilities were built in this decade showed no increase in the bicycle trips. Within central cities areas nearer to bicycle facilities, more increase in the bicycle share was found in compared to the areas away from the facilities.

2.7.2 Safety

Munley et al. (2005) proposed a Bicycle Route Safety model to measure the safety provided by bicycle routes in urban areas. The model was developed by considering the severity of injuries. A logistic transformation of Jersey City's bicycle crash data for the period 1997-2000 was conducted in the modelling process. The model resulted used several operational and physical variables and predicted the severity of injuries. Different factors were considered namely: traffic volume, highway classification, lane width, vertical grades, one-way streets, population density, and truck routes. The bicycle route's safety rating was expected by the value of injury severity predicted.

2.7.3 Economic Benefits

Krizek (2004) stated the economic benefits of bicycle facilities and proposed some methods to estimate them. The aim of efforts for planning and policies in of transportation planning is to increase the rate of bicycling. The primary step here is to access the various facilities exist for bicyclists such as: wide kerb lanes, on-street or off-street bicycle paths etc. Some benefits that the author interpreted from the literature includes: social benefits (e.g. congestion, energy, livability, quality of air, option value etc.), user benefits, safety benefits, health benefits etc. This work provided the foundation for consistent framework, in which the different benefits can be estimated and also can be compared against each other.

Meletiou et al. (2005) took North Carolina Northern as study area and studied the economic impacts of investments in bicycle facilities. The authors found that, by providing bicycle facilities there was a significant economic impacts and the income was around nine times than the one time expenditure to construct the facility. Hence the authors recommended continuous investment in bicycle facilities which can further increase economic impact.

2.8 Bicycle Planning issues

Ryley (2006) estimated the demand for cycling in case of journey to work trips, in West Edinburgh area of Scotland. The author developed discrete choice models based on random utility theory. The author considered the population as a whole rather than giving focus on cyclists only and surveyed 997 households to study about the people’s response for cycling, those who travel to work or study by motor car, bus or on foot. The survey sample was split into various population segments according to the propensity to cycle. The segments provided an indication of the percentage of population liking cycling to study or work. Motorists were found to be the least willing for cycling (i.e. about 31% only). 19% respondents also stated that, they may choose cycling if nature of their employment or education changes. It was found that; both at the destination and on-route the cyclist facilities largely encourage the willingness to cycle to work or study. The cost element is not that much effective; however journey time has major effects cycling.

Several methods are used so far for the development of BLOS models proposed by corresponding authors were listed in table 2.1. The methods are mostly multiple linear regression.

CHAPTER 3

STUDY AREA AND DATA COLLECTION

3.1 General

To achieve the objective of present research both qualitative data that includes the roadway geometrics, traffic volume, parking data, adjoining land use, etc., which effect the level of satisfaction of bicyclist and qualitative data i.e. perceived bicycle comfort level rating for each segment have been collected. In this chapter a detailed discussion has been done on the study area and data collection procedure. The roadway attributes that has been collected, has also been presented.

3.2 Site Selection

The most important criteria in the site selection was to include a various ranges of conditions affecting level of comfort in the heterogeneous traffic flow conditions. Aim was to include all ranges of segments varying from excellent to worst in providing comfort level to the cyclists. With the limited availability of resources, required data was collected from three Indian cities, namely; Bhubaneswar (29 segments), the capital of Odisha state, Rourkela (19 segments), Steel city of Odisha state, and Kottayam (12segments) city of Kerala state. The sixty segments selected in this study can well represent the variability in geometric and operational conditions of Indian midsized city segments. Figure 3.1 shows a sample of six segments in which bicycle comfort level varies from excellent to worst.

 Rourkela club to Sector 3, Rourkela City	Four lane divided carriage way Peak hour volume = 813 PCU/hr Road width = 6.8 m in one direction 85th percentile speed = 42 Kmph No commercial activity Negligible interruptions by public transits No on-street parking
 Sector 2 to Sector 4, Rourkela City	Four lane divided carriage way Peak hour volume = 945 PCU/hr Road width = 6.8 m in one direction 85th percentile speed = 42 Kmph No commercial activity Low interruption of Public transit No on-street Parking
 Kali mandir to Big bazzar, Bhubaneswar City	Eight lane divided carriage way Peak hour volume = 4664 PCU/hr Road width = 14 m in one direction 85th percentile speed = 38 Kmph Semi-commercial area Medium interruption by public transits On-street Parking occupancy = 20-30%
 Master canteen to Rajmahal, Bhubaneswar City	Four lane divided carriage way Peak hour volume = 4517 PCU/hr Road width = 10.5 m in one direction 85th percentile speed = 40 Kmph Commercial area High interruption of Public transit Parking occupancy = 70-80%
 Bomikhal to Laxmisagar, Bhubaneswar City	Four lane divided carriage way Peak hour volume = 2738 PCU/hr Road width = 7 m in one direction 85th percentile speed = 37.5 Kmph Commercial area High interruption of Public transit Parking occupancy = 75-85% High percentage of Heavy Vehicles
 Station chowk to Pallavi complex, Rourkela City	Two lane undivided carriage way Peak hour volume = 1412 PCU/hr Road width = 3.5 m in one direction 85th percentile speed = 27 Kmph Shopping area with high commercial activity High interruption of Public transit Parking occupancy above 90%

Figure 3.1: Service qualities offered by different segments

The variation in geometric and operational characteristics of segments was considerable in the study areas as shown in the table 3.1.

Table 3.1: Range of geometric and operational characteristics of segments in the study area

Sl. No.	Variable	Ranges
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3.3 Data Collection

3.3.1 Field data collection

Traffic flow data was collected from every segments by video cameras placed midway along the segment on the side of road without affecting the traffic flow. Video has been collected for about two hours during the expected peak hour periods in morning (8.30 AM to 10.30 AM) or evening (4.30 PM to 6.30 PM) for every segment.

Figure 3.2: (a) Video camera (b) Tripod Stand

Spot speeds of vehicles were collected by a radar gun in off-peak hours (when there were no congestion in the traffic flow).The radar gun was set to approaching mode and was placed at an angle of about 135^0 to the direction of flow of traffic. The spot speeds of minimum 125 numbers of vehicles were collected from each segments and 85^{th} percentile speed were calculated for respective segments.

Figure 3.3: (a) Radar gun (b) Measuring Tape

Various geometrical measurements were carried out with the help of measuring tapes. The pavement conditions of the segments were rated by following five point rating system as given in table 3.2.

Table 3.2: Five point pavement condition rating

Rating	Pavement Condition
5.0 (Very good)	Only new or nearly new pavements are likely to be smooth enough and free of cracks and patches to qualify for this category.
4.0 (Good)	Pavement, although not as smooth as described above, gives a first class ride and exhibits signs of surface deterioration.
3.0 (Fair)	Riding qualities are noticeably inferior to those above; may be barely tolerable for high-speed traffic. Defects may include rutting, map cracking, and extensive patching.
2.0 (Poor)	Pavements have deteriorated to such an extent that they affect the speed of free-flow traffic. Flexible pavement has distress over 50 percent or more of the surface. Rigid pavement distress includes joint spalling, patching, etc.
1.0 (Very poor)	Pavements that are in an extremely deteriorated condition. Distress occurs over 75 percent or more of the surface.

(Source: U.S. Department of Transportation. Highway Performance Monitoring System-Field Manual, Federal Highway Administration. Washington, DC, 1987.)

Several other data such as number of lanes in one direction, presence of bus/auto stop, on-street parking occupancy, average time interval for transverse turbulence created by vehicles or pedestrians ingress or egress to the on-street parking space, number of driveways present in the segment and average ingress-egress of vehicles to the driveways, land use pattern of road side area, presence of median, presence of sidewalk, presence of shoulder, presence of kerb and gutter etc. were determined by visual inspection.

3.3.2 Perception survey

Perception was carried out in following two phases.

Phase 1

The most dependable input i.e. overall perceived comfort level rating (BLCR) for each segment was obtained in the phage-1 of perception survey. In this study, roadside interview and video survey were carried. The participants with a good cross-section of age, experience level, sex and education were included in the survey. People of age varying from about 14 up to 70 years were included in this study. Children of less than age of 14 were ignored to respond as their maturity and qualification level is less to give proper judgment on roadway and traffic flow conditions. The distribution of age is given in figure 3.4. The gender split was given due consideration in this study and about 45 percent women were responded in the survey.

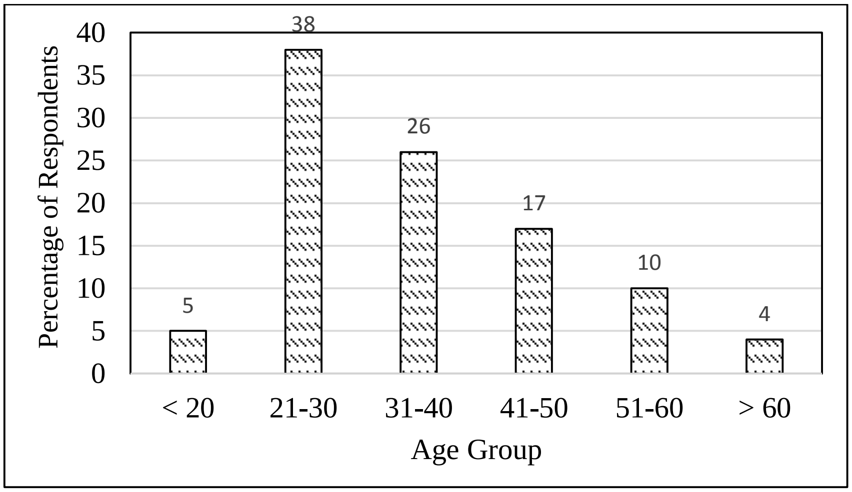

Figure 3.4: Percentage of participants under different age group

All of the major factors affecting comfort level of cyclists were included in a questionnaire format shown in Appendix A and people were asked to answer all the questions on a five point scale ranging from strongly disagree to strongly agree. About 600 respondents (at least 10 respondent per each of all 60 segments) were collected in roadside interview survey. The perceived bicycle comfort level was calculated for each segment from the response of public.

For video survey, representative clips of 30 second were selected from the two hours of video data collected from each segment. Around one hundred people including students, faculties and some co-workers of National Institute of Technology, Rourkela, India were randomly selected and were requested to be gathered at BBA auditorium of NIT, Rourkela. The survey was conducted in four sessions. In each sessions about 25 persons were participated. The clips were shown by a professional video projector on a wide screen and the sound of the video clip was tried to set to actual traffic sound on the roads. After showing one clip, land use pattern of the roadside area, on-street parking, number of driveways, pavement condition and presence of bus/auto stop etc. of the respective segment (as these factors cannot be recognized by the video clips) were thoroughly explained. People were asked to rate each question on a five point scale ranging varying from strongly disagree to strongly agree for each segment if they would ride cycle on the segments. Questionnaire format for video survey (Phase 1) is shown in Appendix B. A 10 minutes of break was given to the participants in the middle of each sessions. Soft-drinks were provided to the respondents in the break for their refreshment.

Phase 2

The phase-2 of video survey was conducted in a very similar way as conducted in phase-1. The people were given a questionnaire format carrying six questions shown in Appendix C and were asked to answer the questions according to their state of mind. The requirement of this survey can be recognized from the section 4.4. A special video survey was also conducted as described in sub-section 4.4.

3.4 Data Extraction

Several data sets were extracted from the video clips, perception survey, geometric measurements and visual inspections for each segments are listed in table 3.3. The perceived bicycle comfort level ratings (BCLRs) of the segments were calculated from users' perception data collected in road side interviews and phase-1 of video survey. After getting the response of the users the overall BCLR was calculated for all users on a 5-point scale for each segment. About

110 responses was collected for each segment in this study, the overall BCLR was calculated by taking the average of all 110 responses for each segment.

Table 3.3: Data collected from road segments

Part A			
Sl. No.	Variable Name	Abbreviation	Units/ Values
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3.4.1 Estimation of peak hour volume

From the two hour traffic data that was collected for each segment, using running average method peak hour has been estimated and the traffic flow in that one hour, expressed in passenger car unit has been considered as peak hour traffic volume for the segment.

Table 3.4: Equivalent PCU factors

Vehicle type	Equivalent PCU factors	
	% composition of vehicle type in traffic stream	
	5%	≥10 %
Motorized two wheelers	0.5	0.75
Passenger cars, Pick-up van	1.0	1.0

Auto-rickshaw	1.2	2.0
Light commercial vehicles	1.4	2.0
Truck, Bus	2.2	3.7
Tractor Trailer	4.0	5.0
Cycle	0.4	0.5
Cycle-rickshaw	1.5	2.0
Horse drawn vehicle	1.5	2.0
Hand cart	2.0	3.0

(Source: IRC-106-1990 Guidelines for Capacity of Urban Roads in Plain Areas)

For converting the number of vehicles to corresponding equivalent passenger car unit (PCU) value, the guidelines prescribed by IRC-106-1990 as given in table 3.4 were incorporated.

3.4.2 85th Percentile speed calculation

Graphs are plotted for cumulative percentage frequency vs. median of spot speeds to determine the value of 85th percentile speed for each segment. For example: In the graph shown in Figure 3.5 the 85th percentile speed for Vanivihar - Rupali Square segment of Bhubaneswar is 40 Kmph.

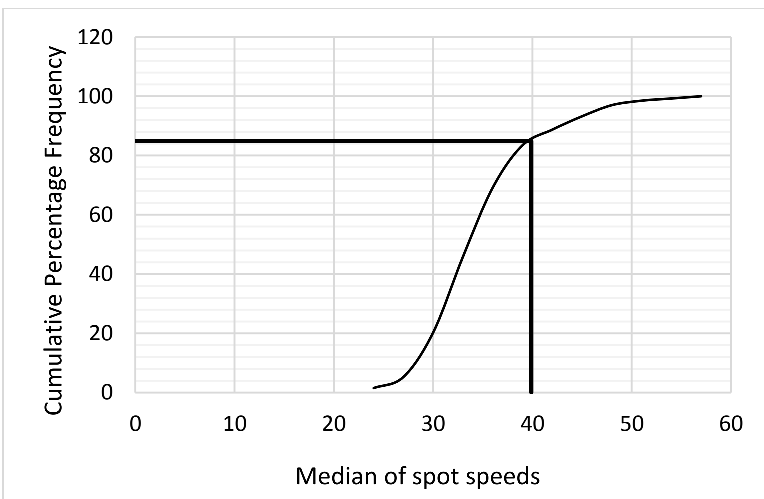


Figure 3.5: Graph plotted for Cumulative Percentage Frequency vs. Median of spot speeds

3.4.3 Non-motorized vehicle volume calculation

Non-motorized vehicle volume (NMV) was calculated in No.s/h by multiplying the number of animal drawn vehicles or cycle rickshaw or trolley etc. with four and then adding the result with number of bicycles. Four was multiplied because the amount of interruption crated by these vehicles is approximately four times more than that of a bicycle. In table 3.4 it can be observed that, IRC-106-1990 also specified PCU conversion factors for these vehicles about four times more than that of a bicycle.

CHAPTER 4

STUDY METHEDOLOGY

4.1 Model Development

BCLR model was developed using the analysis software SPSS V20.0. Multiple linear regression was preferred as the functional technique in this study because, it is more intuitive than other regressions like probit and logit modelling etc. and can be better understood by the public officials, citizens and planners. Before proceeding to statistical analysis all 60 segments were sorted city wise according to corresponding perceived comfort level of the segments. 25% of total data (i.e. data of 15 segments) were selected randomly which can represent various ranges of variables in each city and were kept for model validation purpose. Remaining 75% of data were used for the development of BLOS model.

Model was developed basically in following four steps:

1. Identification of relevant variables (which significantly contribute to perceived BLOS with $p < 0.001$)
2. Development of best combination of variables contributing significantly in the model (with t-stat < 0.05)
3. Finding the coefficients of variables or combination of variables and test their significance
4. Statistical significance test of the model and comparing with other existing models

Pearson correlation was conducted for extensive array of geometric and traffic flow variables (as shown in part 'A' of table 3.3 with respect to the perceived BCLRs. Several variable transformations (e.g. *ln*, inverse, square root, inverse square root etc.) and variable combinations were tested. The variables or combination of variables given below were found to contribute significantly ($p < 0.001$) and hence were considered in the model and all other variables were excluded from further analysis.

Some of the variables shown in the table 3.3 were not significant (at $p < 0.001$ level) to affect perceived BCLR even after trying various combinations and transformations. In real scenario all the variables shown in table 3.3 affects the comfort level of cyclists. But these affects are not significant statistically, may be due to variances of these variables are getting explained by other variables. Hence these variables were excluded from further analysis.

However, while validating the model it was found that the model predict less BCLRs (i.e. better level of service) for some busy roads. Hence the roads were investigated again and attempt was made to find the additional special variables in those roads which are decreasing the level of comfort of cyclists. The additional variables found from investigations are: presence of on-street parking, driveways, encounters (i.e. vehicles or pedestrians moving in opposite direction of traffic flow) and type land use of adjoining area (e.g. commercial area, residential area, office area etc.). It can be noted that, these variables cannot be included in regression analysis as they will produce high standard deviations to the mean. Hence special perception survey was conducted to find out the influence of these variables on level of satisfaction of cyclists. The sum of influences of all these variables was termed as adjustment factor (AF) and was included in the model. The numerical values for adjustment factors are described briefly in the section 4.4

The multiple linear regression was carried out for the four variables (V_1, V_2, V3 and V_4) to determine the coefficients of the variables in the model. The *t*-tests of the coefficients were found to be very highly statically $p < 0.05$ level (table 5.5). The significance of the proposed model and model parameters are discussed in chapter 5 (Results and discussion). Hence, the BCLR model for the urban street segments in midsized cities of India has been developed.

4.2 Adjustment Factor (AF)

How the numerical values of the adjustment factors (F_P, F_t, F_o, F_D, F_E, F_{LU} and F_{BL}) were determined in this study are described in this section.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 General

The regression model developed is said to be reliable and successful if it is statistically significant. The various statistical tests have to be performed on the model and results obtained should be compared and checked if they are within the limits of standard values. In this chapter a brief discussion was done on the statistical tests performed and the results obtained. Further, the model outputs (BCLRs) were classified into six service categories using several classification techniques and the most suitable technique was selected.

5.2 Statistical Significance of The Proposed Model

The model obtained has been tested for its significance and the following results were obtained. It was found that there is high correlation between observed and predicted variables.

Table 5.1: Model summary (with perceived BCLR as dependent variable)

R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
0.870[a]	0.757	0.733	0.28098	2.064

In Anova table (table 5.4), the value of *F*-ratio was found to be 31.123 which is significant at $p < 0.001$ level indicating that the model is fitted significantly to the overall data.

Table 5.2: Anova (with perceived BCLR as dependent variable)

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	9.828	4	2.457	31.123	.000[a]

	Residual	3.158	40	0.079		
	Total	12.986	44			

5.3 Cluster Analysis

An attempt was made to translate the model outputs into six service categories (A-F). The ranges ‘A’ through ‘F’ represent the service quality varying from excellent to worst perceived by the bicyclists while riding on a road segment. Four types of cluster analysis namely; Fuzzy C-Means (FCM), Hierarchical Agglomerative Clustering (HAC), *K*-Means and *K*-Medoid were applied to classify the model predicted BCLRs into six categories. MATLAB V20.0 was used for the development and execution of clustering programs. The numbers of clusters were chosen as six in order to remain consistent with Highway Capacity Manual (HCM). The best clustering technique can be selected by comparing corresponding average silhouette width (ASW) values by following the criteria given by Rousseeuw (1987) and Kaufman & Rousseeuw (1990) as shown in Table 5.3.

Table 5.3: Average Silhouette Width (ASW) Specifications

Sl. No.	ASW	Remarks
1	0.71 - 1.00	A strong structure has been found
2	0.51 - 0.70	A reasonable structure has been found
3	0.26 - 0.50	The structure is weak and can be artificial
4	0.25	No substantial structure has been found

5.3.1 Clustering results

The clustering plots and corresponding silhouette plot of BLSO indices by the four clustering techniques namely Fuzzy C-Means (FCM), Hierarchical Agglomerative Clustering (HAC), *K*-Means and *K*-Medoid are shown below.

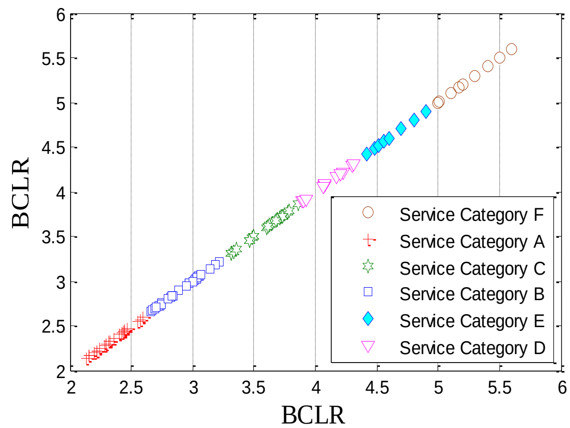


Figure 5.1(a): FCM clustering of BCLRs

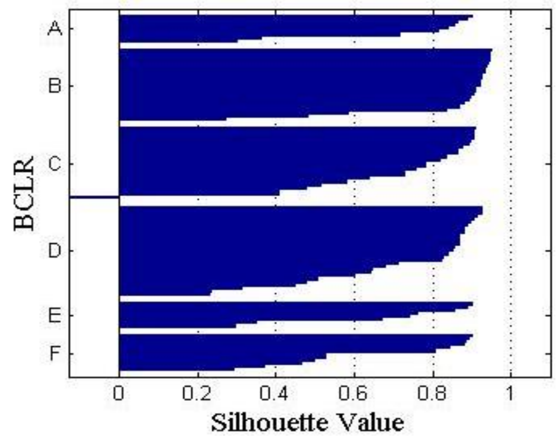


Figure 5.1(b): Silhouettes Plot of FCM Clustering

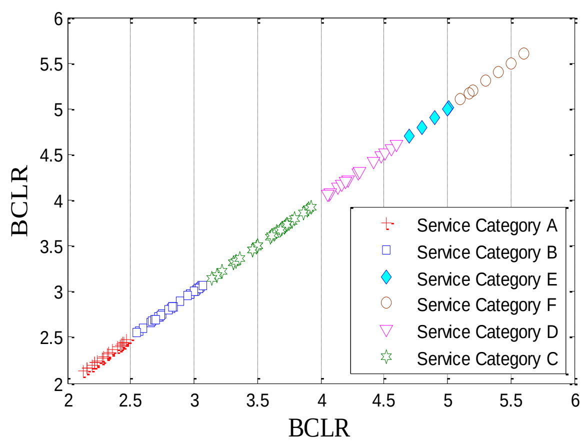


Figure 5.2(a): HAC clustering of BCLRs

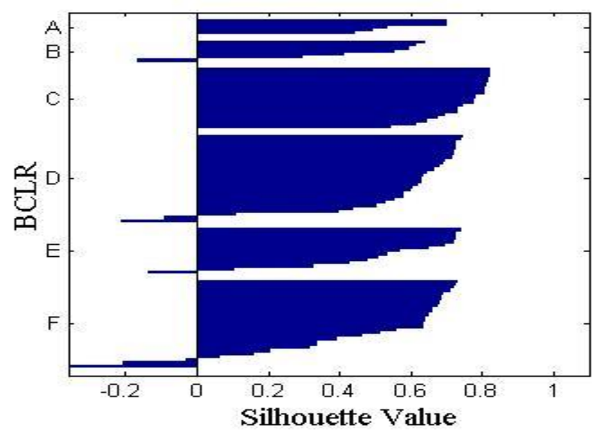


Figure 5.2(b): Silhouettes Plot of HAC Clustering

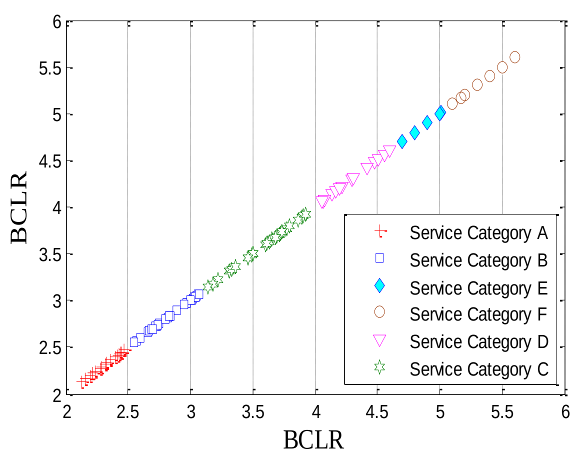


Figure 5.3(a): *K*-Means clustering of BCLRs

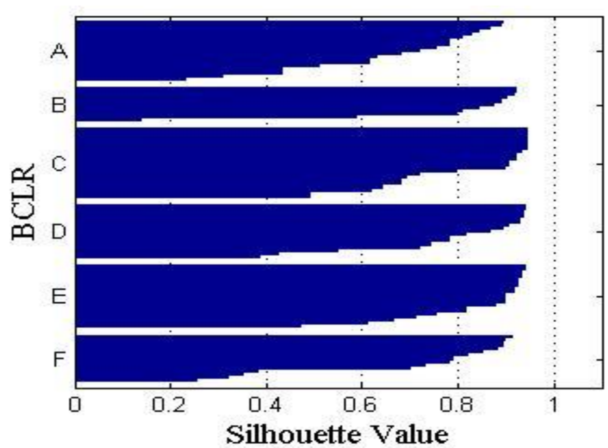
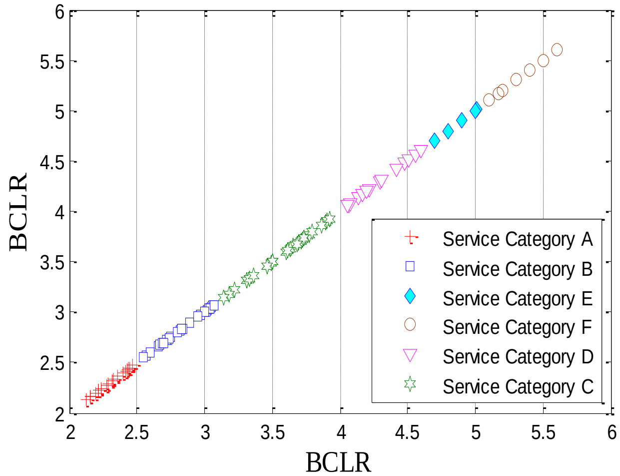


Figure 5.3(b): Silhouettes Plot of *K*-Means Clustering



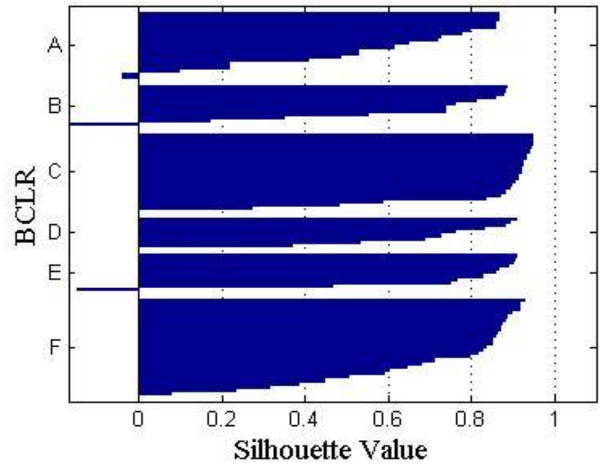


Figure 5.4(a): *K*-Medoid clustering of BCLRs Figure 5.4(b): Silhouettes Plot of *K*-Medoid Clustering

The ranges of service categories as obtained from above clustering techniques are given in the table 5.7.

The average silhouette widths (ASW) were calculated for the four clustering methods in MATLAB to determine the best clustering method in the present context. Figure 5.4 shows the comparison of ASW values obtained from the clustering methods.

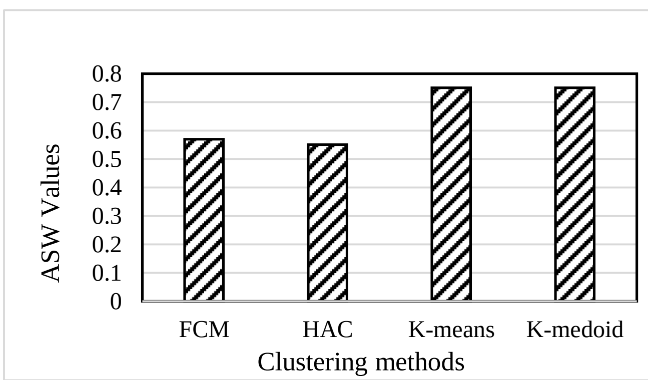


Figure 5.5: Comparison of Average Silhouette Widths (ASW) of clustering methods

Hence *K*-Medoid was proposed as the suitable clustering technique in the present context.

5.4 Model Validation

From the collected data set, 25% data were kept for model validation purpose and were not used for model development purposes. A graph was plotted for observed BCLRs vs. model predicted BCLRs for the road segments as shown in figure 5.5. The slope of the trend line was found to be 44.97 degree which is close to 45^0 indicating that the validation of the model is good.

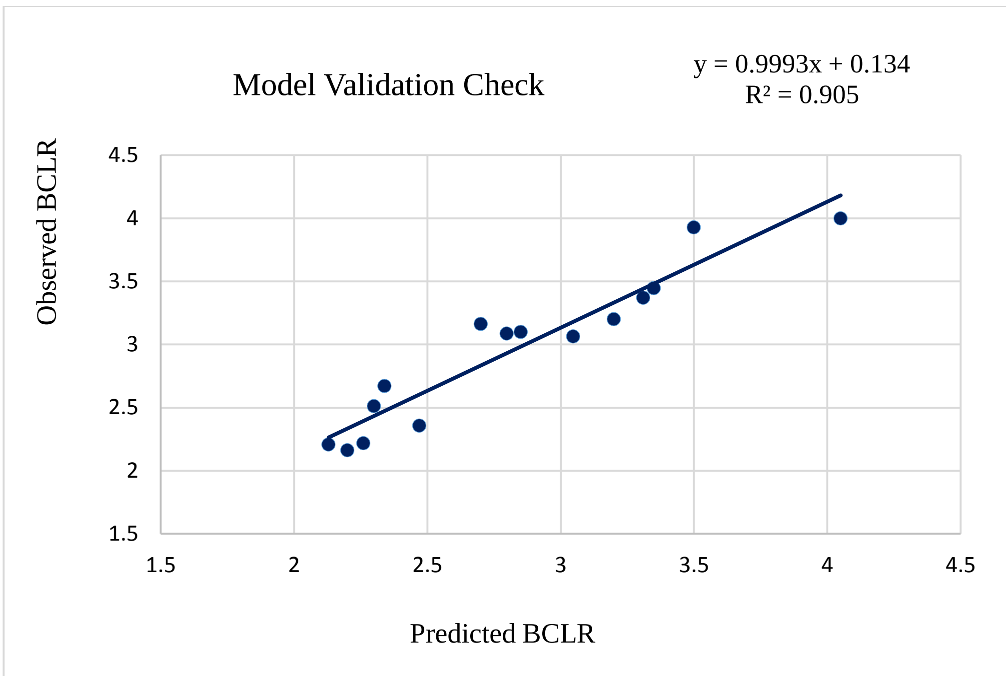


Figure 5.6: Scatter plot of observed BCLRs vs. predicted BCLRs

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary

Bicycle is fundamental mode of transport, which depicts a substantial section of population using bicycle as their major mode of transport. To promote this green transportation, the safety and comfort of cyclists on the road segments are key issues. It was observed that the widely accepted international methodologies available so far to access the service qualities provide by the road segments are applicable for homogeneous traffic flow conditions only and can't be well adopted in Indian heterogeneous traffic flow conditions. Hence this research aimed to develop a model which can be used to evaluate the comfort level of bicyclists on the roadway segments in midsized cities of India.

Various factors effecting the comfort level of bicyclists under heterogeneous traffic flow conditions were accessed and extensive data collection was carried out in the study areas to include all possible ranges of these variables. Quantitate data was collected using camera, radar gun and measuring tape. Qualitative data (i.e. perceived bicycle comfort level ratings or BCLRs of the segments) was collected by roadside interview and video survey on a 5 point rating scale ranging from strongly disagree to strongly agree. The overall comfort level rating of a segment was obtained from the responses of about 110 persons for each segment. The factors which contribute to the perceived BCLR significantly ($P<0.001$) were included in the modelling process.

Stepwise multiple linear regression analysis was performed by considering perceived BCLR as dependent variable and other significant factors as predictor variables. The proposed model was tested and satisfied the significance criteria with correlation coefficient (R square = 0.757). The model also satisfied several other statistical tests like *t*-tests, un-correlation assumption of residuals, normal distribution of standardized residuals etc. Four clustering techniques namely; FCM, HAC, *K*-Means and *K*-Medoid were applied to classify the BCLR model outputs into six service categories (A-F) and *K*-medoid clustering was found to be the most applicable one in the present context. The service categories predicted by the model was also compared with the perceived service categories, and the matching was approximately 93.33%. The model was compared with HCM BLOS model (for link) and two other widely accepted models namely, Bicycle Compatibility Index (BCI) model and FDOT BLOS model; and BCLR model was found as capable of providing to deliver far better results than other models in Indian conditions.

6.2 Conclusion

The critical inferences drawn from the present study on bicycle comfort level on roadway segments in Indian midsized cities are:

1. Increase in motorized vehicle volumes, interruption caused by public transits, non-motorized vehicles volume, pedestrian volume, percentage of heavy vehicles, on-street parking, commercial activities in the roadside area, numbers of driveways in the segment and numbers of encounters decrease the comfort level of cyclists, hence increases the bicycle comfort level ratings (BCLRs). Conversely, increase in road width, pavement condition rating and 85^{th} percentile speed of vehicles increase the comfort level of cyclists, hence decrease BCLRs. The comfort level of cyclists largely increases with the presence of a bicycle lane.
2. The BCLR model was developed by stepwise multiple linear regression and satisfied the significance criteria with correlation coefficient (R square = 0.757). The model also satisfied several other statistical tests like *t*-tests, un-correlation assumption of residuals (Durbin-Watson value = 2.064), normal distribution of standardized residuals etc. F-ratio of the model

was also significant ($p < 0.001$) and the model satisfied the basic assumptions of linear regression.

3. The slope of the trend line in the graph plotted for observed BCLRs vs. predicted BCLRs was 44.97 degree which indicates that the model is well validated.
4. *K*-medoid clustering was found to be the most suitable classification technique in present context.
5. The service categories obtained by *K*-medoid clustering were compared with the perceived service categories and the matching was approximately 93.33%.
6. BCLR model was compared with HCM BLOS model (for link) and two other widely accepted models namely, Bicycle Compatibility Index (BCI) model and FDOT BLOS model; and BCLR model was found to provide far better results than other models in Indian conditions.
7. Bicycle Comfort Level Rating (BCLR) model can be help transportation planners and engineers to obtain bicycle comfort level of users on the road segment in midsized Indian cities.

6.3 Future Work

BCLR model is developed is well suitable for midsized city segments of India. It may not be well applicable in large cities. Hence data from large cities of India like Kolkata, Delhi, and Mumbai etc. should be collected and the generalization of the model need to be carried out for Indian roads as a whole. The impact of gradient of the road segments on comfort level of bicyclists can be studied and added in the model. There is an opportunity to extend the concept of this model and some suitable models to determine the comfort level of cyclists at signalized and un-signalized intersections under heterogeneous traffic flow conditions. An attempt can also be made to put forward some methodologies, to determine the overall comfort level of bicyclists on the urban streets (combination of segments and intersections) in Indian context.

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