EVALUATION OF BICYCLE INFRASTRUCTURE IN BOGOTA, COLOMBIA

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ABSTRACT

An understanding of the bicyclists' perception of level of service (LOS) in Bogota can be useful in developing planning strategy for promoting the use of bicycle commuting in a safe urban environment. The enormous resource investment in the cicloruta requires regular infrastructure audit to ascertain its level of performance as well as possible improvement. Using a sample of 85 participants, this study evaluates the level of satisfaction bicyclists derive from the use of the cicloruta. Videos of 16 segments and 8 intersections were carefully collected and showed to participants who rated their level of satisfaction using a 6-point scale A-F, corresponding to highly satisfied-highly dissatisfied. Other geometry, physical and operational characteristics of traffic in the city was also considered. Ordered probability models were used to estimate random parameters of cyclists LOS perception to account for unobserved heterogeneity for all respondents. The study observed that BLOS was strongly influenced by side path separation, vehicle speed, motorised traffic volume and conflicts with pedestrian. However, many other factors were found to have high probabilities to influence level of service with unit change. They include bicycle lane width, wide outside lane, pavement conditions, trees and benches, daylight, gender and experience of cyclist. In the same manner, intersection LOS was estimated to reveal volume of traffic, conflict with pedestrians and other cyclists, total intersection leg as factors with high influence to cyclist perception of satisfaction. Since segments are not independent of intersections or vice versa, the study uses these two independent models to estimate the level of bicyclists' satisfaction. The impact of these observed variety of factors affecting bicyclists reveal the nature and character of urban transportation in Bogota which suggest a range of important trade-offs in further planning and management of the cicloruta.

Keywords: bicyclist; bicycle level of service; ordered probit models, cicloruta.

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1. INTRODUCTION

This chapter provides background to the research by identifying both societal and case-study specific problems of bicycle transportation and establishing the aim and objectives of the study. It highlights the justification and relevance of the study. It also presents the conceptual framework that indicates the theoretical context which identifies the elements that contribute to bicycle level of service performance measures and standards. Therefore, this together with the research design creates the general framework for the study.

1.1. Background and justification

The promotion of the use and potential of bicycling and walking has become a global strategy in sustainable urban transportation planning. This is with the aim to reducing urban commuter problems that result from the dominance of motorised urban transit (Providelo & da Penha Sanches, 2011). These problems include traffic congestion leading to noise, accidents and outright death, urban air quality degradation as well as high energy consumption. Until recently, the driving force of this trend according to Asadi-Shekari, Moeinaddini, and Zaly Shah (2013) has been speed rather than energy efficiency. Therefore the argument that increasing emissions of carbon dioxide from transport-related activities accelerate climate change scenarios seems tenable according to the United Nations Intergovernmental Panel on Climate Change (IPCC) models (IPCC, 2007a). In addition, the fourth assessment report also noted that 50 per cent of the observed increase in global temperatures during the last five decades can be attributable to anthropogenic greenhouse emissions part of which transport play a key role (IPCC, 2007a).

It is consequent upon the role of transport in global carbon monoxide (CO), various hydrocarbons (HC), oxides of nitrogen (NO_x) and particulate lead (MCPB) emissions that opinion has been unanimous on the need for the development of non-motorised transport as a way of reducing global CO_2 emissions (Hickman, Saxena, Banister, & Ashiru, 2012; Hull, 2010; Kenworthy, 2008). For instance the South Korean government developed a 'low carbon green growth' as a national vision, thus promoting the use of bicycle as a mitigating factor against traffic congestion and carbon emission (KMOCT, 2001). This is in view of Korean's 1.2% bicycling population compared to 14% and 21% of Japan and Netherlands respectively. Accordingly, the plan was aimed at expanding bicycle lanes from 9,170km to 17,600km in 2012. Elsewhere in the Netherlands, a recent BBC report indicates that there are more bicycles than residents, noting that up to 70% of intra-urban commuter journeys in Amsterdam and Hague are undertaken by bicycles (BBC News Magazine, 2013). Furthermore, based on such parameters as 'daily cycling levels, bike sales, safety, cycle tourism and advocacy activity', the European Cyclists' Federation Barometer identified ten (10) most bike-friendly countries in Europe. There include Denmark, Netherlands, Sweden, Finland, Germany, Belgium, Austria, Hungary, Slovakia, and United Kingdom (ECF, 2013).

A measure of this bike-friendliness in terms of users' satisfaction differs from country to country and from city to city. This is due to different socio-economic, cultural and technological development, weather and topographic conditions, driving orientation and most importantly different satisfaction levels as perceived by residents across countries and cities. This is perhaps why there have not been any statistically calibrated models for assessment of the satisfaction from non-motorised transit commuters. Though at city levels, several attempts are made to develop measures and standards for assessing non-motorised users' satisfaction. For instance, Dixon (1996) used the segment as a unit of analysis to develop a bicycle and pedestrian level of service performance measures in Gainesville, Florida as a congestion management plan. From the user's perspective, K. Kang and Lee (2012) similarly developed a bicycle level of service for South Korea using 'facility, operation, intersection and safety characteristics'. Their analysis using ordered logit and probit regression models revealed an increasing satisfaction with increasing width of bicycle lane. Providelo and da Penha Sanches (2011) on the other hand used successive interval analysis to develop a level of service for medium-size Brazilian cities that describe the level of satisfaction from bicycle infrastructure. Moreover, in their 'real-time human perceptions' study of American cities towards a bicycle level of service, Landis, Vattikuti, and Brannick (1997) mathematically expressed for road segments basic traffic conditions that influences bicyclists' level of service perceptions. Accordingly, basic variables of the equation developed include, per-lane motor vehicle traffic volume, speed of motor vehicles, traffic mix, potential cross-traffic generation, pavement surface condition and width for bicycling.

Several other studies on assessment of commuter satisfaction on non-motorised infrastructure such as bicycle and pedestrian level of service exists. For instance, Harkey, Reinfurt, and Knuiman (1998) developed the bicycle compatibility index for American bicycle coordinators, traffic engineers, transportation planners and so on, using linear regression models. Emery, Crump, and Bors (2003) developed the bicycle and pedestrian suitability assessment model to validate the assertion that suitable biking and walking conditions influences the activeness of community members. However, Petritsch et al. (2007) adopted both segment and intersection bicycling level of service (BLOS) models to determine the perception of Florida residents on satisfaction levels. They found the model as being highly reliable with a correlation coefficient of R^2=0.74. Bicycle and pedestrian level of service (BLOS/PLOS) was developed for Copenhagen to examine satisfaction levels which were dependent on variables such as 'motorised traffic volume and speed, urban land uses, types and widths of roadway facilities, volume of pedestrians, bicyclists and parked cars, presence of medians, trees and bus stops' (Jensen, 2007). The influences of the built environments on walking and cycling have been identified in Bogota (Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009). They observed that attributes of built environment such as urban densities, land use mixes, accessibility and proximity have a corresponding association with bicycling and pedestrian behaviour as well as 'Ciclovia participation' in Bogota. However, some of the methodologies adopted by these studies correspond to what Brussel and Zuidgeest (2012) identified as planning of new bicycle infrastructure, the evaluation of existing cycling infrastructure and/or the role of physical environment in levels of cycling accessibility.

There is also growing consensus from many scientific studies that assesses bicycle impacts on physical activity levels that bicycling is healthy, promoting cardiovascular health, reducing obesity and morbidity (Andersen, Schnohr, Schroll, & Hein, 2000; Bassett Jr, Pucher, Buehler, Thompson, & Crouter, 2008; Cavill, Kahlmeier, & Racioppi, 2006; Dill, 2009; Huy, Becker, Gomolinsky, Klein, & Thiel, 2008; Roberts, 1996). Essentially, these findings provide combined evidence that reveals corresponding health benefits from cycling that far exceeds bicycling traffic risk. This however helps to disprove the misconception that bicycling is more dangerous than associated net health benefits (Jacobsen, 2003; Robinson, 2005; Wardlaw, 2000). This increasing evidence from non-motorised transport may have informed the decision of many government agencies and other related organisations to advocate the use of bicycling. This they argue also reduces greenhouse gas emissions from transport (Cavill et al., 2006; WHO, 2000a). Nevertheless, the question of how to increase bikability has occupied the minds of researchers and policy makers. This is not without consideration of attendant huge capital investments on infrastructure and different perception levels on satisfaction. For instance, in 1999 to 2002, the Bogota city government has invested US$1.7 billion on infrastructure related projects, where US$180 million was spent alone on bikeways (Hook, 2004). The main goal was to integrate bicycling as an alternative intra-urban transport system thereby reducing congestion, accidents and pollution levels, and promoting wellbeing in Bogota.

From the foregoing therefore, the theme for this study emerged to evaluate bicycle infrastructure in Bogota. It is the capital of Colombia and home to some 7 million inhabitants. The high population and volume of socio-economic activities has the attendant consequences of movement difficulty which often results in traffic-related impacts. These include traffic congestion, noise, accidents, loss of man hours, and pollution at all levels, thus slowing down the socio-economic pace of the city. However, it is these realisations that lead to the development of the bus rapid transit (BRT) otherwise referred to as 'TransMilenio' (55 km) and the extensive network of bicycle dedicated path called 'CicloRuta' measuring about 300 km. The multi-million dollar projects according to Skinner (2004) has brought Bogota to limelight of urban transit literature. In the next 30 years he also affirmed, the Dutch-advised program is expected to double and therefore become a world class infrastructure for NMT. Much is still expected to be achieved in view of Hook (2004) observation that, 'the US$180 million that the city spent on bikeways from 1990 to 2002 was about half the amount the entire United States spends annually on cycling infrastructure'. The focus of this research will be towards estimating a bicycle level of service (BLOS) and thus a bicyclibility map at different road segments of the 'cicloruta'. The estimated model will provide practitioners with relevant tools to evaluate existing bicycle facilities and hence determine required improvements along specific road segments and intersections. Based on the model, they can also determine demand, control, geometric and operational requirements for bicycle and related facilities to realize specific level of service objectives. Therefore, an understanding of the level of bicyclists' satisfaction will help to facilitate the prioritisation of infrastructure investment and related policies to enhance cycling in Bogota. The research is expected to be able to recognise key factors that affect bicyclists based on different facilities for cycling at different road segments and intersections. This key factor will be chosen to reflect relevant local circumstances. Results are hoped to also stimulate further research on a combination of bus, pedestrian, bicycle and automobile level of service. The results will also help to propose analytical and realistic measures that address cycling infrastructure in Bogota and elsewhere.

1.2. Research problem

The overwhelming need for people to reduce spatial inequality and the psychological hold on the use of the automobile according to Stern (2007) makes it difficult to achieve reasonable reductions in transport-related CO_2. There is therefore the growing question of how to influence a change in current patterns of travel behaviour without compromising spatial interaction and economic, social and recreational opportunities. Schafer and Victor (2000) estimated that the 'average world citizen in 2050 may travel as many kilometres as the average European in 1990, with the world citizen's travel distance increasing from an average 38,000 billion passenger km (2005) to between 104,000-150,000 billion passenger km in 2050'. In the same vein, Sperling and Gordon (2009) also predicted about two billion cars globally by the year 2030. Against this backdrop therefore, it remains difficult to achieve a reduction in global CO_2 emissions from motorised transport despite significant improvement in vehicle technology. Growing interest in sustainable transportation is evidenced from the many researches that have now been conducted to show how organisations, government, communities and individuals are involved in sustainable projects (Litman & Burwell, 2006; Mohan & Tiwari, 1999; Wei & Lovegrove, 2012). The nature, scope and implications of sustainability for transport planning and management are evidenced (Banister, 2000; Boarnet, 2010; IHT, 1997; Litman & Burwell, 2006).

The task of providing accessibility and mobility to all commuters in the city in a sustainable manner remains complex due to the conflicting modal choices of commuters, different income classes and preferences, safety concerns and the lack of supporting infrastructure for some of these modes. The inability to strike a balance between modes that reduces pollution and those that reduces speed or accident has also been of concern to transport planners. For instance, increasing the average vehicle speed may lead to low emissions and can also lead to increased rate of accidents. According to the world health organisation, young people lead in the 1.1 million globally estimated traffic deaths every year. Of this figure, the vast majority of victims are bicyclists and pedestrian from developing countries. In 1997, Bogota had 2 to 3 traffic related deaths every day. This was the highest in Latin America, even though it has now dropped to 1 to 2 due largely to development of walking and bicycling infrastructure. In April 2011, WHO also published road traffic accident death rate that shows Colombia reached 7,586 or 4.41% of total deaths (WHO, 2011). Most public discussions on transport problems often focussed on air pollution and its impacts on health. This is because of the palpable and deleterious effects of air pollution. Sustainable transportation is therefore not possible without non-motorised transport. The critical role of non-motorised transit has been documented (Banister, 2000; Mohan & Tiwari, 1999; Wey & Chiu, 2013; Yazid, Ismail, & Atiq, 2011). Consequently, the need for the supporting infrastructure for these modes of travel, the perception of users and potential for use is what even more is challenging. It is therefore not known the motivation for use and potential of bicycle commuter trips.

Nevertheless, the assumption by most governments and transport planning agencies that traffic flows are fixed or that there are fixed number of trips generated per land use irrespective of improvement on road space is most misleading (Meyer & Miller, 2001). It negates the science of traffic flow and travel behaviour that is based on supply and demand. Meyer and Miller (2001) further observed that derived demand is the determinant of travel behaviour and that people will always adjust their travel behaviour to take advantage of the new facility. Decades of research in transport studies have proved that more people are likely to travel with lower cost of travel (generalised cost) and that expanded or increased road space also effectively reduced travel cost leading to more travels (Downs, 2003; Meyer & Miller, 2001).

Steiner (2007) observed the inability to account for non-automotive trips as another fundamental transport problem. He noted that most transport studies are unable to recognise the diverse transport choices available to commuters such as walking, bicycling, carpooling, use of a transit system and so on. Not until a few decades ago, most transport models focussed mainly on automobile trips. Similarly, even with a plethora of levels of service (LOS) standards, most planners and governments alike uses LOS standards that hardly reflect their local transport circumstances. This leads to unrealistic government policies incapable of solving many transportation problems.

Essentially therefore, it is neither true that Bogota is not without traffic congestion as a developing economy, nor do we expect that all residents have equal access to all modes of urban transit. The corollary is that the proportion of urban residents with access to non-motorised transit is yet unknown. It is also yet unknown what has been the motivation for use and potential of NMT especially bicycling. This further raises the question of perception of satisfaction with this mode of transport. This is more so that the city of Bogota has recently undergone major transport revolution with the development of Transmilenio and

Cicloruta for bus rapid transit and bicycling respectively. It is on the basis of these that the study seeks to examine the bicycle level of service based on the satisfaction level of cyclists. However, no single method has so far gained universal recognition in achieving results on satisfaction level. Different methods seem to produce different results when applied in the same place and in different places. This study will therefore apply several methodologies provided in earlier studies on bicycle and pedestrian LOS (Jensen, 2007; Landis et al., 1997; Landis, Vattikuti, Ottenberg, McLeod, & Guttenplan, 2001). This is because there have more wider acceptance and has been adopted with modifications in the highway capacity manual (HCM, 2000). Modifications shall also be offered where necessary to reflect specific objectives of the study, and local travel and infrastructure circumstances of the study area. This is in a view to developing acceptable methodology for the study area.

1.3. Research objective

The aim of this study is to develop a bicycle level of service (BLOS) methodology for bicycle coordinators, transportation planners, and traffic engineers which could help in examining perceived satisfaction level of bicyclists along the Cicloruta. This will enable policy makers evaluate the quality of service and increase understanding in the use of bicycle transport facilities, thus making appropriate budgetary or prioritisation of investments in specific bicycle infrastructure to accommodate bicyclists.

1.3.1. Sub objectives

Specific research objectives include the following:

1. To develop a methodology for the estimation of bicycle level of service by using residents' perception of satisfaction and other road geometry, physical and operational measurements.
2. To develop intersection level of service and examine how it affects bicycle level of service.
3. To predict the probability of satisfaction levels of residents given unit changes in some road geometry, physical and operational measurements.
4. To compare Bogota BLOS model with earlier estimated models with a view to identifying strength and weakness of methodology.

1.4. Research questions

Research question according to Bryman (2012) 'is a question that provides an explicit statement of what it is that the researcher wants to know about'. For the purpose of this study therefore, the following research questions are formulated:

Sub objective (1): To develop a methodology for the estimation of bicycle level of service by using residents' perception of satisfaction and other road geometry, physical and operational measurements.

- What is average perception BLOS for rated segments of the ciclorutas?
- Which are the determinants of participants' bicycle level of service?
- What is the bicycle level of service model (at segment level) in Bogota?

Sub objective (2): To estimate intersection bicycle level of service model and examine how it affects bicycle level of service.

- What is average perception BLOS for rated intersections of the ciclorutas?
- What is the bicycle level of service model (at intersection level) in Bogota?
- What major determinants influence the BLOS intersection model?

Sub objective (3): To predict the probability of satisfaction levels of residents given unit changes in some road geometry, physical and operational measurements of transport in Bogota.

- Which are the average marginal effects for the perceived level of service model for segments?
- What is the bicycle suitability of the Cicloruta.

Sub objective (4): To compare Bogota LOS model with earlier estimated models with a view to identifying strength and weakness of methodology.

- What main differences exist in methodology amongst models?
- What strengths/weaknesses are associated with each method above?

1.5. Conceptual framework

Both qualitative and quantitative researches in urban planning practice, and transportation planning and policies reveal a good number of potential factors that can influence bicycling. A review of some of this literature reveals three key themes that impacts bicycling in any community or city. These are physical environmental factors, individual socio-economic factors and government policies (figure 1.1).

In terms of the physical environmental factors, five sub-themes can be identified as functional, safety, aesthetics, destination and physical conditions. The functional sub-theme describes the physical characteristics of the bicycle pathway that reflects basic structural aspects of the local environment. Some of these factors include design of intersection, design, location, directness and surface of bicycle pathways and streets, traffic volume and parking facilities (Caulfield, Brick, & McCarthy, 2012; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003).

The safety factors of the physical environment indicates the need for the provision of security to safeguard life and property of bicyclists, provision of complimentary road infrastructure such as crossing aids, lighting, surveillance, verge width, and so on. Therefore, two elements of safety will be incorporated into this research such as personal safety in terms of security of bicyclists and traffic safety provided. This is in line with Jacobsen (2003) findings that the 'the likelihood that a given person walking or cycling will be struck by a motorist varies inversely with the amount of walking or bicycling'. However, the varying size of community, design of intersections and traffic peak periods are all consistent with the pattern of safety. The development of separate bicycle pathway has often been commended by transport planners, however, there cannot provide a sole policy for bicyclist safety. It is therefore recommended that a multi-faceted approach that includes a wide range of measures such as 'traffic calming of residential neighbourhoods; urban design oriented to people and not cars; restrictions on motor vehicle use; better traffic education of both motorists and non-motorists; and enforcement of traffic regulations protecting cyclists' (John Pucher, 2001).

Aesthetics provides one of the motivations and deterrents for bicycling. The pleasantness of the environment characterised by its cleanliness, appealing sights, green parks, trees, pollution-free streets, layout of landscape and street architecture all indicate relative importance in the promotion of bicycling and walking. Bicycle pathways that are separated from excessive traffic noise and pollution, and pathways with beautiful scenery have been shown to provide high motivation for bicycling (Kamphuis et al., 2008; Pikora et al., 2003; Winters, Davidson, Kao, & Teschke, 2011).

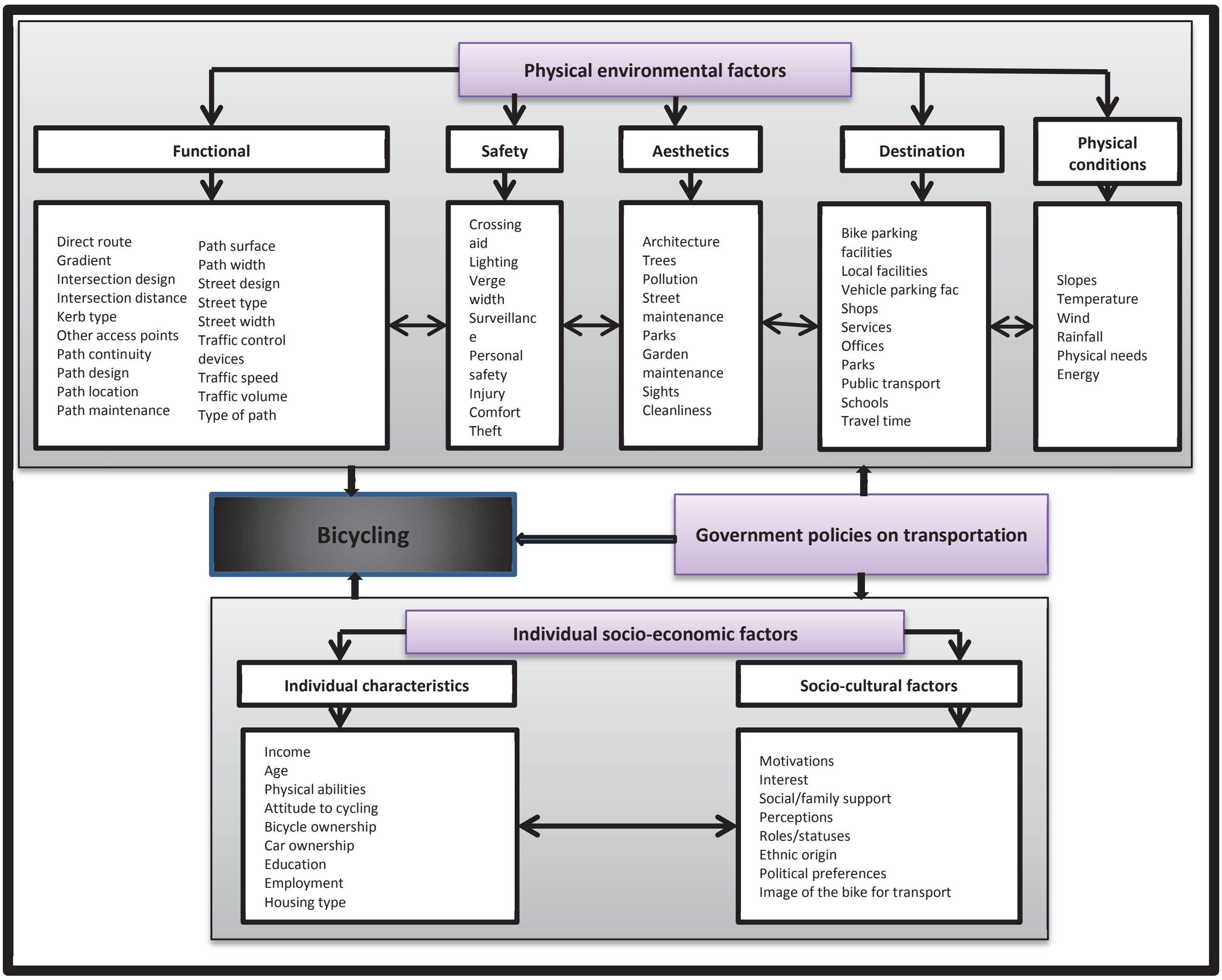


Figure 1.1 Factors affecting bicycle use

Destination also plays a very important role in influencing bicycling. This is because travel is a derived demand. People do not travel for just travelling sake (exception of leisure trips) but to satisfy activity need at the trip end (Banister, 2008; Hesse & Rodrigue, 2004). Several primary trip purposes have been identified to include work, shop, school and recreation (Kevin J Krizek, 2003). Other facilities such as location of facility, bike facilities, public transport, and general land use structure are basic determinants of bicycling. Although, the conventional wisdom that travel is a derived demand is contested at least as an absolute. This is not to suggest that the principle of most travel is derivative, but argues the fact that humans possess an intrinsic desire to travel, a point previously made by some researchers pointing on the 'wandering nature' of early man (Mokhtarian & Salomon, 2001; Mokhtarian, Salomon, & Redmond, 2001). This notwithstanding, traffic generating land uses such as school, shops, offices, parks, transport facilities such as bus tops and train stations form basic components in the influence of cycling.

Physical conditions of communities such as slopes, temperature, wind and rainfall influences bicycling. For instance, Winters, Friesen, Koehoorn, and Teschke (2007) identified more days of precipitation and freezing temperatures per year as having strong association with utilitarian bicycling in Canadian cities. In the same vein, Cervero and Duncan (2003) also identified a strong evidence on the importance of landscapes in foot and bicycle travel in San Francisco Bay Area. Therefore, weather has a significant influence on bicycling. In his study of 'the effect of weather and climate on bicycle commuting in

Melbourne, Australia', Nankervis (1999) identified both short and long term weather conditions and seasonal variation in pattern of commuting among tertiary students. He concluded that certain extreme weather conditions are perceived as been non-viable for cycling by the study population.

The figure also illustrates different levels of individual characteristics such as income, age, physical abilities and attitude to bicycling, bicycle ownership, car ownership, education and employment type. For example, income determines car or bicycle ownership; age correlates strongly with physical fitness; gender influences perceived traffic and personal safety. This framework seeks to facilitate this work by enhancing the collection of relevant socio-economic data and their relation to bicycling. Incoordination and segmentation thus occur without such a framework. Pikora et al. (2003) developed framework that reflects four specific behaviours such as walking for transport, walking for recreation, cycling for transport, and cycling for recreation. This study does not define purpose of cycling, rather satisfaction level of bicyclists. Winters et al. (2007) noted that 'in the general population, older age, female gender, lower education, and higher income were associated with lower likelihood of cycling' and concluded that bicycling patterns have high relationship with individual demographic characteristics and local climate regimes.

Differences in cultural tradition, with probable relation to ethnicity deserves a more explicit role in bicycle travel surveys and the analysis of non-motorised travel behaviour than it usually receives (Rietveld & Daniel, 2004). Our framework on socio-cultural factors focuses on the image and perception of the bicycle as a transport mode, motivations for use, interest in its use, social and family support for its use, roles and statuses in society, ethnic origin and political preference.

The role of government is conceptualised in two sub-themes. Firstly, government policy on public transportation involving parking cost, taxation on fuel, charging of tolls, and supply of public transportation service. The provision of the Bogota bus rapid transit (BRT), otherwise referred to as the Transmilenio is typical example of the influence of government policy on public transport, thus the use of bicycle. Secondly, government policy on the access and cost of bicycle use. This includes bike parking sheds, ownership, maintenance, bike lanes such as the cicloruta, and bike renting facilities. Local authority initiatives can arrange the internal urban structure to accommodate or facilitate the use of bicycle. Government policies on transport and land use are instrumental to the boom in bicycle use in Denmark, Germany and the Netherlands (J Pucher & Buehler, 2008)

The focus of this study is to develop relevant methodology for the evaluation of the quality of satisfaction derived from the use of the cicloruta, thereby directing efforts and resources at specific problems of the infrastructure.

1.6. Research design

This research work is set up in Bogota. It has one of the most extensive bicycle infrastructure networks in South America. The research was conducted in three phases (figure 1.2). The first phase involved the development of key concepts of non-motorised transit and assessment of existing data on Bogota for background understanding. The second phase basically deals with research elements of data collection which included both secondary and primary data. Secondary data included transport infrastructure geometry and exhaustive literature review. Primary data involved socio-economic and cultural characteristics of bicyclists, rating of specific bicycle transport infrastructure by stakeholders, video clips of relevant bicycle road segments and intersections, measurements of geometric and operational variables of

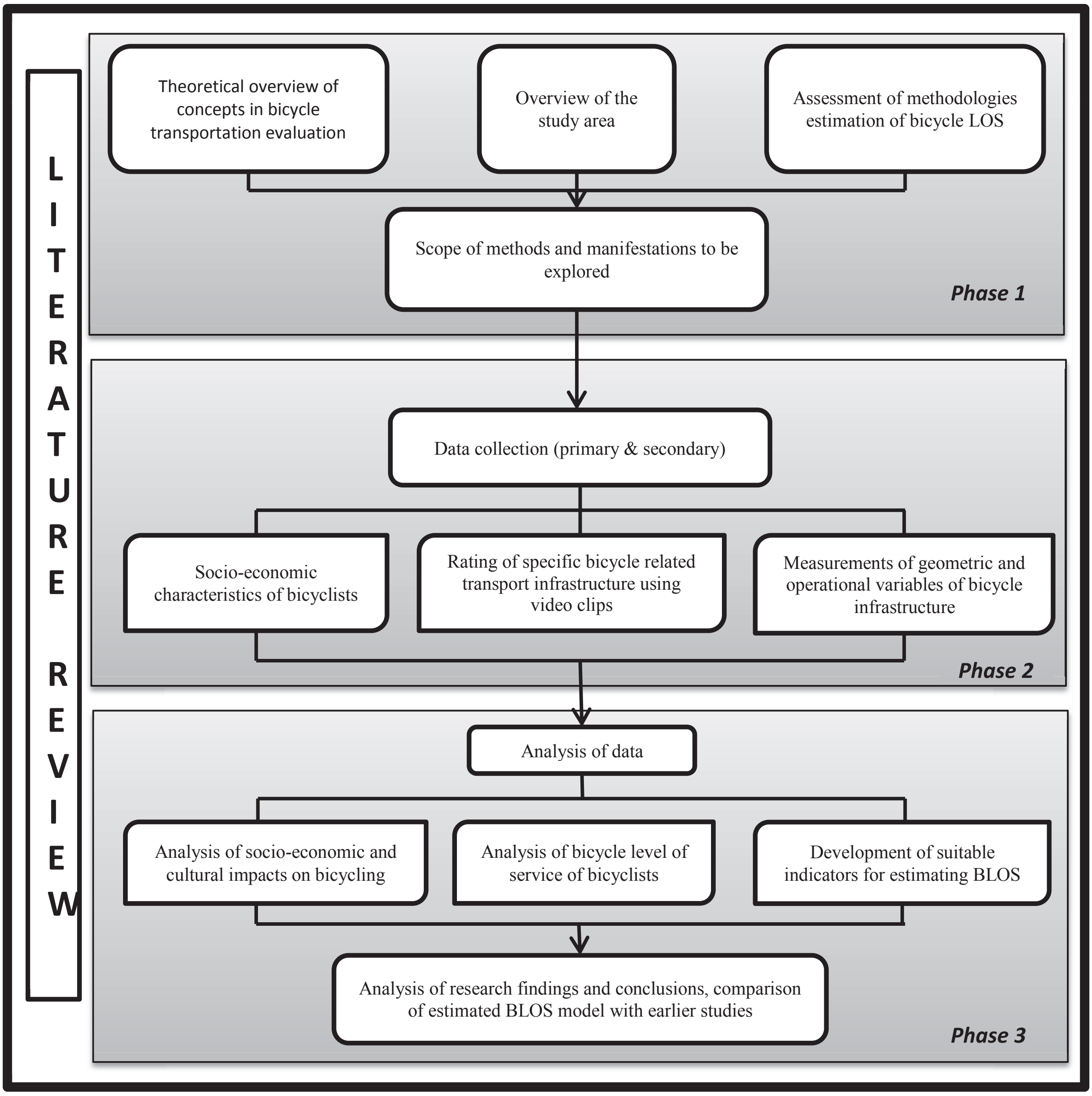


Figure 1.2 Schema of research design

bicycle pathway segments and intersections. The method involved the use of specialised camera to acquire data which is shown to participants during group viewing and rating their level of satisfaction.

Generally, analysis of data constitutes the third phase, where the impact of certain socio-economic and cultural characteristics on bicycle use are analysed. The level of stress as perceived by bicyclists will be analysed to ascertain the ease with which bicycle transport is carried out in Bogota. Other analyses include the development of bicycle level of service model to provide an understanding of the capability of segments of the cicloruta to accommodate bicycle transport. The safety of bicyclist is also ascertained with the development of intersection level of service in the cicloruta. All of these analyses culminate in the development of relevant indicators for estimating the suitability or the level of service of the bicycle network in Bogota. The study shall therefore discuss its findings and compare estimated models with previous research findings. Generalised Linear Models (GLMs) is used to set up probit ordered models which also include independent and class variables, leading to estimation of BLOS and IntBLOS models.

1.7. Significance of the study

The most essential function of transportation is providing mobility for people and goods. This is why the Florida Department of Transportation level of service (FDOT, 2009) identified four dimensions of transportation. They include: the quality of transportation which deals with traveller's satisfaction; the quantity of travel that deals with magnitude of use of a facility of service; accessibility as the ease with which travellers can engage in desired activities; and capacity utilization as the quantity of operations relative to capacity. This is based on what highway capacity manual (HCM, 2000) had earlier identified as level of service (LOS) and defined as 'quantitative stratification of a performance measure or measures that represent quality of service'. There is therefore the need for quantitative stratification of a performance measure(s) that represent quality of service that ranges from 1-6, representing highly satisfied, moderately satisfied, a little satisfied, a little dissatisfied, moderately dissatisfied, and highly dissatisfied conditions respectively

Moreover, the need for development of transportation facilities and for that matter non-motorised becomes imperative in view of the more than 7 million inhabitants in Bogota city with various movement needs. It is already established that many governments at local and federal levels are investing huge financial resources in non-motorised transportation infrastructures. In 1999 for example, the city of Bogota built a high capacity bus system (TRANSMILENIO) to address transport needs of residents. The CicloRuta which is about 300km was followed shortly in 2000. It is estimated that about US$180 million was spent on these infrastructure. It is therefore not unlikely that there may be other factors that encourages its use or otherwise.

However, essential data and generally acceptable methodologies for measuring the use of these facilities are unavailable for planning and management purposes. It is therefore difficult to achieve 'evidence-based choices among investment alternatives and to optimise management of infrastructure and transportation systems' due largely to lack of data and necessary tools for estimating facility use (Lindsey, Hoff, Hankey, & Wang, 2012). Transportation planners and engineers alike need information and scientific tools for estimating bicycle traffic volume and pattern of facility use. The theme of this research therefore emerged to evaluate the level of satisfaction of bicyclists thereby developing suitable indicators that helps policy makers prioritise their investments in new and existing bicycle infrastructures. Relevant segments of the bicycle road network can thus be improved or redesigned especially in terms of intersection to enhance the capability of the cicloruta to accommodate bicycle use. Generally, this helps to increase understanding of bicycle transportation facilities in Bogota.

1.8. Organisation of thesis

The framework for this thesis conforms to topical presentation using chapters for separate themes. Chapter one basically involves general background of study; chapter two deals with literature review; chapter three provides basic information on study area; chapter four presents methodological overview; chapter is presentation of results; while chapter six is discussion of findings, conclusion and recommendations.

2. A THEORETICAL PERSPECTIVE ON EVALUATION OF NON-MOTORISED (BICYCLE) TRANSPORTATION

Chapter 2 essentially provides a brief review of literature that offers a summary of researches on non-motorised (bicycle) transportation infrastructure. Since the 1970s, there has been methodical research in non-motorised transportation thereby increasing understanding in the pattern of use and factors. Evidently, transportation planners and managers still lack reliable data and scientific tools for analytic and science-based decisions. This may not be most practical, but many such applications could help optimise investment efficiency on non-motorised infrastructures by opening doors to new facilities or in operations and maintenance of current infrastructures. The chapter summarises research that reveals the general understanding of non-motorised transportation facilities such as bicycling, bicycle stress level, bicycle compatibility index, intersection level of service and bicycle level of service.

2.1. Use of non-motorised (bicycle) transportation

The contribution and potential of use of non-motorised (bicycle) transportation to promote health and enhance high quality of environment has increasingly been recognised. This is evidenced in the huge investments in the development of viable infrastructure for bicycling and walking. For example, the US$180 investment in the cicloruta project has helped to reduce congestion and has ushered in a new urban life in Bogota. This includes the revitalisation of recreational parks and sidewalks, creation of pedestrian zones, development of the bicycle pathway and thus creating an egalitarian society.

2.1.1. Patterns in non-motorised (bicycle) traffic

The level of non-motorised traffic is expected to increase with the promotion of new urbanism and smart growth. The low carbon emission nature of non-motorised transport and the promotion of user's health are also reasons for its increased use. However, transportation planners are faced with the problem of limited data for well-informed plans on the use and demand patterns of non-motorised transport. As much as motorised traffic, non-motorised traffic also exhibit temporal and spatial patterns. These patterns differ across modes such as automobiles versus cycling versus walking. In terms of temporal scale, hourly, daily, weekly and seasonal variations can be observed. For instance, C. Zhang, Jennings, Autman-Hall, and Benoit (2010) used data from geo-coded land use and street network data, geo-coded pedestrian/bikeways network, and multiple-day continuous pedestrian and bicyclists counts to examine pedestrian/bicyclists patterns in Chittenden County, Vermont. The result showed some differences in hourly non-motorised traffic pattern on weekdays, Saturday and Sunday from location to location and therefore establishes the influence of land use distribution on pedestrian and bicycle pattern. This pattern is due largely to neighbourhood design features such as socio-demographics, land use mix, bicycle facilities (on-street or off-street), volume of pedestrian and bicyclists, weather and so on (Hankey et al., 2012).

Some researchers also point to the existence of regional differences in non-motorised traffic pattern. For instance, the study conducted by Jones (2009) observed that 'unlike vehicle use patterns, there appear to be significant regional differences in seasonal patterns' of non-motorised traffic as evidenced from pattern of trail use in Indianapolis, different from other regions of America. The study therefore concluded that such regional variations could only be accepted by transport planners as being natural but requires greater care in their estimation process. This point for bicycle infrastructure mediations was highlighted in the review of J Pucher, Dill, and Handy (2010) indicating 'considerable variation in estimated impacts, both by type of intervention and by study design, location and timing'. Similarly, Aultman-Hall, Lane, and Lambert

(2009) assessed the impact of weather and season such as temperature, relative humidity, precipitation and wind on variability of pedestrian traffic volume in Vermont, United States. Furthermore, the results indicated 30 per cent variability in the relationship between weather variables, season and pedestrian volume was consistent. Aggregate pedestrian volumes were reduced by 20 per cent owing to cold temperature and precipitation. The Federal Highway Administration (FHA, 1999) summarised the different factors accounting for variability of non-motorised transport to include 'link characteristics and friendliness, network characteristics and friendliness, supporting policies, population characteristics, climate/weather, characteristics of other modes, and land use'.

Non-motorised transport (NMT) are not only limited to walking and bicycling but include all transport modes other than motorised such as human or animal powered modes of transport. Other examples include pedicabs, tricycles, rickshaws, handcarts, becaks, bullock, camel and horse carts. These are presently more dominant in Africa and Asia (Pendakur, 2011). But literature on the subject matter cuts across the globe. For example, in analysing non-motorised commuter journeys in five major Irish cities, Lawson, McMorrow, and Ghosh (2013) observed gender, car ownership and journey distance as having the largest effect on the use of non-motorised transport using multiple logistic regression modelling. Plaut (2005) identified various forms of non-motorised commuting such as in the United States to include bicycling, walking to work and working at home. He identified high salary income and more expensive housing as having higher propensity to work at home, but lower propensity to walk or bicycle, while also noting college education as having greater propensity for walking and bicycling. In his paper on 'biking and walking: the position of non-motorised transport modes in transport systems' Rietveld (2001) identified income growth and urban sprawl as major contributors to the decline of NMT in developing countries. He however identified the need for the complementarity between motorised and non-motorised transport modes for sustainable transportation.

Key findings of the study of Lindsey et al. (2012) on 'understanding the use of non-motorised transport facilities in Minneapolis, Minnesota' reveal that 2-hour peak-hour manual count as the most common type of pedestrian and bicyclists count. They noted further the inevitability of error irrespective of the approach adopted in the count which they observe significantly vary by 'location, infrastructure type, day of the week and month of year or season'.

In the area of impacts on environmental quality, the role of NMT in the defence of public land and enhancement of aesthetics in Bogota has been acknowledged by Montezuma (2005). This according to him included the recovery of 338,297 square meters and the construction of 147,000 square meters of space under bridges and 432,000 square meters of sidewalks, thus giving a total of 917,000 square meters of public space. This is in addition to 1,034 parks (or 54%) of green spaces, 70,000 trees, 183,651 planters, 202 kilometres of roadside greenery and 280 hectares of parks in the city. This advantages notwithstanding, while NMT is beneficial to citizens and the environment, it is not without some potential costs according to Litman (2013).

A study conducted in two low income localities (Santafe and Tunjuelito) in Bogota by Gomez, Sarmiento, Lucumi, and Espinosa (2004) revealed the prevalence of factors associated with walking and bicycling transport among young adults. Using an adjusted prevalence odds ratio [95% confidence interval], the increased likelihood of bicycling was noted among groups with strong affiliation 2.99[1.49, 6.02], residents of hilly Tunjuelito terrain 2.94[1.96, 4.42] proximity to ciclovia 2.28[1.32, 3.93]. The research therefore recommended further investigations on the influence of socio-demographic, social and physical environmental factors on walking and bicycling in Bogota.

Munoz-Raskin (2007) investigated the relation between walking accessibility to bus rapid transit (BRT) and residential property values in Bogota using the Transmilenio as a case study. Hedonic multiple regression modelling of data from 130,692 housing units of legal status obtained from Bogota department of housing control (2000-2004) was used. The results of the study indicate that walking proximity of not more than 5 minutes from feeder lines significantly relate to high housing market value compared to property 5-10 minutes walking distance. In terms of socioeconomic class, the results showed that middle income property were more valuable when there are located close to the system while this is reverse for low income housing. The research further showed that high income housing with greater proximity to feeder lines was more valuable while those close to trunk stations revealed opposite results.

2.2. Travel-related infrastructure for bicycle transportation

There is an increasing growth in the body of literature from empirical research that examined the influence of infrastructure on bicycle transportation. However, some of these researches are limited by the range of infrastructure been studied perhaps due to the multiplicity of factors which affect bicycling. For example, one of the bicycle studies conducted in Australia revealed high likelihood for bicycling by people who agreed that there were bicycle tracks along their travel route and existence of possible short cuts between their origin and destinations (Titze, Stronegger, Janschitz, & Oja, 2008). This likelihood is twice that compared with those whose residence and trip purpose is not served by such tracks. The study which adopted a computer-assisted telephone interview of 1000 inhabitants of Graz as a representative sample further concluded that 'cycling-related social support and perceived benefits and barriers, bike lane connectivity may be an important determinant of cycling as a means of transportation among adult city dwellers'. Consequently, a revealed preference survey of bicyclists in Texas confirmed a strong positive relationship between respondents' overall rating of bicycle facilities and the frequency of commuting with bicycle (Sener, Eluru, & Bhat, 2009). Data for the survey was drawn from a web-based stated preference survey of bicyclists in Texas covering comprehensive attributes such as 'bicyclists characteristics, on-street parking, bicycle facility type and amenities, roadway physical characteristics, roadway functional characteristics, and roadway operational characteristics'. Conversely, Sisson, Lee, Burns, and Tudor-Locke (2006) did not observe a significant relationship between rating for bicycle commuting by elementary school pupils and number of parked bicycles in school but however concluded that other factors such as 'intraindividual, social, school, and community' are likely to contribute to choice of biking to school.

At both city and regional levels, several cross-sectional studies revealed a corresponding positive relationship between bikeability and presence of bicycle lanes or tracks. For example, a cross-sectional study of 43 American cities revealed a corresponding high level of bicycle commuting with availability of bicycle infrastructure (Dill & Carr, 2003). They further observed that other facilities such as striped lane or separated bicycle track increase bicyclists' perception of safety and thus their willingness to cycle. Parkin, Wardman, and Page (2008) used UK 2001 census data based on a logistic regression model and estimated determinants of cycle choice. The result of their study further showed that though physical conditions of the highway, rainfall and temperature show significant influence on bicycle commuting, hilliness revealed the most significant of all physical variables. Though conventional wisdom according to Nelson and Allen (1997) suggests that when you build bicycle tracks, people would use them, it was not enough to conclude on this if other extraneous variables are not held constant. They however concluded in their cross-sectional study of 18 US cities that there is a corresponding positive relationship between 'miles of bicycle pathways per 100,000 residents and percentage of bicycle commuters', holding weather, terrain, and number of college students as constant.

Though, some longitudinal studies however corroborates earlier findings that provision of bike lanes or tracks encourages commuting by cycling, sometimes such effects are mediated (Barnes, Thompson, & Krizek, 2006; Cleaveland & Douma, 2009). The study of the influences of built environments on walking and cycling in Bogota, acknowledges that whereas road facility designs (density, connectivity, and proximity to ciclovia lanes) are associated with physical activity, density and land use mixes are not. This is perhaps due to the uniformly compact, mixed land use composition and comparable levels of transport accessibility that characterised the very nature of urban development in Bogota (Cervero et al., 2009). Similarly, de Geus, De Bourdeaudhuij, Jannes, and Meeusen (2008) also observed that people living in areas of adequate bicycle infrastructure also have 'individual determinants (psychosocial, self-efficacy, perceived benefits and barriers) outperform the role of environmental determinants in their sample'. They however recommended promotion campaigns aimed at increasing 'self-efficacy, raising ecological and economic awareness' for bicycle commuting in addition to bicycle infrastructure development. Another survey conducted in Oregon, United States, higher levels of cycling were found to have close association with higher level of street connectivity and not necessarily with proximity to off-street trails and bike lanes.

However, several stated preference surveys on bicycle commuting further reveal bike lane preference over none existence of facilities or enhanced bicycling due to improved bike lanes (Abraham, McMillan, Brownlee, & Hunt, 2002; Akar & Clifton, 2009; Landis et al., 1997; Madera, 2009; Parkin, Wardman, & Page, 2007; Stinson & Bhat, 2003; Wardman, Tight, & Page, 2007). Most of the studies combined revealed preference (RP) and stated preference (SP) to form large and comprehensive models to predict urban commuter behaviour and trends in modal split over time that helps to predict also the impact of multiple measures to encourage bicycle commuting. Different methods of data collection ranging from stated preference internet surveys, web-based surveys to posted questionnaires were employed by the authors. All studies revealed the presence of bicycle lane especially separated track as, automobile traffic, surface condition of bike lane, and so on as important determinants in bicycle commuting. These references may however differ depending on the level of experience of each cyclist. For example, experienced cyclists may likely have preference for bicycle lane than separated bike tracks (BTS, 2004; Hunt & Abraham, 2007; Stinson & Bhat, 2003; Tilahun, Levinson, & Krizek, 2007) or may have little or no preference for striped lanes over none-striped lanes (Sener et al., 2009; Taylor & Mahmassani, 1996). Furthermore, several studies on 'before-and-after' bicycle counts in North American cities and United Kingdom including San Franscisco (2004), Toronto (2001), Vancouver (1999), Sallaberry (2000), and London (2004) show increases in volume of bicycle commuting after certain bicycle infrastructures were developed. Though, other studies also investigated the influence of bicycle lane markings on bicyclists' perception of safety but however do not attempt to measure the resultant changes in cycling volume (Daff & Barton, 2005; Harkey & Stewart, 1997; W. W. Hunter, Stewart, & Stutts, 1999; Van Houten & Seiderman, 2005).

In terms of the effect of a two-way travel on one-way streets on bicyclists, a UK study of six sites observed a no effect relationship as respondents expressed a feeling of safety as far as the lane is correctly designed. The research which was conducted by video filming and interviews also used supplemental data from local transport authorities on vehicles speed and reported accidents, recommended for 'motor vehicle speeds, delivery vehicles, parking and side roads' as vital considerations on the construction of contra-flow schemes (Ryley & Davies, 1998). In the same vein, another German study found no negative effect on traffic safety of bicyclists. The study found out that more than 80 per cent of 669 streets whose vehicle speed limit is 30 km per hour observed for 3-to-4 years had no recorded bicycle crash and only 3 per cent of the streets recorded more than one crash (Alrutz, Angenendt, Draeger, & Gündel, 2002). Similarly, shared bus/bicycle lanes was observed to be popular amongst bicyclists in a UK study carried out in Hull, Edinburgh, Derby and London. About one quarter of survey participants (bicyclists) agreed that riding in bus lanes including contra-flows was safer and more direct than cycling in general traffic and therefore influenced their route choice. Though few instances of conflict thus exist and occasional delays to bus drivers, the authors opined that such conflicts can easily be resolved by design of wider bus lanes and 'mutual awareness' (Reid & Guthrie, 2004).

With respect to off-street paths, there are conflicting evidences as regards the level of influence on cyclists (Aultman-Hall, Hall, & Baetz, 1997; Dill, 2009). For instance, a disaggregate cross-sectional study that uses 608 randomly selected respondents, 'objective parcel-level GIS measures of land use and infrastructure conditions' as primary data in urbanised King County, Washington. They found both perceived and environmental conditions as likely contributors to bicycle commuting (Moudon et al., 2005). They further observed 'proximity to trails and the presence of agglomerations of offices, clinics/hospitals, and fast food restaurants, measured objectively, are significant environmental variables' that correlates strongly with bicycle commuting. Conversely, the study of Kevin J Krizek and Johnson (2006) in Minneapolis which used multivariate modelling techniques upheld the statistical significance of distances to retail and bicycle facilities as predators for active mode choice at close distances but not necessarily any linear relationship between them. Another stated preference survey by Shafizadeh and Niemeier (1997) observed that longer routes using a path was preferred to a shorter route using a motor vehicle lane by 40 per cent of bicyclists. An observational study in Australia where 6589 cyclists through bicycle census were interviewed and clearly showed that women preferred off-road paths to lanes and lanes with facilities to those without (Garrard, Rose, & Lo, 2008). Using a self-completion mail-back questionnaire technique, an intercept survey in Melbourne, Australia observed that 50 per cent of sampled bicyclists spent their riding time on off-road facilities and an approximate 20 per cent agreed that they would change mode if off-road facilities were not available (Rose, 2007). Furthermore, about 60 per cent of those who would turn to public transport if off-road facilities are not available are opposed to the use of car as an alternative. This underscores the role of bicycle commuting in Australia's intra-urban transit. There is also a corresponding preference for separate bicycle paths by inexperienced cyclists. Separate bike lanes breed a feeling of safety and thus build confidence on new-comer cyclists. In other to determine level of bicycle use in San Diego, 3,800 were conducted by telephone where majority of those who bicycle to work indicated they do so on separated bicycle lanes (Jackson & Ruehr, 1998).

Furthermore, a Copenhagen study of influence of cycle tracks on bicycle traffic safety and congestion using before-after crash, injury and traffic data observed a 10 per cent increase in safety effect from bicycle tracks in both crashes and injuries. While in bicycle lanes, it increased by 5 per cent in crashes and 15 per cent in injuries in urban areas (Jensen, 2008). Similarly, in terms of bicycle lanes, safety increased by 5 per cent increase in crashes and 15 per cent in injuries. The study also highlighted safety implications of implementing bicycle facilities and vehicle parking conditions especially at intersections. A 20 per cent increase in bicycle commuting after implementation of cycle track lead to a 10 per cent decrease in vehicle traffic mileage while bicycle lane marking resulted in a 5 per cent bicycle transport use thus mopping or reducing vehicle traffic mileage by 1 per cent. A London survey also corroborated the findings above, where the implementation of two-way cycle track in London revealed a considerable reduction in bicycle related crashes (TfL, 2005). Another survey on the attractiveness of bicycle facilities in Germany also revealed the unattractiveness of major roads to cyclists and a rather high preference to separate cycle tracks as this provides 'the feeling of subjective safety' (Bohle, 2000). Generally, men seem to be more satisfied with existing bicycle traffic conditions than women, just like young people are also more satisfied than the elderly and urban dwellers than rural dwellers (Jensen, 2007). The research was conducted in Denmark and randomly selected 407 Danes who were shown video clips of 56 segments from a walking pedestrian and a bicycle rider. The result further revealed motorised traffic volume, urban land uses, rural landscapes, and other variables that influence satisfaction levels of both pedestrian and bicyclists.

In Sweden and the United States to mention just but a few, some studies also looked at coloured lanes and cycling levels. For instance, Gårder, Leden, and Pulkkinen (1998) developed 'before-and-after methodology' to evaluate bicyclists' perceived safety due to an increase in urban bicycle crossing from 4 cm to 12 cm. the results showed a 50 per cent more bicyclist owing to feeling of safety. A combination of multiple factors such as surveys of bicyclists and experts, conflict data, and a quantitative expert model in a Bayesian technique showed 30 per cent risk reduction as likely effect of raising the bicycle crossing. The city of Portland, Oregon also studied blue pavement markings from 1997 to 1999 'marking 10 conflict areas with paint, blue thermoplastic, and an accompanying "Yield to Cyclist" sign'. All sites have a history of conflicts with high volume of both cyclists and motorists. A video tape analysis at a point where cyclists travelled straight while motorists crosses, revealed a change in behaviour as motorists waited for cyclists to pass and thus enhanced comfort and safety levels of cyclists (W. Hunter, Harkey, Stewart, & Birk, 2000). Many other studies investigated the outcome of various safety measures rather than levels of bicycle commuting (W. Hunter et al., 2000; Konig, 2006; Sadek, Dickason, & Kaplan, 2007).

Moreover, sharrows or shared lane markings on road segments help to inform motorists and bicyclists alike that they must share the facility while operating. Studies have shown both remarkable change in behaviour of motorists and cyclists from a pre-sharrow era to a post-sharrow period, though many have avoided determining volume change. For example, a United States study on the 'evaluation of shared lane markings was specifically interested in evaluating sharrow design and other shared lane pavement markings on safety and operational measures of cyclists (W. Hunter, Thomas, Srinivasan, & Martell, 2010). Basic findings include the placement of sharrows at a 10-ft to control doors of parked cars, used to control parking, and used to create a bicycle lane in a busy commuting road, respectively in Cambridge, Chapel Hill and in Seattle. The study which concluded by acknowledging the importance of sharrows to consistently raise awareness of road users and thus enhances safety of bicyclists corroborates findings of earlier researches (APD, 2004; FHA, 2003; Pein, Hunter, & Stewart, 1999).

Wide range of results was shown in terms of bicycle use and bike boxes otherwise referred to as advanced stop lines. For instance, Daff and Barton (2005) used series of videos to summarise over 10,000 motorists behaviour towards bicyclists on a marked Melbourne arterial roads. They concluded that the width of the kerbside significantly affected the clearance drivers gave cyclists as they overtook them; there was large site-to-site variations in this clearance between drivers; all overtaking drivers virtually squeezed cyclists into narrow spaces when there was a car in opposite direction; and that cyclists reported less stress and increased feeling of comfort and safety as they drive on marked lanes even though there was no reduced conflicts recorded. Similarly, 'evaluation of innovative bike-box application in Oregon' illustrated the behaviour of motorists and cyclists in a 'bike box' installed intersection using a video technique and concluded that the frequency of conflicts before and after installation was insignificant (W. Hunter et al., 2000). The video survey of the 'before' and 'after' an advanced stop line (ASL) facility in London similarly revealed a 'slight but not statistically significant increase in saturation flow of 1.5% and 5.5%' at London Road/York Road and Epsom Road/A247 respectively, where the number of lanes remained the same

(Wall, Davies, Crabtree, & Britain, 2003). Along Epsom Road/Boxgrove Road eastbound and westbound where traffic lane was removed, they was a significant reduction in saturation flow of 47% and 38% respectively and therefore concluded that there was no video evidence to a change in 'cyclist queuing/positioning, although there was small bicycle flow in four sites sampled. Another study found out an increased perception of bicyclists' safety and reduction in the frequency of accidents (Newman, 2002). He observed a crash reduction of 40% between 1999 and 2000 for roads marked in 1998, and a reduction of 24.5% observed in 2000 for those marked in 1999. He further drew a comparison between treated intersections and non-treated intersections and ascertained a significant reduction of bicycle related crashes at 'traffic signal controlled intersections' since 1997.

Pavement quality and litter of debris on bicycle pathways (lane and tracks) could have significant influence on decision to cycle and perception of safety. A 'cycling for business' survey in London revealed the doubling in the volume of bicycle commuting due to bicycle path resurfacing in 2004 (TfL, 2004). Parkin et al. (2008) also used census data in UK to reveal a 43% significant increase in bicycle commuting development in off-street bicycle lanes and other physical variables.

2.3. Integration of bicycle commuting with public transportation

There is a growing consensus on the assertion that the integration of bicycle commuting with most public transport such as suburban rail and metro stations increases bicycle use for transport. This integration has given rise to new designs in such public transport facilities especially in the Netherlands, Denmark and Germany, to accommodate large amount of bicycles for safe parking in addition to high car parking taxes in city centres, comprehensive traffic education, separate lanes for bicycles and other incentives (Fietsberaad, 2006; J Pucher & Buehler, 2008). There has also been reported massive bike parking facilities in Japanese rail stations (Harden, 2008). According to the survey, an estimated 740,000 bikes are reportedly parked at Tokyo's metro and train stations daily. In the Netherlands, it is also estimated that there are over 350,000 bike racks in Dutch train stations (DNR, 2009; Martens, 2007). Similar integration strategies to include the provision of bicycle lockers at bus-stops leading to a combined use of bike-and-bus, various bicycle renting schemes, thus increasing bicycle use have also been noted by (Martens, 2007). He observed that the Netherlands present an extreme situation as an industrialised country with one of the highest level of bicycle commuting which J Pucher and Dijkstra (2000) ascertained as accounting for more than 27 per cent of all urban trips.

The importance of providing better parking facilities at metro and train stations has be revealed to have influence on public transport. Rietveld (2000) revealed a significant increase in public transport use and bicycle commuting as a result of good parking system at the train stations in the Netherlands. He noted a 23 per cent (lower than the country's average share of 28 per cent) average share of bicycle as an entry or exit mode for train passengers. Some of the reasons advanced include the fact that there is usually not a bike available at the activity end where the bicycle share is 10 per cent unlike 35 per cent at the home end; and the discouragement for bicycle use due to inadequate parking facilities that guarantees bike safety from theft. Similarly, (Martens, 2004, 2007) identified a strong relationship 'between public transport type and the share of bike-and-ride in access and egress trips' in three European countries of Denmark, Netherlands and Germany. He concluded that though both countries show strong similarities in public transport access and egress distances, faster public transport can attract 4 or 5 km bike and ride while for lower ones, the distance of bike and ride ranges from 2 to 3 km.

Researches on non-motorised transport integration with public transport has been unanimous on the mutual benefits of such coordination on both modes and most importantly enhancing the use of bicycle in urban transit (Brunsing, 1997; Hegger, 2007; May & Roberts, 1995; McClintock, 2003; NMT, 2009; J Pucher & Buehler, 2009). For instance, using some North American and Canadian major cities, namely: San Francisco, Portland, Minneapolis, Chicago, Washington, New York, Vancouver and Toronto, J Pucher and Buehler (2009) identified five major strategies taken to facilitate the progress being made in to a decade coordination programme of cycling with public transport. These include: parking provisions at rail and bus stations; bike service facilities; bike racks on buses; bike hooks on train/trams; and extensive cycle lanes/paths.

The percentage of buses with bike rackets was raised from 27 per cent in 2000 to 71 per cent in 2008 in the US alone thus encouraging bicycle commuting. Although, the extent of bike and ride is only considered by a few transit systems, available evidence is however encouraging. In Washington for example, they further remarked that from 2002 to 2007, there has been a 60 per cent increase in the number of bicyclists riding on Metrorail and many stations bicyclists accounting 4 per cent of passengers boarding; Minneapolis recorded over 250,000 bicycles annually on metro transit and a 'doubling of bikes on buses between spring 2007 and fall 2008'; 4 per cent of Portland MAX light rail passengers were reported to have carried their bicycles with them; while in San Francisco Bay Area, there was an increase of 2.5 per cent in 1998 to 3.5 per cent in 2008 on passenger share accessing BART stations by bicycle 'with an average of 10,920 bike-and-ride trips per day'. However the above may sound good, McClintock (2003) however cautioned against bicycles prejudicing the legitimate needs of other passengers including the physically challenged people in such public transit. It is therefore fundamentally important to give recognition to the importance of a holistic approach that serves the needs of all passengers using different modes from the planning phase to operations.

Short term bicycle rentals have been widely implemented in Europe. It uses smart card technology like ov-Fiets public transport bicycle rentals in the 156 rail stations in the Netherlands as well as the 16 German train stations Call-a-bike rentals (Martens, 2007; J Pucher & Buehler, 2008). Some of these coordination policies have been revealed to have a corresponding positive influence in the volume of bicycle commuting in the Netherlands, Denmark, and Germany. J Pucher and Buehler (2008) notes them to include: bike parking facilities at rail stations; 'call a bike' programmes; bike rentals; and various bike services.

Similar bike rental systems have also been developed under different programmes in different cities as the examples of 'Velib' in Paris, 'Velov' in Lyon, and 'Bicing' in Barcelona mostly located near metro and train stations, strongly suggests (Holtzman, 2008; Litman, 2009a; Martens, 2007). Mostly common in North America (but rear in Europe), bicycle racks on buses account for about 72 per cent of all public transport buses equipped with bike racks and about 82 per cent in Canada (APTA, 2008; J Pucher & Buehler, 2009; TRB, 2005). Most other studies such as Hagelin (2005) focussed on the influence of bike racks on buses and drew conclusions on the improved revenue generation due to increased use compared with cost of installation of racks.

2.4. Influence of bicycle parking and end-of-trip facilities on bicycle commuting

Generally speaking, a range of parking and end-of-trip facilities influences the level of bicycle commuting in cities. This underscore the quality and quantity of bicycle parking facilities that litters urban landscapes especially in Europe, Australia, North America and most recently Asia and south America. Available data in some cities reveal the doubling or tripling of bicycle parking facilities. J Pucher and Buehler (2005) examined cycling trends and policies in six Canadian cities to encourage cycling and noted that though, the level of cycling doubled or tripled in most cities in a decade, bike use level was soon reached due to lack of 'critically needed infrastructures' such as separate bike lanes and paths, intersection modifications, parking and so on. Other failure policies include the increasing trip distances owing to urban sprawl and lack of deliberated policy to significantly restrict car use. They reported the construction of about 4,000 km additional bike ways in Quebec (making a total of 7,000 km), a quarter of which (about 28 km) are two-directional (VéloQuébec, 2004a); 210 km of separate bike paths, 95 km of bike lanes and 66 km of bike routes on lightly travelled roads' in Montreal. Most impressive however according to VéloQuébec (2001) is the $120 million bikeway otherwise referred to as 'Route verte' with a wider connection to all parts of the province. Additionally, bicycling is promoted amongst students in many schools by Québec car insurance company SAAQ (La Société de l'Assurance Automobile du Québec) through the distribution of 'free bicycling safety instruction materials to all schools in the province'; free bikes and helmets as motivation to winning students at various cycling safety competitions (J Pucher & Buehler, 2005). Other bicycle safety programmes such as Toronto and Ottawa 74 'CAN-BIKE courses in 14 community centres in 2003, producing about 400 graduates, are also recorded (CoT, 2001, 2003). This is in addition to the extensive use of a 'variety of posters, stickers, decals and brochures showing proper helmet use, proper procedure for cars passing bikes, reminders to watch for bikes when opening car doors, and warnings to cyclists not to ride on sidewalks'.

In another comparative survey, (J Pucher & Buehler, 2006) observed that 'Canadians cycle about three times more than Americans' despite their colder climate. For instance, the Canadian bike share mode for work trips increased from 1.1 per cent in 1996 to 1.2 per cent in 2001 while in US, the same is noted to have decreased from 0.5 per cent in 1998 to 0.4 per cent in 2000 (Statistics-Canada, 2003; USDoT, 2003). This is due to 'Canada's higher urban densities and mixed-use development, shorter trip distances, lower incomes, higher costs of owning, driving and parking a car, safer cycling conditions, and more extensive cycling infrastructure and training programs' (J Pucher & Buehler, 2006). End of trip facilities such as parking spaces, storage and shower/changing rooms provide high motivation for bicycle commuting as it enhances bicyclists' convenience and security at destinations (Litman, 2009b). According to him, important factors to be considered when developing a parking facilities for bicycles include, type of location, visibility, security, weather protection, clearance, and amenities.

Furthermore, J Pucher et al. (2010) reports the incomplete nature of statistics on bike parking facilities in non-public places such as private residences, work places, commercial buildings, and mostly universities. This is in addition to offering incentives through green building guidelines such as LEEDS-US, BREAM-UK, Green Star-Australia, in various cities that requires the provision of specific levels of parking facilities for bicycles in new buildings (Kessler, 2008; Litman, 2009b; J Pucher & Buehler, 2008). Although, most bike racks for parking on sidewalks, plazas, or other open places are unsheltered, there is a growing trend toward roofed or some sort of sheltered racks. In northern Europe especially the Netherlands, Germany and Denmark where bike theft is common, sheltered parking facilities are common in schools (mostly universities), train/metro stations, and many office apartments. Bike lockers are on the other hand practiced in North America and visibly present in most train and metro stations. Wardman et al. (2007) developed a mode choice model that combines revealed preference and stated preference with data from UK National Travel Survey where he forecast a 7.1 per cent increase in bike mode share due to the provision of showers and indoor parking facilities from a base share mode of 5.8 per cent. However, provision of outdoor parking facilities is forecast to increase bike share mode to 6.3 per cent while indoor parking facilities would lead to 6.8 per cent bike mode share. It can be seen therefore that the provision of end-trip facilities such as indoor parking and showers at work can have corresponding improvements on the level of cycling to work. Similarly, a stated preference survey in Edmonton, Canada estimated significant influence of secure parking facilities on attractiveness to bicycling 'equivalent to reduction of 26.5 min cycling in mixed traffic'(Hunt & Abraham, 2007). Showers provided at destinations showed a small but statistically significant influence on cyclists' preference which is equivalent to a reduction of 3.6

minutes cycling in mixed traffic. The study corroborates earlier findings that more experienced cyclists find it less dangerous to ride on mixed traffic. Taylor and Mahmassani (1996) conducted a stated preference survey using hypothetical scenarios to rank cyclists preferences for work trip by car only, park and ride, or bike and ride. A nested logit choice model was developed to draw inference among three policy variables such as 'on-street bicycle facility type, bicycle parking facility type, and bicycle access distance to transit' whose result support cyclists preference for bike lockers as preferred parking facility to increase use of bike and ride. However, a combination of good outdoor and indoor parking facilities, clothes storage lockers, showers, bicycle stations and other incentives have been revealed to have significant impact on levels of bicycle use. They may not be scientific studies on the impact of bicycle stations on bicycle use at the moment, but the adequate use of such facilities where there exist points to the significant impact it have on bicycle commuting (Litman, 2009b; Martens, 2007; J Pucher & Buehler, 2008).

2.5. Intersection level of service

Intersection presents some of the most complex components of many transportation networks. Majority of intersection researches were either based partly on or a combination of methodology from leading bicycle level of service studies (Epperson, 1994; Harkey et al., 1998; Landis, 1994; Landis et al., 1997; Sorton & Walsh, 1994). An intersection design with consideration for safety of bicyclists can provide transport planners with basic tools for an evaluation of satisfaction levels. Although, it is difficult to scientifically prove the extent to which perception of safety at intersections has direct correlation with the use of bicycle infrastructure since many other factors along the segment influence satisfaction, there is overwhelming evidence on the need for intersection designs that accommodate bicyclist. For example, 60 participants of a real-time roadway bicycle course provided responses on safety at signalised and un-signalised intersections in Florida, USA (Landis et al., 2003). Pearson Product Moment Correlation was used to analyse about 1000 combined real-time responses from participants to formulate the intersection bicycle level of service thus:

TM IntBLOS = $_{a1}W_t + {}_{a2}CD + {}_{a3}(Vol_{15}/L) + C$
where
TM IntBLOS is perceived hazard of shared-roadway;
W_t is total width of lane; CD is crossing distance:
Vol_{15} is 15 minutes directional traffic volume; and
L is the total number of lanes

Adpted from (Landis et al., 2003)

The study therefore concluded that 'roadway traffic volume, total width of outside through lane, and intersection crossing distance' remained important considerations for planning bicyclist safety at intersections.

Wang and Nihan (2004) developed a probability based methodology for estimating bicycle-motor vehicle accident risks at intersections in the Tokyo Metropolitan area. They estimated three negative binomial regression models using the maximum likelihood method based on 4-year (1992-1995) data set from 115 signalised intersections. The study further revealed that wider road median have higher bicycle-motor vehicle accident risk which is due to poor vision angle and thus presents difficulty to detect opposite through vehicles. In other to examine accident levels due to drivers scanning behaviour at two intersections in the city of Helsinki, Summala, Pasanen, Räsänen, and Sievänen (1996) 'first tested an explanation that drivers turning right simply focus their attention on the cars coming from the left-those coming from the right posing no threat to them-and fail to see the cyclist from the right early enough'. They used hidden cameras that recorded these drivers behaviour and supported the hypothesis that 'drivers turning right scanned the right leg of the T-intersection less frequently and later than those turning left'. This suggest that drivers develop a visual scanning strategy to concentrated on more dangers than less ones like the cyclists, and therefore result in frequent collision with cyclists. In view of their findings that high-speed countermeasures like bumps, forms another vital component of driver's visual scanning strategy, the paper suggested high safety intersection designs including the use of speed limits (Summala et al., 1996). Gårder, Leden, and Thedéen (1994) examined the safety implications of bicycle paths at signalised intersections using the Bayesian technique to predict a 40 per cent probability of likely accidents involving cyclists if a cycle path is planned across a signalised intersection.

In assessing bicyclist comfort level in Minneapolis, Minnesota Kevin J. Krizek and Roland (2005) collected data on 30 identified bicycle lanes with discontinuities. Thses primary data was obtained from measurement of physical attributres of cycle and motorised infrastructure and cyclists' perception of satisfaction. Multivariate analysis including ordinary least squares method was used to analyse data, leading to the formulation of the model:

$$\text{Discontinuity}_{score} = f(\text{Attributes}_{discontinuity}, \text{Preferences}_{individual}, \text{Characteristics}_{individual})$$

where

$\text{Discontinuity}_{score}$ is the score each respondent assigned to each discontinuity;

$\text{Attributes}_{discontinuity}$ is a vector representing physical characteristics of each of discontinuity; $\text{Preferences}_{individual}$ is a vector representing individual preferences (city/suburban residence, number of bicycles owned, number of cars owned, preferred cycling conditions, and average number of days they cycle);

$\text{Characteristics}_{individual}$ is a vector of individual socio-demographic characteristics (e.g., sex, age, household size; gathered from the survey)

Adapted from (Kevin J. Krizek & Roland, 2005)

The results were useful in investigating cyclists satisfaction levels occasioned with path discontinuity that frequently exposed cyclists to intersection crossing.

2.6. Bicycle level of service models

This section provides basic theoretical background on perception of bicyclists' satisfaction levels and review of relevant literature on this level of service models. The need for investigation on the level of cyclists satisfaction is based on the consensus that bicycle transportation produces less externalities to the environment as compared to the enormous green gases that are emitted into the atmosphere by motorised transportation (Gatersleben & Appleton, 2007; Kwok & Yeh, 2004). The fact that bicycling increases physical activity and enhances good health is also another benefit (Cavill & Davis, 2007). The advantages of bicycle transportation notwithstanding, it is a very dangerous mode of transport, leading to series of injuries and deaths, especially if infrastructure for it is not well planned (Litman, 2011). This lack of suitable facilities reduces the use of bicycle transportation. Some studies observed limited cycling paths in transport networks which underscores the fact that cycling is not a transport system that is for specific streets (Larsen, Patterson, & El-Geneidy, 2013). Several researches have proposed different kinds of facilities to encourage the use of bicycle for urban transport commuting (Dill & Carr, 2003; Rietveld & Daniel, 2004; Wardman, Hatfield, & Page, 1997). However, a consensus thus exists on some factors such as availability, quality and type of cycling facilities as been prominent among others that influence cycling. For example, off-road bicycle paths and trails was observed to attract more cyclist by Tilahun et al. (2007). Similarly, Dill and Carr (2003) investigated the influence of bicycle facilities on bicycle commuting rates while Hyodo, Suzuki, and Takahashi (2000) evaluated bicycle lanes influences on road choice decisions. From the foregoing therefore, different terminology and methodologies have emerged for investigating bicyclists' satisfaction from use of specific facilities. Some of these models are presented below:

2.6.1. Bicycle Safety Index Rating (BSIR)

The bicycle safety index rating (BSIR) is one of the first attempts to evaluate comfort and safety level of bicyclists using mathematical models (Davis, 1987). He developed the mathematical model to provide an index of bicycle safety and satisfaction levels from physical road way characteristics. It is comprised of a roadway segment index (RSI) used for evaluating individual street segments and an intersection evaluation index (IEI) used in evaluating connecting intersections within segments. Four rating system ranging from excellent to poor was adopted, while seven input variables were used, viz: 'Average daily traffic volume per lane (ADT/L); Speed limit; Width of outside traffic lane; Pavement factor (pavement condition, presence of hazardous railroad tracks or drainage grates); Location factor (parking and turning lanes, grades, sight distance/visibility, driveway frequency, and adjacent land use); and Signalization/Intersection factors' (Davis, 1987). He tested these on seven Chattanooga roads but however did not compare it to actual safety and comfort perception of bicyclists or accident records.

This model (RSI) was used by the Broward County in 1991 as roadway condition index (RCI). No additional changes were made in the model except for the modification of some values for location and pavement indicators. In 1993, the Dade County also adjusted and used the model. The adjusted model was called the modified RCI. Percentage of heavy vehicles and simplification of values for location and pavement factors (FHWA, 1988). Profound amongst criticisms of this model was (Epperson, 1994) the non-inclusion of information on signalised intersections, non-validation of rating system against bicyclist perception or real time accident data, and contributions of vehicle volume, speed and lane width overwhelmed by pavement and location factors. In an apparent attempt to revise BSIR, Davis (1995) postulated the bicycle suitability rating (BSR) where he examined roadway segments as a component of bicycle suitability rating, haven dropped the intersection evaluation index. The modified model has five categories of rating from superior to very poor. It is given as:

$$RSI = [ADT/Lx2{,}500] + [S/56] + [(4.25\text{-}w) \times 1.635] + \sum[PF] + \sum[LF]$$

where:
RSI = Roadway Segment Index;
ADT = average daily traffic (vehicles);
L = number of traffic lanes;
S = speed limit (kph);
W = width of outside traffic lane (m);
PF = pavement factors; and
LF = location factors

Adapted from (Davis, 1987); (Epperson, 1994)

2.6.2. Roadway Condition Index (RCI)

With no major changes, the Broward County, Florida adopted David's Roadway Segment Index portion of the BSIR. They renamed it roadway condition index (RCI) to assess the perception of bicycle suitability on major streets and arterials using coloured maps which were used to code existing or proposed bicycle suitability for major arterials. This was to direct improvement attention to areas of high roadway condition index values shown as red colour. An application of this model with some modifications in Oregon, Washington State to examine bicycle level of service for many neighbourhoods have been reported (Eddy, 1996).

2.6.3. Bicycle Stress Level (BSL)

The concept of bicycle stress level was used to relate bicyclists' perception of satisfaction on specific roadway geometry and traffic conditions (Sorton & Walsh, 1994). This was one of the first attempts to gather responses from independent participants other than team members of project. Rankings ranged from 'safe streets' to 'streets not appropriate for cyclists'. The study used 'vehicle peak-hour volumes, kerb land speeds and kerb lane widths' as primary variables while secondary variables included 'quantity of commercial driveways per mile, the number of parking turnovers and the percentage of heavy vehicles. Funding limitation however excluded the use secondary variables from the model. The lack of noticeable indicators like bike lanes and pavement conditions attracted criticisms for the model.

2.6.4. Bicycle Compatibility Index (BCI)

This model was proposed to evaluate 'cycling-friendly environment' by estimating the quality of streets from rated grade levels of 'A' for highly compatible and 'F' for highly incompatible for cycling, and nine other variables (Harkey et al., 1998). The actual model development was by Hallett, Luskin, and Machemehl (2007). The model has also been used by the Highway Safety Research Centre at the University of North Carolina for the Federal Highway Administration. A major criticism of the model is the exclusion of some indicators considered as important such as 'lighting, bike box, parking, signage and markings'.

2.6.5. Interaction Hazard Score (IHS)

The interaction hazard score was developed to evaluate bicycle suitability in some urban areas of the United States of America, including: 'Birmingham, Alabama; Charlotte-Mecklenburg, North Carolina; Philadelphia, Pennsylvania; Tampa, Florida; and many others' (Landis, 1994, 1996). The major advantage of this model is the use of several factors in association with other criteria to evaluate cyclist's perception of satisfaction of bicycle infrastructure. This model had widespread applications thus necessitating for its review. Mathematically, it is stated thus:

$$HIS = [(ADT/L) \times (14/W)^2 \times [a_1S/30 \times (1+\%HV)^2 + a_2PF] + a_3LU \times CCF] \times 1/10$$

where:
IHS = Interaction Hazard Score;
ADT = average daily traffic (vehicles);
L = total number of through lanes;
W = usable width of outside through lane (includes width of any bike lanes; measured from pavement edge, or gutter pan, to center of road, yellow stripe, or lane line, whichever is less);
S = speed limit;
%HV = presence of heavy vehicles (e.g., trucks) expressed as a decimal;
PF = pavement factor (the reciprocal of FHWA Highway Performance Monitoring System (HPMS) PAVECON factor, see below);
LU = land use intensity adjoining the road segment (commercial value=15, non-commercial value=1);
CCF = curb cut (or on-street parking) frequency, a measure of uncontrolled access (i.e., turbulence per unit of distance); and
a ,a ,a = calibration coefficients initially equal to unity

Adapted from (Landis, 1994, 1996)

2.6.6. Bicycle Level of Service (BLOS)

The BLOS is the outcome of research to validate the IHS (Landis et al., 1997). In doing this, they employed about 150 bicyclists to reflect diverse cycling experiences, ages and socio-economic characteristics to ride round 30 distinctly selected roadway segments in Tampa, Florida. Each segment of the roadway segment was rated by bicyclists as they rode round. Other variables included in the survey are 'traffic volume (15-minute) in outside lane; traffic speed and mix of vehicle types; transverse turbulence caused by driveways, intersecting streets, etc; pavement surface condition; and proximity of bicyclist to vehicle traffic stream (including presence of pavement striping)' (Landis et al., 1997). They therefore undertook a combination of all 'variables in an equation that provided the best fit with the subjective rank order ratings provided by cyclists riding the test course' (Turner, Shafer, & Stewart, 1997). Major findings of this study included the discovery of the importance of bike lane stripping to bicyclists as well as the importance of pavement condition. The variables were added in the model. Prior to this study, these two variables were not given important consideration. It is defined as:

$BLOS = a_1 \ln(Vol15/L) + a_2 \ln(SPD_p(1+\%HV)) + a_3 \ln(COM15 \times NCA) + a_4(PC_5)^{-2} + a_5(W_e)^2 + C$ where: BLOS = bicycle level of service, or perceived hazard of the shared roadway environment; VOL = volume of directional traffic in 15-minute time period; 15 L = total number of through lanes; SPD = posted speed limit (a surrogate for average running speed); p %HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual; COM15 = trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of "15," multiplied by the percentage of the segment with adjoining commercial land development; NCA = effective frequency per mile of non-controlled vehicular access (e.g., driveways and/or on-street parking spaces); PC_5 = FHWA's five point pavement surface condition rating; W_e = average effective width of outside through lane: $= W_t + W_l - \sum W_r$ where W_t = total width of outside lane (and shoulder) pavement; W_l = width of paving between the outside lane stripe and the edge of pavement; $\sum W_r$ = width (and frequency) of encroachments in the outside lane; = Wp × % of segment with on-street parking + Wg where Wp = width of pavement occupied by on-street parking activity; W_g = combined width and frequency factor of other encroachments; and, $a_1 = 0.589$ (calibration coefficient) $a_2 = 0.826$ (calibration coefficient) $a_3 = 0.019$ (calibration coefficient) $a_4 = 6.406$ (calibration coefficient) $a_5 = 0.005$ (calibration coefficient) C = 1.579 (calibration coefficient)

Adpted from (Landis et al., 1997)

2.6.7. Bicycle Intersection Safety Index (ISI)

This model was developed to provide insight into the ability of transportation planners to evaluate the level of safety in intersections. It was carried out in North Carolina and its methodology was based on the use of video data and online safety rating survey of 67 intersection approaches. The study used variables which indicate a high probability of risk by bicyclists such as 'traffic volume, the number of lanes, the speed limit, the presence of a bike lane, the presence of parking and the presence of traffic control to a given rating for an intersection approach according to a six-point scale' (Carter, Hunter, Zegeer, Stewart, & Huang, 2007). There has been widespread application of this model to intersection LOS studies in many countries especially in the USA and elsewhere. It is often referred to as Intersection Evaluation Index and given as:

$IEI = [VC+VR/10,000] + [VRx2/VC+VR] + \sum[GF] + \sum[SF]$ where: IEI = Intersection Evaluation Index; VC = cross street volume (ADT); VR = traffic volume on route being indexed (ADT); GF = geometric factors; and SF = signalization factors.

Adapted from (Davis, 1987); (Epperson, 1994)

2.7. Policies, programmes and legal interventions to promote urban bicycle commuting

Various programmes and policy interventions ranging from trip reduction, general travel awareness, automobile reduction and bicycle-specific programmes exist in different countries and cities to increase the level of bicycle use for urban commuting. The 'Travel Plans' in the UK is acknowledged as providing the legal instrument for executing most employer-based programmes that aim to reduce car use through incentives and provision of facilities for other urban transit modes such as public transport, walking and bicycle use. Although such policies and programmes are reported to have focussed on reduction in automobile travel, encouraging results have been documented on high levels of bicycle use. Rye (2002) reported the doubling in bus use and tripling in bicycle use to work in Manchester Airport between 1996 and 2000. According to him, these lead to a 63 per cent reduction from 83 per cent of staff who drive alone to work despite an increasing staff numbers. In Hewlett Packard Edinburgh, a staff survey that was conducted and replicated in 1997 and 1999 respectively revealed a modal shift as the proportion of staff driving alone reduced from 65 per cent to 59 per cent due to 14 per cent increase from 8 per cent rail use. In Stockley Park, despite increasing number of employers, car use decreased from 88 per cent to 84 per cent in 1997 and 1999 respectively, public transport increased from 10 per cent to 12 per cent while bicycling more than doubled under the same period (Rye, 2002).

In the US, Shoup (1997) used eight firms with 1,694 staff to investigate the impact of California law that requires employers to leave employees the option of cash instead of parking subsidy. The result showed that the number of 'solo drivers' reduced by 17 per cent, car-poolers, transit riders and cyclists/pedestrians increased by 64 per cent, 50 per cent and 39 per cent respectively. This also resulted in reduction of vehicle-miles travelled by 12 per cent and 367 kilograms of carbon dioxide emissions per employer. Touwen (1997) also examined a 'mobility management' policy measures such as 'financial bonuses, improved physical conditions, financial regulations and physical restrictions' in the Netherlands and observed an 8 per cent increase in the number of bike users to work from a previous zero per cent. Using a sample size of 295 employees from three Glasgow workplaces, Mutrie et al. (2002) observed that a 'walk in to walk out' educational campaign did not provide significant increase in bicycle commuting. Rather, the programme increased active commuting by walking from 31 per cent to 49 per cent in six months of its introduction. Furthermore, a 7-day analysis of mode share of walking to work in the post-programme era indicates a positive intervention effect of 125 minutes from initial 61 minutes of walking per week. Another stated preference survey in Edinburgh revealed that 2 pound financial incentive per day for workers would not significantly increase bicycle commuting but however concluded that the propensity to cycle in Scotland was dependent on 'cyclist facilities, primary at the destination but also en route' (Ryley, 2006).

Many individualised marketing programmes first implemented in Europe and now US and Australia exist to provide comprehensive programmes with targeted or personalised information, incentives (transit passes, coupons to bike stores), and events. There are also called TravelSmart in Europe and Australia and SmartTrips in the United States. Using 'SOCIALDATA and the International Association of Public Transport' a demonstration study was carried out by Brög (1998) to experiment the level of awareness for public transport use through 'individualised marketing'. He reported an extremely successful experiment where public transport use doubled among a monitored select group who were given tickets to use public transport free of charge for one month. He therefore concluded that 'individualized marketing has proved to be a quick, cost-effective method to increase area wide public transport patronage'. Similarly, an Australia Greenhouse Office (AGO, 2005) reported a review of 'before-and-after' evaluations of five neighbourhoods where house hold results revealed 4-15 per cent decrease in use of car and a considerable rise in walking, bicycling and public transport use, consistent with findings in Europe and North America. Furthermore, in terms of work places, the report observed more variable results due to 'diversity of organisations, transport needs, international cultures and locations' which made direct comparison impossible among them. However, available data indicates a 0-60 per cent reduction in car use, about 50 per cent increase in public transport use and a modest cycling and walking increases. Similarly, Brög, Erl, Ker, Ryle, and Wall (2009) remarked that 'soft' measures such as voluntary travel behaviour change (VTBC) have emerged to challenge the thinking that only 'hard' system-based measures were capable of achieving modal shift. They further observed that dialogue marketing approach developed by social data

(IndiMark) has a wide range of application 'in more than 100 pilot and nearly 150 large-scale projects, targeting a total of more than three million people on three continents'. Furthermore, they concluded that more consistent with this approach is a detailed travel behaviour before-and after IndiMark intervention using detailed evaluation design. Several other evaluation studies in Australia and the United States revealed an increase in daily trips share mode on bicycle transport due to implementation of individualised marketing (Brog & Barta, 2007; Cooper, 2007)

A wide range of travel awareness programmes exist to reduce motorised commuting and rather increase public transit and non-motorised transport which are often implemented by local authorities and community organisations. The study of 'smart choices: changing the way we travel' noted the growing interest in soft transport policies such as 'workplace and school travel plans; personalised travel planning, travel awareness campaigns, and public transport information and marketing; car clubs and car sharing schemes; and teleworking, teleconferencing and home shopping (Cairns et al., 2004). The study developed low intensity scenarios to include 'a reduction in peak period urban traffic of about 21% (off-peak 13%); a reduction of peak period non-urban traffic of about 14% (off-peak 7%); and nationwide reduction in all traffic of about 11%'. However, high intensity scenarios include 'a reduction in peak period urban traffic of about 5%, and a nationwide reduction in all traffic of 2%-3%'. The uncertainty of the results of such scenarios notwithstanding, soft measures can be very effective in discouraging automobile use. For example, a soft policy known as 'You-Move-nrw' organised in North Rhine-Westphalia, Germany was used to promote transport modes that are environmentally friendly through public awareness (Reutter, 2004). A comparison of impacts on participants through before and after participation interviews showed no significant difference (which might be due to the age distribution of the sample size) there however seem to be a high level of awareness on mobility among the participants than ever before.

Safe routes to school (SR2S or SRTS) have also emerged as safety programmes that encourage walking and cycling to school through education, encouragement, development of infrastructure and enforcement of policies. According to J Pucher et al. (2010), the movement which was believed to have started in Denmark in the 1970s also increased in number in the United States during the 1990s. The before and after evaluation of ten traffic improvement projects under the SRTS in the US among parents of school children about perceived safety revealed an increase to non-motorised commuting to school by children (Boarnet, Day, Anderson, McMillan, & Alfonzo, 2005). Many other factors were reported by Davison, Werder, and Lawson (2008) as including individual and household, school characteristics, and community and environment characteristics. For example, research shows that Hispanic and African American children are likely to cycle or walk to school than white American students. Higher commuting with cycling or walking was observed to be higher in schools with higher composition of Hispanic and African American in 34 sampled schools in California (Braza, Shoemaker, & Seeley, 2004). School characteristics such as administration, location from communities where children live also has been observed to have effect on mode of commuting to school. Students in public schools have higher tendency to cycle or walk to school than children in private school (Merom, Tudor-Locke, Bauman, & Rissel, 2006). In addition to schools and families, community and environmental characteristics such as transport facilities including pedestrian walk, cycle lanes/tracks, access to public transport and weather conditions (physical environment), and social norms and crime (social environment). Studies on influence of the physical environment on mode of transport to school by children suggests the likelihood of children to cycle or walk to school if the route to school is direct (Timperio et al., 2006) and navigation through steep slope is minimal, and the environment is walkable or cyclable, measured in terms of 'residential density, retail floor ratio, intersection density, and land use mix (Kerr et al., 2006; McMillan, 2007)

2.8. Some practical case studies of selected cities that implements multiple interventions

A wide range of policies that promotes cycling and improves safety have been implemented at different scale in many cities. Based on the collection of primary and secondary data, various findings were made on the impact of policies of cycling levels in many cities (Buehler & Pucher, 2009; Fietsberaad, 2006; J Pucher & Buehler, 2007). Some of these findings in specific cities are summarized below:

2.8.1. Bogota, Colombia

The Ciclovia is one of the foremost cycling programmes in Bogota whose history dates back to its first and second attempts in 1974. However, 1976 marked the urban development study and creation of the Ciclovia concept, which lead to the mayoral Decree defining and establishing four Ciclovia routes in Bogota city. In 1982, the city introduced the policy of space recovery for her citizens leading to the inauguration of the weekly Ciclovia and its committee lead by many actors such as government (department of Transit and Transportation, Urban Development Institute, City Hall, Police Department, National Cycling Federation, etc.) and community organisations (Pro-Recreation Foundation & Ciclopedia bike shop). Interestingly, the policy underwent series of transition stages including the reprioritization phase (1985-1994), modernisation phase (1995-2007) and the continuity phase (2008 to present) (Uniandes, 2010).

The transition above lead to a 0.8 and 3.2 per cent increase in bicycle share of trips in 1995 and 2003 respectively, while ciclovia participation grew from 5,000 from inception in 1974 to 400,000 in 2005. Associated infrastructures and programmes include: the construction of 344 km separate bike lanes in 1998-2000 to connect major destinations and public transport such as the Transmilenio; closure of about 121 km stretch of road network to cars on Sundays and holidays used for Ciclovia; the introduction in 2000 of car-free first Thursday of every February; car restrictions to certain days of the week based on even and odd number plates ('pico y placa'); car parking restrictions and retrieval of public spaces from cars and other built-up areas; and vigorous educational campaign at all levels on the need, use, safety and behaviour of motorists and cyclists alike in the city (Cervero et al., 2009; Despacio, 2008; IDRD, 2004; IDU, 2009; Montezuma, 2005; Parra et al., 2007).

2.8.2. Amsterdam, Netherlands

According to the 2008 Travel Survey by the City of Amsterdam (CA, 2009), 'bikes have shaped the image of Amsterdam' to such an extent that, for many people throughout the world, Amsterdam is almost synonymous with cycling. In 2008, cycling accounted for 38% of all vehicle trips-a bike mode share unheard of in other European cities of comparable size. Amsterdam has a population of 743,000 and retains the status of the largest city in the Netherlands with an estimated 600,000 bikes in 2006. Since 1970 the bike share mode has increased from 25 per cent to 37 per cent in 2005 while there has also been a 40 per cent reduction in serious accidents.

Other achievements of bicycle policies in Amsterdam according to Fietsberaad (2006) and include deliberate tax policy targeted at reduction in car parking in the central city; introduction of many car-free neighbourhoods in the central city, traffic calming (30 km/h) including some woonerfs ('living yards') with about 7 km/h speed limits; doubling bicycle infrastructure between 1980 and 2007, and also bridges and short-cuts leading to a complete bicycle network. others include the permission of bi-directional travel in one-way bicycle paths; bike parking facilities in train stations and expansion of guarded, sheltered bike parking; development of ov-fiets programmes (public bike rental system); and improvement of intersections with advanced stop lines and boxes as well as priority traffic signals for bicyclists (Fietsberaad, 2006; J Pucher & Buehler, 2007).

2.8.3. Copenhagen, Denmark

Evidence available from photographs of urban scenes clearly suggests the use of bicycle in Copenhagen since the first quarter of 1900s. Across different social classes, people used the bicycle for other trip purposes other than recreation. In 1998, bicycle mode share increased from 25 per cent to 38 per cent in 2005 for age group above 40 years. There is also 70 per cent recorded increase in total bicycle trips in 1970 to 2006, and a reduction of about 60 per cent in serious injuries between 1995 and 2006 (Fietsberaad, 2006; J Pucher & Buehler, 2007).

Moreover, about 345 km of massively expanded bicycle tracks and curbs protected lanes have been built since 1970s and additional 14 km of unprotected lanes. There is also a redesign of road infrastructure to resolve intersection difficulty such as 'advanced bike stops lines and bike boxes, bicycle access lanes, priority traffic signals for cyclists, and bright blue markings of bike lanes crossing intersections' (J Pucher et al., 2010). Other policies to encourage cycling include the permission of bi-directional bicycle travel along one-way streets, increase in guarded facilities from 1 in 1982 to 30 in 2006, calming of motorised traffic in many residential areas in the central city, increase in designated car-free zones and reduced car parking in the city centre. The city also introduced an extensive and mandatory bicycle education programme for all school children, provision of over 20,000 bike parking spaces, bi-annual surveys to examine bicycle infrastructure and bike sharing schemes which places over 2000 free bikes across 110 locations throughout Copenhagen (Fietsberaad, 2006; J Pucher & Buehler, 2007)

2.8.4. Portland, Oregon

Bicycle modal share of commuting has been on the increase in Portland. For example, it was 1.1 in 1990; 1.8 in 2000 and 6 per cent in 2008 (Portland, 2008). The study also revealed an increase in the 'number of miles of bikeways from 79 in 1991 to 274 in 2008'. Bicycle infrastructure developed, including coloured bike lanes to avoid potential conflicts with motorists, redesign of four bicycling difficult intersections, installation of loop detectors at 'actuate traffic signals on bike routes', street bike parking locations, installation of bike racks on transit buses, allowing bikes on trains, first 'bike Sunday' held in 2008 and regular education and marketing events to promote bike use.

The impact of wide variety of improvements on bicycle commuting has been summarised. Not many studies showed immediate impact of interventions, however, results of deep rooted and long term interventions have proved useful in changing complex pattern of behaviour on bicycle commuting in many case studies reviewed. This is encouraging even more so that the lack of documentation of positive impacts of many of these interventions does not suggest that there are none. There is considerable difference in the impact of intervention based on time, place, and design, just as there are many different methodologies for estimating diverse perception of satisfaction. It is also difficult to generalise the impact or effectiveness of individual interventions as there do not exist a consistent methodology in these studies. Furthermore, most studies cannot be considered to have satisfied some basic ideal research design that accommodates before and after interventions programmes. Based on this premise therefore, there is need for studies that reflect individual geometry, physical and operational characteristics of study location. This underscores the need for this research to develop a methodology for evaluating the level of satisfaction from the use of bicycle infrastructure in Bogota.

3. INTRODUCTION TO BOGOTA

Knowledge of background information about the study area is essential for better understanding of the theme of this study. This chapter provides some historical, socio-economical and development perspectives on the evolution of Bogota as an infrastructure heaven. More effort is directed at transportation characteristics of the city to provide an explanation of Bogota urban mechanism.

3.1. Background to study area

The study was set up in the "Sabana de Bogotá", the capital of Colombia. It is usually referred to as a 'plateau'. It is about 2,640 meters above sea level, located in South America, and has an average temperature of 17^{0}C. It is just at the foot of two important mountains such as Cordillera Mountains Guadalupe and Monserrate and is bounded by Panama in the North-west, Venezuela in the north-east, and Ecuador, Peru and Brazil in the south (figure 3.1). It has been geologically proven that this land once existed as a lake which is attested to by the Homedale's wetlands. The city has an approximated area of 1775.98 square kilometres (33,000 acres) and a population of 7.2 million inhabitants, 15 per cent of which is the total population of Colombia (MEHTP, 2010). The urban area accounts for about 21.64% of its surface. High population density is about 286 inhabitants per hectare, with an annual growth rate of 2.5 per cent. The city has a relatively flat topography in the north-south axis but show varying levels of high areas in the east-west. Most low area slopes of about 4 degrees exist as residential land uses. Other high topography ranges from 4-28 degrees and are considered as unstable due to low soil cohesion and small compressibility. Moreover, extreme cases of topography such as 12-40 degrees also exist in rocky and unstable landforms where development is avoided.

Historically, since the 1830s Bogota has remained the capital of greater Colombia after cleavage from Spain on 20 July, 1810 and final independence in 1819. Major changes in population, architecture, and urban development have occurred since then, haven remained as a symbol of the country's economic, social and political centre. It consists of 20 districts otherwise called 'localidads' (figure 3.1). The last few decades had witnessed Bogota evolve from an area of insecurity due to terrorist attacks from drug cartels to an area of amazing culture and infrastructure transformation. Other challenges on environment, infrastructure, and most especially intra-urban transportation also existed. The election of Antanas Mockus as the city's mayor in the mid-1990s marked a turning point in infrastructure development in Bogota city. He was noted to have 'introduced extraordinary measures and pedagogical methods to improve the daily lives of Bogota residents. The administration of Enrique Penalosa, the succeeding mayor, focused on investing in the infrastructure system such as new libraries, parks, bike paths, pedestrian zones (Cervero, 2005).

3.2. Economic and infrastructure development

Bogota is headquarters to many banks, many financial institutions and companies. The city is acknowledged to host more than 100,000 individual businesses contributing to the over 4 billion dollars foreign capital investments in the country. Most products in Bogota market are produced locally which is due to deliberate policy of government. For example, car importation is not allowed in Colombia. The late 1990s had witnessed an extraordinary scale of investment in infrastructure development in Bogota and this has attracted the attention of infrastructure experts the world over. This has attendant impact on population growth in the city thus raising its productive capacity as well as exerts enormous pressure on existing infrastructure, hardly designed to cope with such growth in population and activities. Figure 3.2 revealed socioeconomic strata and population distribution in the city. Low population density with

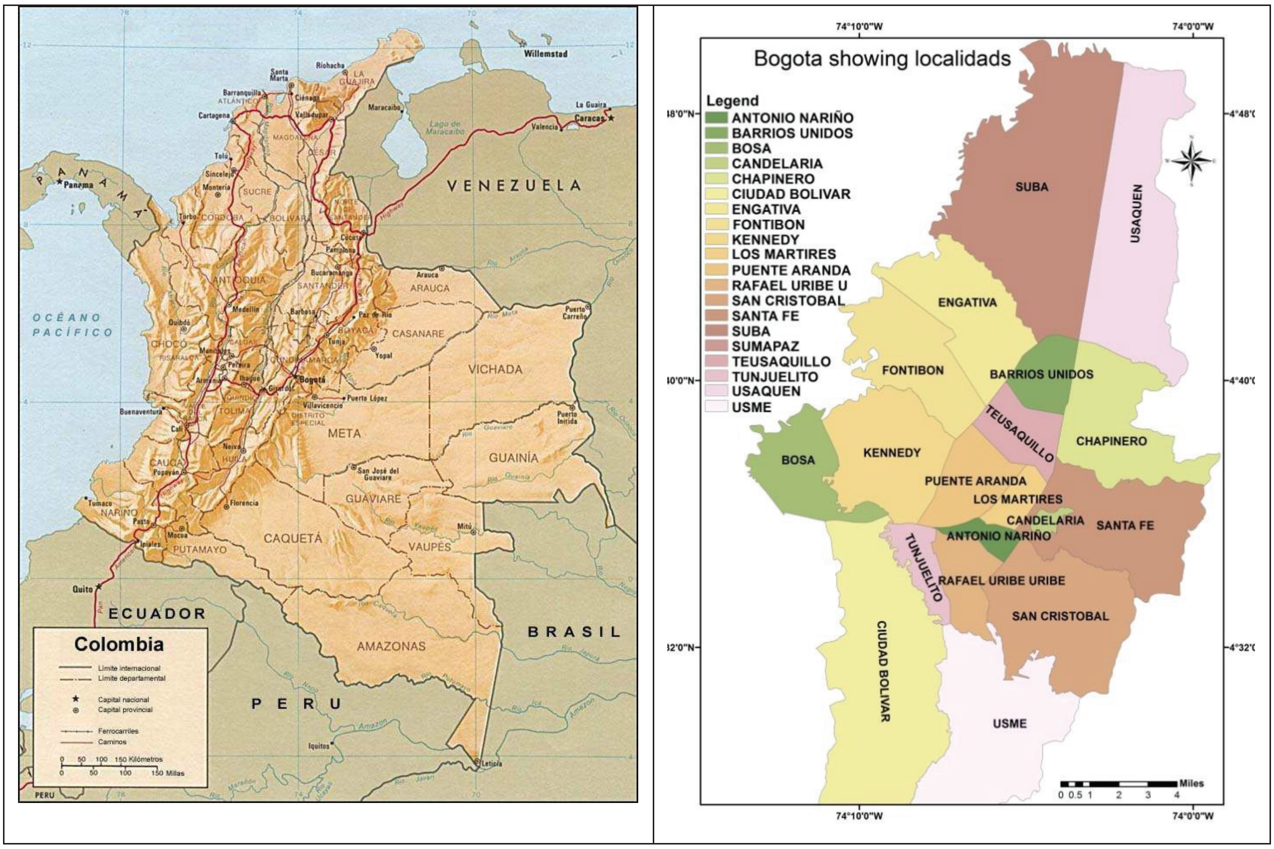


Figure 3.1 Colombia and surroundings; Bogota showing localidads.

accompanying high quality residential development is spread around the north-east of the city. North and west areas are mostly suburbs with high population density while as expected the central business district area has very low population density (figure 3.2).

3.3. Transport development

There is no doubt that the scale of infrastructure development is revolutionary. This is a result of long history in urban transport development that has transformed from one stage to the other. For instance, in 1884, transport was by horses or mules drawn carriages for a single intra-urban route between Bogota municipality to Chapinero. The same year witnessed the opening of a 20 passenger urban railway in the sme route. In 1890 the first bicycle was used while in 1900 a taxi system was put in place. 1910 witnessed the first tram whose capacity was soon exceeded due to population growth (figure 3.3). Buses were introduced in 1927 and several policy changes occurred where there were finally left in private hands until 2000 when the TransMilenio was introduced.

However, before the introduction of the Transmilenio, various intra-urban movement difficulties were encountered in the city. For instance, in 1998, average trip was 1.10 hours at an average speed of 12-18 km/h. for example, average distance of trips made by residents per urban planning zone (UPZ) is shown in figure 3.4. About 16-20 km average distance for daily trips is covered by residents of Suba (north), Bosa (west) and Usme in the south. Average time of trips per day by residents in UPZ reflect similar results for distance. Cuidad Bolivar and San Cristobal records hifhest travel times up to 65-80 minutes. Least average travel distances and time correspond to localidads around the CBD such as Chapinero, Teusaquillo, Candelaria and Barrios Unidos. This is due largely to location of principal occupations like work and school (figure 3.5). It is remarkable to note that over 70 per cent of the city's higher institutions (mostly

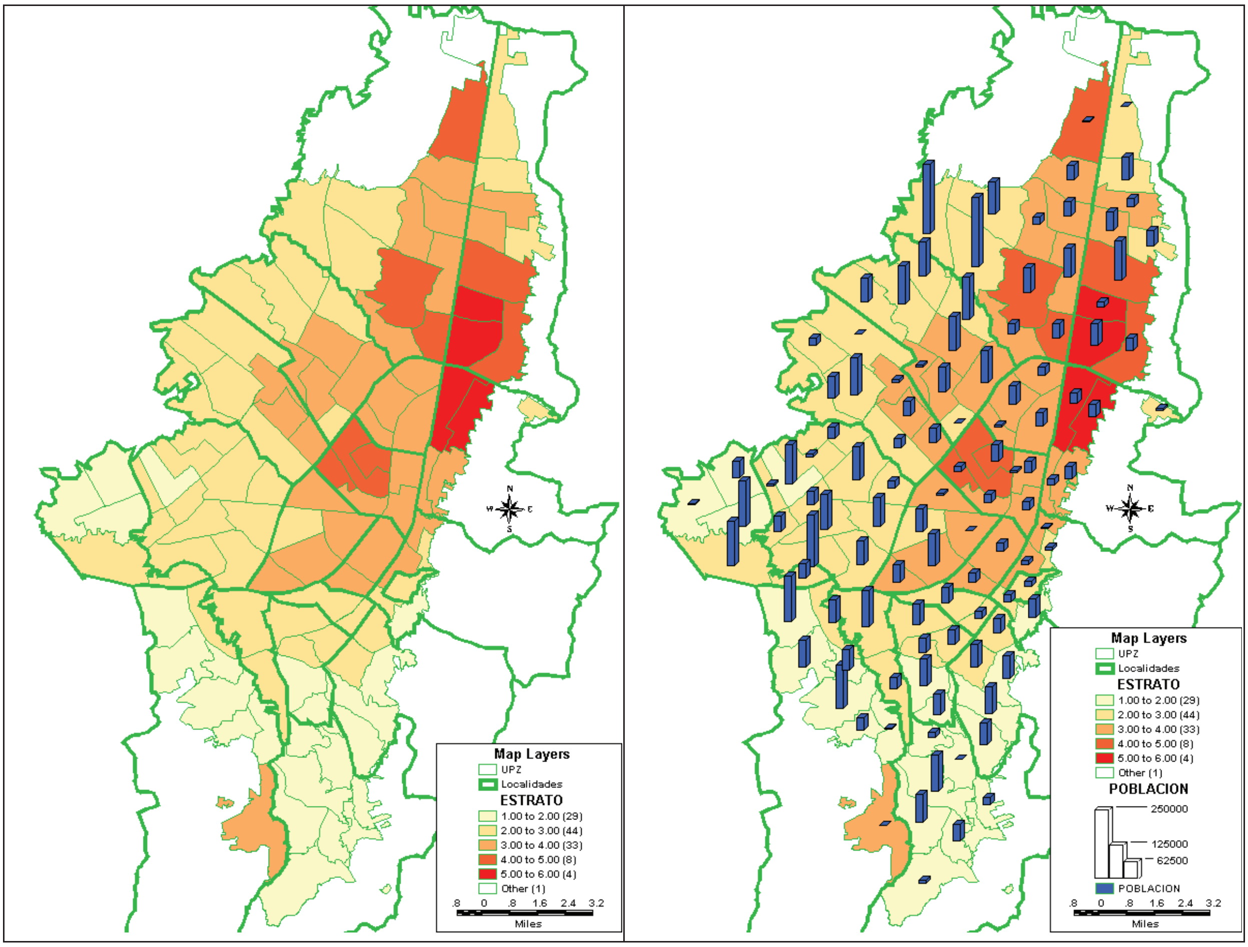


Figure 3.2 Socioeconomic stratum; population distribution in Bogota

Source: www.arqueologiaypatrimonioindustrial.com (1910)

Source: www.museovintage.com/transporte/ (1968)

Figure 3.3 Early transportation developments in Bogota city

universities) are located here (Movilidad, 2013). Video survey was administered in universities located around this zone. This can be attributed to safety concerns that this area addresses. Secondly, the zone also locates most secondary jobs that compliment availability of casual employment from student population (figure 3.5). Traditional buses accounted for 45% occupancy rate on all arterials, 95% of all road infrastructure used by private cars that only transported about 16% of the city population leading to approximately 1,378 car accidents and 66 road fatalities (MEHTP, 2010).

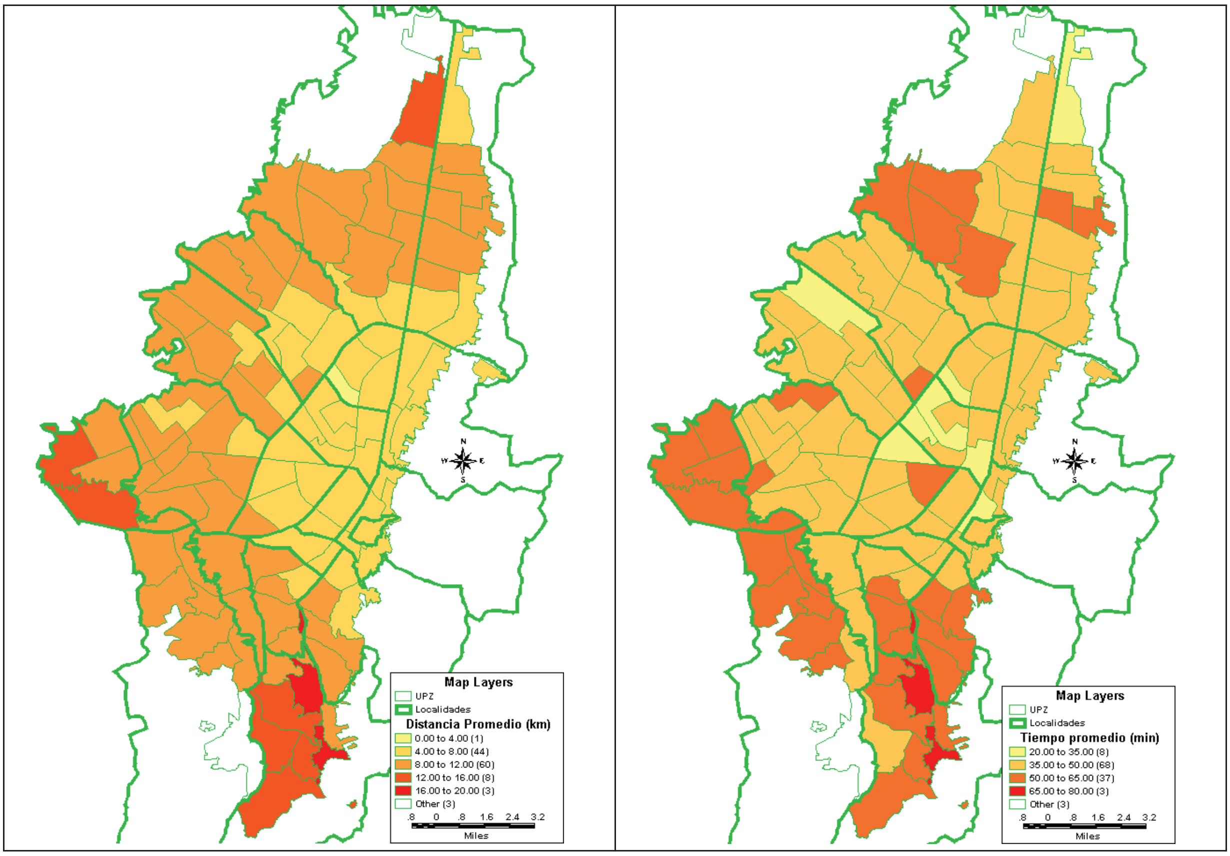


Figure 3.4 Average daily trips of residents per UPZ in kilometres; and average daily trips in minutes.

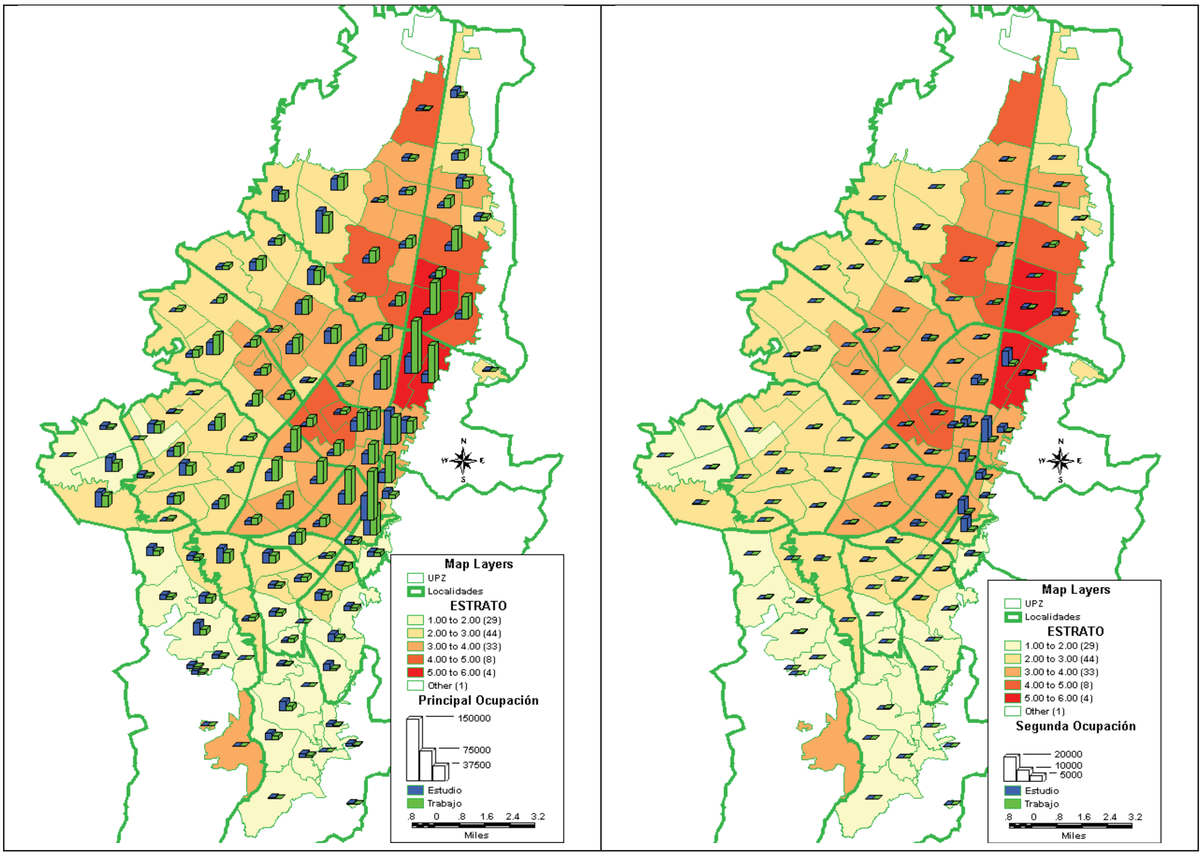


Figure 3.5 Distribution of principal occupations per UPZ; secondary occupations per UPZ

The Bogota urban transport system is composed of three components namely: vehicles, road network and parking areas. Despite government responses to studies of demand and supply of transport facilities, the growth of population and transport demand far outweighs the available infrastructure in the city leading to severe congestion problems. The result of this has been the development of two ambitious programmes: the TransMilenio and Cicloruta. The transminelio was opened to the public in 2000 and serviced Avenida Caracas and Calle 80. It has been extended to traverse different sections of the city with new flet of buses covering about 112 km and conveys about 1.9million passengers daily, thus acknowledged as one of the world's largest bus system (TRANSMILENIO, 2013). Figure 3.6 shows the transmilenio network and some related infrastructure.

A parallel non-motorised transit system was also developed to provide alternative transportation to resisdents of the city. It is referred to as the cicloruta, adjudged as the most extensive bicycle network in South America with about 300 km of cycle lanes/paths across the entire city. Most ciclorutas are located beside major arterials and pedestrian walkway. The resolve of the city administration to reduce pollution levels also made the use of bicycle the preferred choice. A recent survey by Movilidad revealed a changed travel pattern across the city (figure 3.7). Public transport now accounts for 47.5 per cent of total daily trips in Bogota, while bicycle trips increased to 2.3 per cent in 2010 from 0.5per cent in 2000. The weekly ciclovia provides residents the opportunity to ride across ciclorutas as well as some designated roads on Sunday mornings and holidays. Figure 3.8 illustrates some of the elements of the cicloruta.

Moreover, household bicycle ownership is more dominant in the south and western part of the city (figure 3.9). Major explanation for this trend is the socioeconomic stratification earlier shown in figure 3.2, where low and middle income residents are located in the south and west of the city. The steep topography of the north-east is also an explanation which residents attested to during field survey. The distribution of households with bike can also be explained by the availability and quality of cycle paths in the north, west and southern parts of the city. As can be seen in later sections, the cicloruta is best in the west part of Bogota. Households without bicycle is still high acros the city, thoufg remarkable improvement is observed in north south localidadas of Suba, Engativa, Pontibon, Kennedy and Bosa (figure 3.9). Other areas in the south with high household bicycle ownership include Rafael Uribe Uribe, Tunjuelito and Antonio Narino.

Therefore, given the significance of perception of satisfaction from use of bicycle transportation, this chapter provided insight into the local geography, socio-economic and transportation characteristics of Bogota. For the purpose of this study, reference is made to bicycle lanes/paths as segments separated by two intersections and facility or cicloruta comprised of different segments defined as a single route.

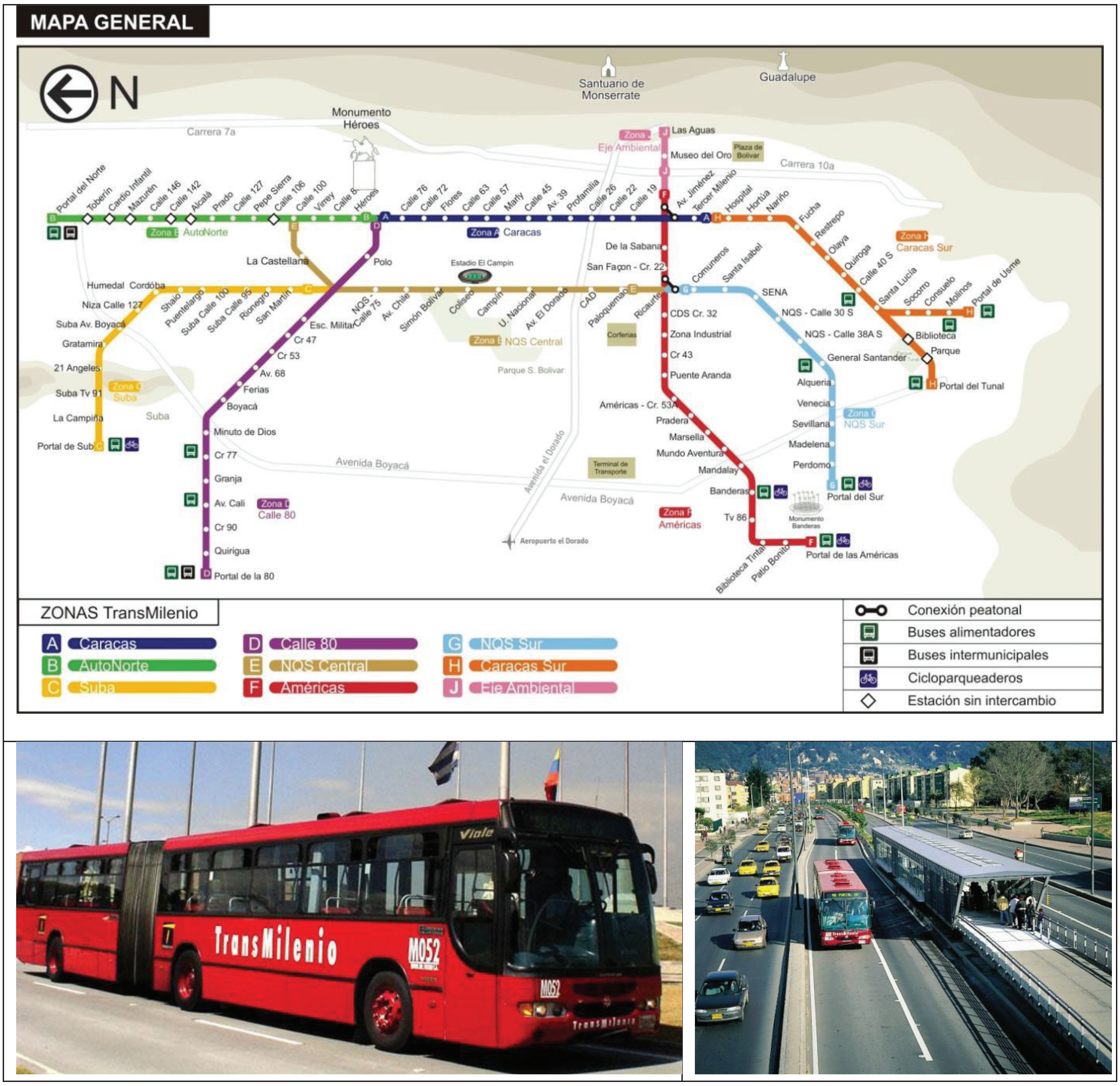


Figure 3.6 TransMilenio network and portals; a TransMilenio bus; and accompanying infrastructures

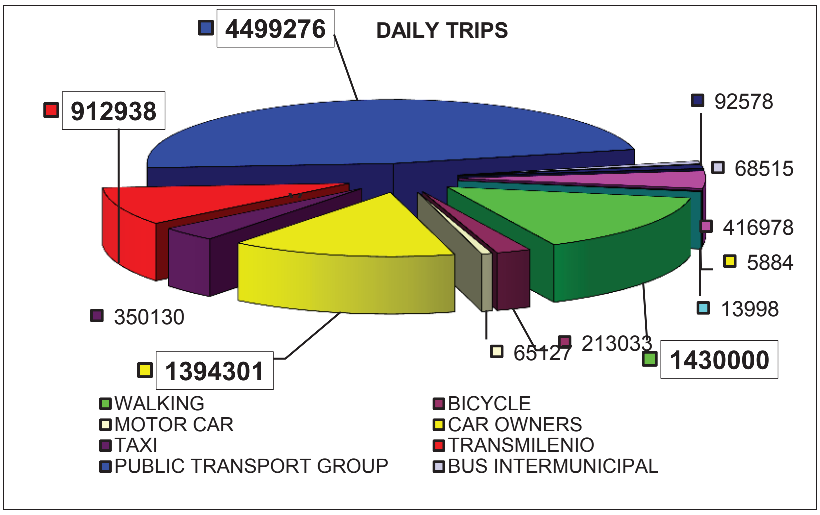


Figure 3.7 Distribution of daily trips by mode in Bogota

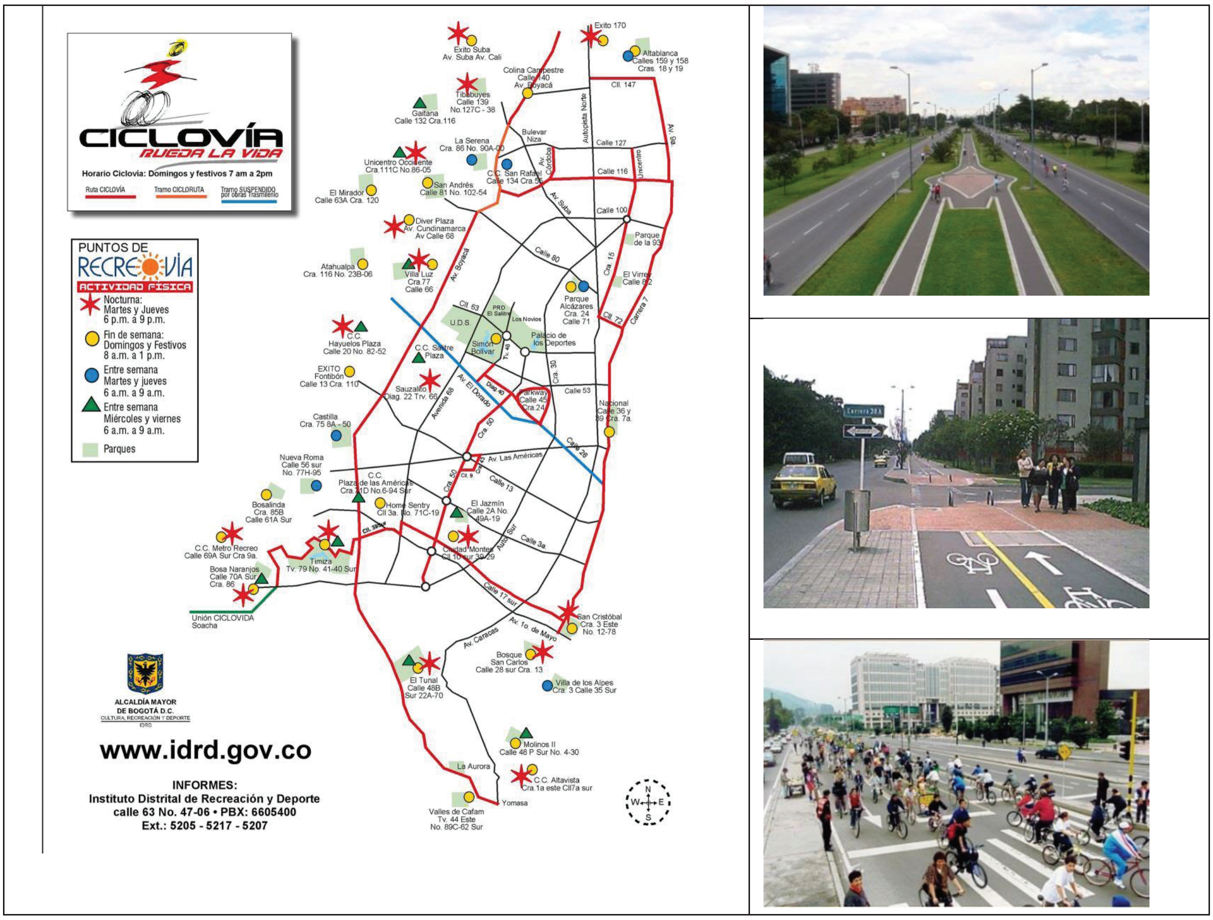


Figure 3.8 Major cicloruta lines; cicloruta infrastructure; and bicyclists on ciclovia event

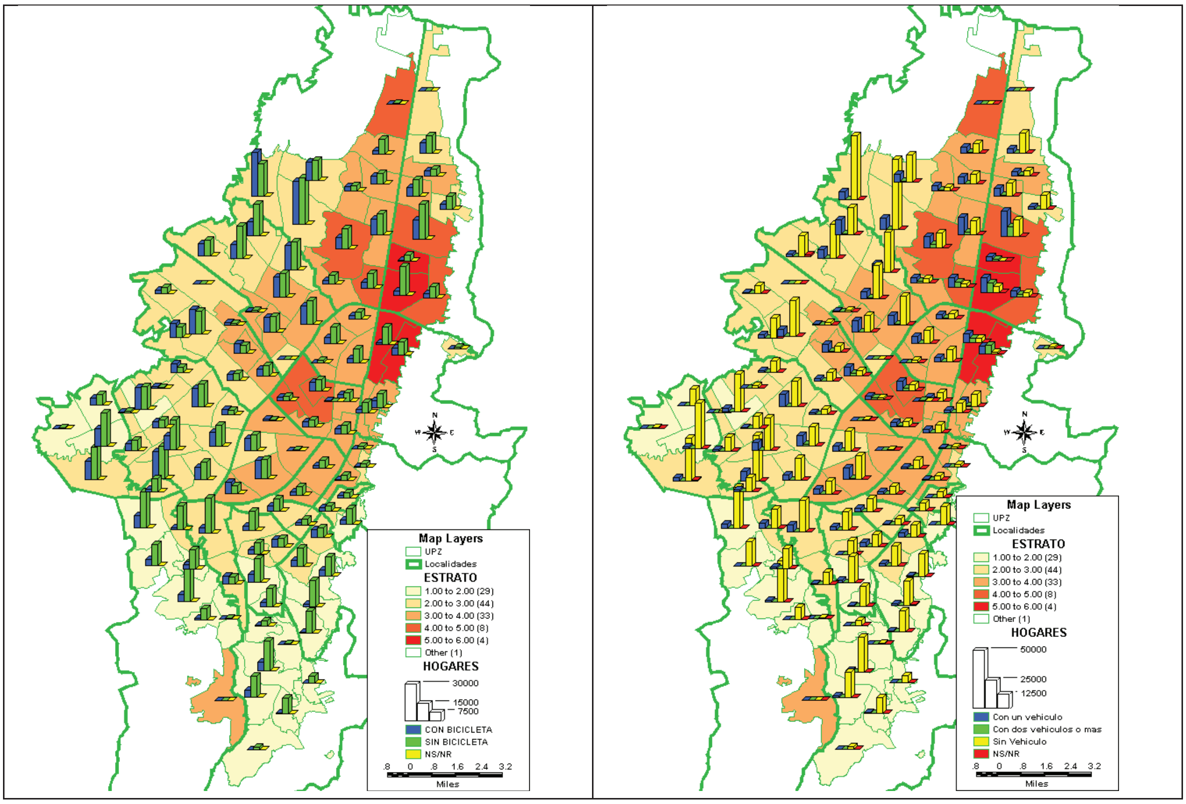


Figure 3.9 Household bike ownership; household car ownership

4. STUDY METHODOLOGY

This chapter describes the approaches and methods for data collection, processing and analysis. It provides a systematic approach to solving the research problem using both primary and secondary data. Some approaches adopted in this study are objective specific and also in relation to data type. Method of data collection is typical of fieldwork which formed vital component of the research. Primary focus was the use of Cicloruta infrastructure, production of video (segments and intersections), group participation survey as well as collection of other geometric, physical and operational measurements. Some secondary data were collected from relevant transport infrastructure organisations like Instituto de Desarrollo Urbano (IDU), IDECA, and MOVILIDAD. Probit ordered choice models was used to analyse data leading to estimation of bicycle level of service and intersection models which are used in ArcGIS for real-time estimation of BLOS at both segment and facility levels. Therefore efforts are made to describe the procedures accordingly.

4.1. Overview of methodology

Different layers of data was used in this study, principal among which is perception rating data for both segments and intersections; geometric, physical and operational characteristics of road infrastructure based on both measurement and observational data; and cicloruta data (shape) as revised in 2013. Both statistical and GIS operations were carried out to calculate BLOS scores and visualize results. In terms of statistical operations, the extent of relationship between variables is examined using correlation statistic, while ordered probit model in generalised liner models is used to estimate parameter, predicted logit and predicted probabilities. The generated model is however exported into GIS to compute BLOS scores at both segment, and facility levels, and visualised in GIS. Furthermore, marginal effect matrix is estimated to reveal the probability of each variable to predict a level of service. These operations are summarised in figure 4.1.

4.2. Pilot surveys

Two pilot surveys were carried out to ascertain the validity of the method. First survey was carried out on familiar audience in Enschede and another in Bogota.

4.2.1. Pilot survey in Enschede

A pilot survey was carried out in Enschede to verify the workability of the chosen data collection techniques. Efforts were also made towards testing survey instruments on familiar respondents to ascertain fatigue level and their suggestions sought. Two weaknesses of this pilot include the use of a hand-held camera (due to delayed procurement) other than the field camera and use of participants with no experience on the cycling environment of the study area. The above weaknesses notwithstanding, the experience and information gathered however assisted in subsequent implementation of data collection techniques in Bogota. Specific objectives of the pilot study include the following:

a. Examine the participants' rating of geometry and operational conditions of road segments, traffic volume, speed conditions, and speed of data collection, compared with actual field experience;
b. Consider the perception-reaction distance, manoeuvre distance and queue storage distance of bicyclists at intersections;
c. Identify the level of fatigue associated with participation in all three sections of the survey.

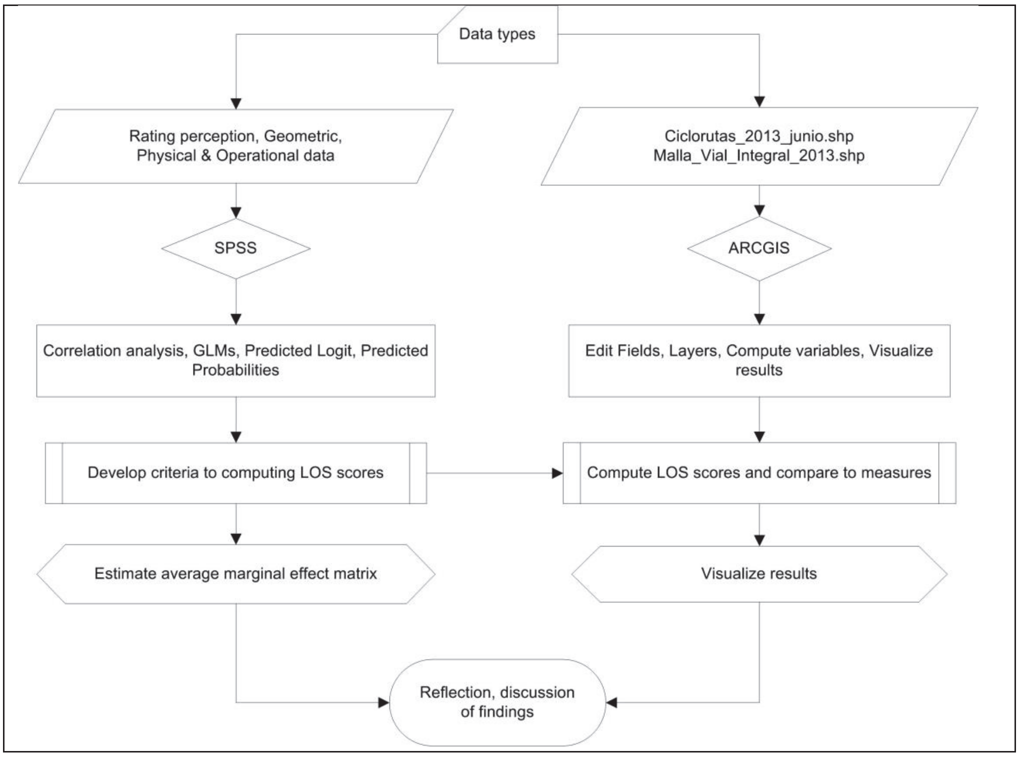


Figure 4.1 Summary of research methodology

4.2.2. Pilot survey in Bogota

On arrival in Bogota, initial cycling survey was carried as part of reconnaissance and to test equipment. This was facilitated by joining BogotaBikeTours (http://mikesbogotabikeblog.blogspot.com) as a tourist. This involved cycling in company of other tourists and tour guide along some sections of the Cicloruta. Subsequent cycling activities on reconnaissance were as advised by local assistant(s) based on author's laid out data collection criteria. This is aimed at appraising the nature, geometry and operational characteristics of distinctive segments and intersections along the Cicloruta. Other characteristics such as signalisation, traffic operation variables, land uses, traffic volume, and so on were examined. Specifically, routes were identified (route defined as roadway containing segments separated by intersections) along the Cicloruta based on criteria indicated in 'site selection'. The number and categorisation of intersections was identified using criteria discussed in 'intersection LOS'. Two important traffic video trial surveys on segments and intersections were carried out in IDU (figure 4.2) and later form core data collection technique for estimating the bicycle level of service model. Other road geometry and traffic characteristics were also measured during the survey. Some of the specific objectives of this pilot include:

a. valuating camera positioning and ascertaining the extent of coverage thereby accommodating multiple road facilities of interest;
b. Determine the length of time for each videotape that is reasonable and necessary for distinctive and objective site selection; and
c. Editing videos to address concerns expressed by participants at the pilot.

However, the research fieldwork was carried out in different phases namely:

a. Identification of segments and intersections that would be representative of the study area based on the scope of the research (reconnaissance survey).
b. Videotaping the selected street segments/intersections and collecting supplemental geometric or operations data;

Figure 4.2 Trial surveys at Instituto de Desarrollo Urbano (IDU), Bogota

a. Reducing the collected video clips into a format that could be used in the video survey;
b. Video survey and reducing responses of participants into analysis format.

4.3. BLOS

4.3.1. Site selection (segment and intersection)

The scope of this study does not allow for a complete video-taping of all segments of the Cicloruta. Secondly, it was not possible for survey participants to view and rate all segments due to lack of time and fatigue associated with lengthy videotapes. Therefore different road segments were chosen for recording to reflect the following criteria:

a. Land use categories and urban characteristics of the surrounding
b. Trails, ciclocarrils and ciclovia (Sunday cycling)
c. Curb lane traffic volume and speed
d. Road categories (highway, arterial or collector)
e. Dead ends of network
f. Various curb lane widths
g. Number of through travel lanes
h. Presence/absence of gutter pans, benches, sidewalks or medians.
i. Different time of the day including night
j. Three different categories of the Cicloruta to reflect different widths and other facilities.
k. Cicloruta across different socio-economic neighbourhoods

Table 4.1 shows these selected segments in the study area to reflect criteria above. Segments were initially called by adjoining arterials but later reconciled to indigenous cicloruta names.

The choice of intersection was much more complicated as there are different categories. However, for easy assessment and possible aggregation, the number of intersections in each route was identified and categorised according to three-leg (T-leg), four-leg and multiple legs intersections (DelDOT, 2011). Additional criteria for sampled intersections other than those contained in criteria for segment choice include:

a. Width, signalised and un-signalised
b. Economic efficiency of the design and number of level and streams
c. Shape of surrounding terrain and situation of intersection within the alignment

4.1 Distribution of segments that constitute study area

s/n	Segment (survey) name	Cicloruta name	No of segments
1	Calle 13	Av. Jimenez-Americas	18
2	Carrera 7	KR 11-13	1
3	Cicloruta Avenida El Dorado	Las Aquas-Av. El Dorado (tunel)	13
4	Calle 26	Las Aquas -Av. El Dorado	13
5	Calle 26 (ciclovia)	Las Aquas -Av. El Dorado (ciclovia)	13
6	Canal Arzobispo	Canal Salitre-Juan Amarillo	17
7	Paerque Simon Boliva	Simon Boliva (trails)	13
8	Calle 53	Cl 100-Av 68 (trail)	27
9	Carrera 50 (ciclocarril)	Avenida Boyaca	38
10	Carrera 13	KR 11-13 (norte)	18
11	Centro Internacional	Canal Salitre-Juan Amarillo (s)	17
12	Avenida Pepe Seirra	Avenida Pepe Seirra	3
13	Alameda El Porvenir	Av. Tintal Porvenir	19
14	Carrera 71d	Av. Agoberto Mejia	9
15	Avenida Americas Costado Norte	NQS	23
16	Puente Avenida 68xAmericas	NQS H/way (roadway)	23

d. Traffic canalisation methods and management
e. Allowed crossing travelling and methods of transportation of cyclists

With respect to choices made above on segments and intersections, figure 4.3 show segments and intersections where data was collected based on these criteria. However, it is important to note that all choices were made to reflect segments and intersections on the cicloruta network. In table 4.2, different categories of these intersections are also shown.

4.3.2. Video production/editing

A team of at least 3-6 personnel participated in data collection that lasted for three weeks, making videos of segments/intersections at different times and days of the week as trajectory of some of the sample ciclorutas revealed in figure 4.3. Four days of data collection trajectory were shown: day 1 (Track_20131025) involved 37 km; day 2 (Track_20131027) 44 km; day 3 (Track_20131102) 29 km; and day 4 (Track_20131104) 73 km. About 5 or more videotapes were made using a digital HD video camera recorder (HDR-AS15/AS10) for every identified route to enhance a wider range of choice for subsequent survey. Camera was set at high quality resolution (HQR) with the capacity for 250 minutes videos in a 32GB storage device. Only one video was used to represent a particular segment in the survey after editing. Each segment was filmed for 20-40 seconds while riding bicycle at a speed of about 5-15 km/h. The camera was worn on the head by use of a strap (figure 4.4) appropriately set to enhance stability and overall quality of the videotapes. The camera was set at such an angle of inclination of 45 degrees to capture images and traffic related activities as much as the naked eye could possibly see on a bicycle. Since the camera is worn on the head, it is possible to represent approximate eye height of bicyclists on curb lane as well as produce reasonably stable videos. Other curb lane variables were simultaneously observed and/or subsequently obtained through secondary measurements. There include both curb lane and bicycle pathway widths, curb lane motorised volume (veh/h) and vehicle speed (km/h), bicycle volume on segment, median width if present and so on. Videos were taken at different times and days to reflect various traffic situations and also at night to test for night cycling satisfaction.

Videos were downloaded from equipment using PlayMemories Home app and subsequently edited with iMovie app. During editing, videos were reduced to between 10-16 seconds and an instant 'repeat mode' of same time to allow review by participants. All segments and intersections were also appropriately

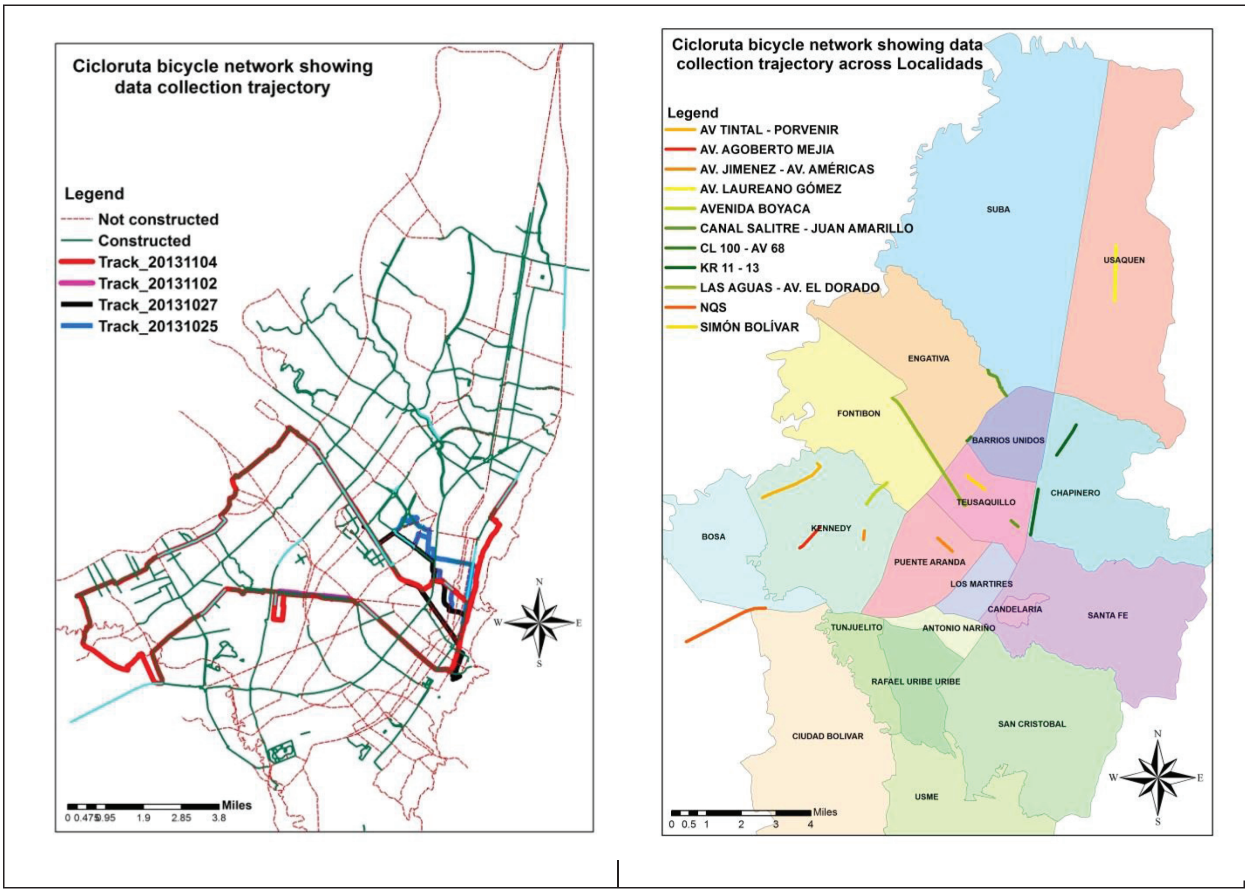


Figure 4.3 Data collection trajectory and segments on cicloruta bicycle network, and by localidad

4.2 Distribution of intersections in the study area

s/n	Intersection	Description
1	Carrera 19xCalle 13	3legs
2	Carrera 13xCalle 51	4legs
3	Carrera 24xCalle 53	4legs
4	Carrera 80xCalle 38c	Multiple legs
5	Carrera 13xCalle 34	4legs
6	Carrera 13xCalle 54	Multiple legs
7	Carrera 7xCalle 19	Multiple legs
8	Carrera 71dxCalle 3s	3legs


Figure 4.4 Demonstrating camera position as used by author during field survey

named at the beginning of each video and a 5 seconds break was introduced between intervals of successive videotapes to separate each video one from another. Sixteen (16) videos constitute data for segments (see figure 4.3). Videos and rating sheets used in the survey were translated to Spanish to enhance effective participation (Appendix ii). Actual viewing of segment videos take about 7 minutes while response to the first section on socio-economy and experience of cyclists was estimated at about 5 minutes, excluding author's explanations.

4.3.3. Video and satisfaction rating surveys

Many researches have employed the video technique for bicyclist and pedestrian studies since the late 1980s after Whyte (1988) pioneered the use of film. He used ground level and overhead cameras to record pedestrian behaviour in New York City and therefore made objective and quantitative comparisons between roadway segments. Jensen (2007) employed the use of a Steadicam camera in his study of 'pedestrian and bicyclist level of service on road way segments in Copenhagen'. The video was later shown to a group of stakeholders who answered questionnaires after viewing each segment of the roadway. More technological development in the use of video in pedestrian level of service has been documented. For example, Willis, Kukla, Kerridge, and Hine (2002) developed a 'microscopic, agent-based model of pedestrian flow' (PEDFLOW) which can be used to stimulate environmental change effects on walking across the urban land space. Interviews were also conducted to understand perception of participants on their satisfaction levels. L. Kang, Xiong, and Mannering (2013) also used video data as well as observed and measured road geometry and physical characteristics to analyse pedestrian perceptions of level of service in three Chinese cities. Harkey et al. (1998) collected video data from 67 selected sites from five cities (each from a different state) to reflect among other things, 'variety of on-street bicycle facilities that range in widths, traffic volumes, and motor vehicle speeds'. Other geometric and operational characteristics were considered for the model haven collected response data from 202 participants. Similarly, video data of 67 intersections was used to conduct an online rating surveys to evaluate bicycle intersection safety index in North Carolina (Carter et al., 2007).

However, in this study, a bicyclist LOS questionnaire was administered to stakeholders during group view of segments of road samples. The first part comprises of socio-economic information of each stakeholder including age, sex, occupation, residence location, house type, location of occupation, length of commuting time on cycling per day, ownership of bike and car, residential status, and so on. The second and third parts had to do with level of satisfaction with respect to watched videos on relevant segments and intersections of the Cicloruta respectively. Whereas the method has the perceived weakness to reflect fatigue and personal opinion in responses, such may not constitute large error since it takes about 16 minutes and constitutes only an average of all responses. The strength of this approach include the ability to reach a more wider response group with minimal risks, more cost effective than having to interview each respondent on site, and most importantly, having to get relevant information on satisfaction level per road category. A major deviation from many LOS studies and perhaps significant contribution to the rich body of literature on this subject matter is the use of both qualitative (participants' ratings) and quantitative (measurement and observation) data to estimate LOS for Bogota.

This study therefore uses the video and questionnaire approach to satisfy the objectives of the study. It would adopt the segment approach within a chosen route in estimating bicycle LOS. A segment consists of a length of street that is between two intersections while a route contains more than one segment and intersection. This therefore means that the study route will be divided into analysis segment and multiple intersections. The choice of segment is due to the need to ensure uniform demand, control and geometry of the road. This in real situations may be difficult along a road with more than one intersection; therefore, different criteria would be adopted to guide the choice of segments to reflect different motorised and non-motorised transport characteristics. Different studies had employed the segment a unit of measurement in quality or level of service assessment and their results already discussed in previous sections (Asadi-Shekari et al., 2013; Dixon, 1996; HCM, 2000; Jensen, 2007; Landis et al., 1997; Landis et al., 2001; Providelo & da Penha Sanches, 2011).

Basically, participants were drawn from government and non-governmental organisations, academia, bicyclists, pedestrian, students, civil and public servants first got introduced to the general objective of the study before being allowed to start with Section 1 (figure 4.5). Some questions in this section that required multiple responses or rating of activity were emphasized. Instructions on how to complete rating forms (questionnaire) was read out to them, and questions answered to provide clarifications. This was followed by an experimental videotape shown to all participants who were drawn across active bicycle riding ages (15-70 years). Survey was conducted in three sections namely: personal data of participants; bicycle level of service rating through videotapes; and bicycle intersection rating through videotapes. Table 4.3 shows the distribution of respondents and dates of respective surveys. Piloto University (students) had all responses nullified due to inconsistences in rating. This is not unconnected with the fact that the survey was responded to from YouTube video without author's presence.

4.4. BLOS variables

4.4.1. Bicycle lane width (BLW)

This is defined as the width of the cycle lane or path. Secondary data was validated by measurements of various ciclorutas during field survey. Average width ranges from 1.5m for first generation ciclorutas to 3m for third generation or most recently constructed ones. The classes range from 0-5, and therefore, three groups can be obtained. In figure 4.6 the frequency and percentage distribution of widths of ciclorutas in the study area is shown. Narrow lanes less than 2m; typical with equal to and less than 2.5m; and wide with more than 2.5m account for 33.5, 10.3 and 56.2 per cent respectively. Ciclorutas with zero widths are mostly unconstructed however still in use by residents. Author presents graphic evidence in figure 4.6 of this category of cicloruta still used by residents, as he has rode across several of such segments.

4.4.2. Wide outside lane (wol)

This is also referred to as curb lane width and defined as the width of the outside through lane. For the purpose of this study we limited our classification of arterials to highways and major arterials. This is because most constructed ciclorutas exists beside existing arterials except for some trails around park areas. Arterials affect the determination of bicycle LOS. Outside lane width is measured in feet during fieldwork, use of Google street map and secondary data from IDECA. The study classifies curb lane as 1 if less than 10feet, otherwise zero.

4.4.3. Pavement condition of lane (pcl)

This refers to the general pavement condition of the bicycle lane. Because this can be subjective, the study adopts two distinct classes such as good with value of 1, and bad assigned zero. Good pavement conditions correspond mostly with recently constructed ciclorutas and the first generation ciclorutas was observed to be good as well. Data was collected by author as explained under data collection and other secondary sources complimented.

Figure 4.5 A cross section of participants at (1) Bogota Humana; (2) Piloto University; (3) IDU; (4) Los Andes University; (5) Rosario University; and (6) topic translated in Spanish

Table 4.3 Distribution of participants during video surveys in Bogota

s/n	Name of participating organisation	No of participants	Percentage	Date of survey
1	Piloto University (staff)	10	10.75	06/11/13
2	Bogota Humana	8	8.6	07/11/13
3	IDU	6	6.45	08/11/13
4	Piloto University (students)	8	8.6	08/11/13
5	Los Andes	48	51.6	08/11/13
6	Rosario University	13	14.0	12/11/13
Total		**93**	100	

Source: Author's field survey (2013).

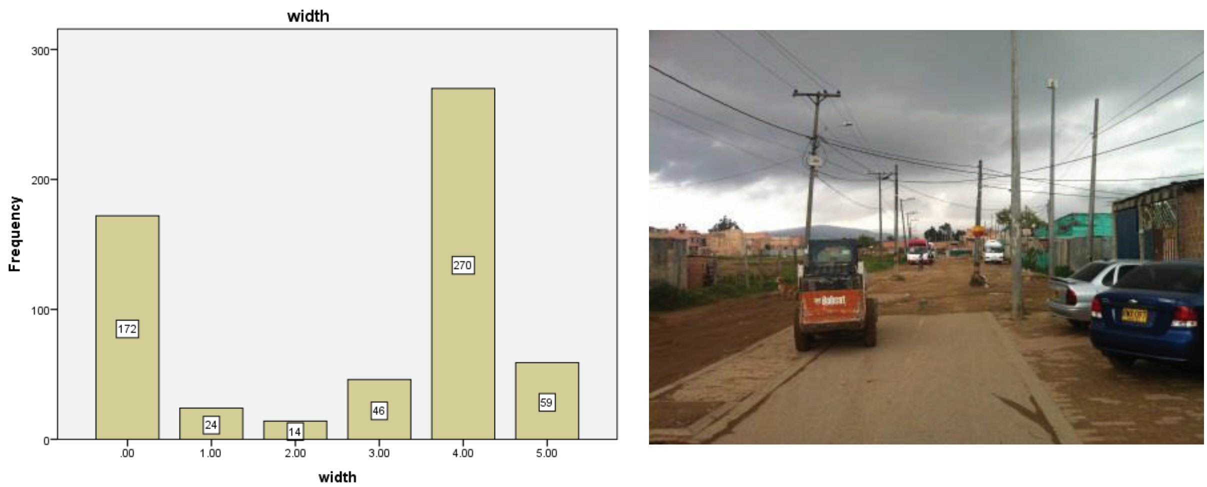


Figure 4.6 Distribution of cicloruta bicycle road network width; cross section of an un-built segment

4.4.4. Side path separation (sps)

This is the separation in terms of distance (in feet) from the side path to the edge of the roadway. Because no such data exist in secondary form, field measurements were recorded from different classes of cicloruta and some extrapolation carried out based on field observation and complemented by using Google street map. Categorisation was based on whether there is separation = 1 or non = 0. Raised shoulder or trails are assigned same value as those for separation.

4.4.5. Number of through lanes (ntl)

This is the number of through lanes value usually two-directional that represents the road way cross section. HCM (2010) indicates this value as excluding 'left turn bays and centre two-way left turn lanes'. Therefore they range from 2 for urbanised or transitioning areas to 1 in rural areas. However, the scoring principle adopted here is to assign a value of 1 where NTL is less than 2 through lanes, otherwise zero.

4.4.6. Vehicle speed (vs)

The speed of vehicles refers to posted speed limits in urban road network or the maximum speed at which vehicles travel over a roadway segment. Observation in the study area revealed non posted speed limit as speed is determined by present traffic conditions. Motorised speed mostly increase away from the most urbanised city centre. A value of 1 is assigned to speed of less than 30 mi/hr, otherwise zero.

4.4.7. Motorised traffic volume (mtv)

Motorised traffic volume across relevant road segments determine to a great extent the value of bicycle LOS. Data is available through secondary source. Based on data in table 4.4 (IDECA, 2013), some generalisations were made over major arterials. The study therefore assigns a value of 1 for arterials with less than 600 cars/15mins and zero otherwise.

4.5. Intersection LOS

4.5.1. Site selection

The choice of intersection for LOS estimation is critical for an unbiased estimation. Previous studies whose efforts were based on existing data fall short of this as the choice of location for such data may be subjective. For example, data from advocacy groups, municipal authorities, transport agencies, communities, all reflect mostly areas with high volume with reported problems while other areas of relatively low volumes with minimal challenges are neglected. Since it is not possible to investigate all intersections due to scope of study, typology of intersection was adopted in our choice. These include: Three-leg or T-intersection; Four-leg intersection; and Multi-leg intersection (as mentioned earlier). In addition to this stated criteria, selection would also be made to reflect other transport characteristics as cyclist volume, diversity in land use, transportation characteristics and infrastructure as well as neighbourhood socioeconomic characteristics. In view of the network characteristics of the study area, 8 intersections were sampled to reflect 3legs, 4legs and multiple legs and other geometric and physical characteristics (see figure 4.7). Strategic process employed in the selection of intersection for the model estimation includes, identify from relevant road maps and field observations number of segments as a measure of intersections in the transport corridor. Therefore the following variables were shown on video clip to participants:

1. Bicycle facilities on approaches
2. Bicyclist positioning on approaches
3. Sight distance
4. Number of driveways on main streets

Table 4.4 Motorised traffic volume in sampled arterials of the study area per 15mins peak

Peak	L1	L2	L3	L4	Cars	Buses	trucks	Motorcycle	Total
8.15am	419	532	297	117	1003	24	56	160	1275
	119	51	45	383	374	109	55	86	648
%	-	-	-	-	-	-	**8.7%**		
Average_4L									**961**
8.15am	130	209	39		220	35	19	76	377
	186	365	360		380	169	50	121	912
%	-	-	-		-	-	**5.4%**		
Average_3L									**644**
8.15am	186	241			164	92	13	37	402
	225	521			502	70	13	143	747
%	-	-			-	-	**2.3%**		
Average_2L									**574**

Source: MOVILIDAD, 2013

Figure 4.7 Illustration of some intersection categories in the study area

5. Pavement conditions
6. Bicycle signals
7. Motorised traffic control
8. Motorised traffic speed
9. Number of lanes
10. Number of total intersection legs
11. One-way or two-way roadway being crossed
12. Street lighting
13. Crossing width
14. Motorised traffic volume (right-turning)

15. Motorised traffic volume (left-turning from opposite direction)

4.5.2. Video production

About 3-5 videotapes were made for every identified intersection. In principle therefore maximum three videos can be produced in any route to reflect three kinds of intersection (figure 4.7). Only one of each intersection category can be examined while weighting is given to others of same class and multiplied by the number in that type, and used in the survey after editing. Each intersection was filmed for 10-15 seconds a few meters away as far as sight of the intersection variables were unhindered. The positioning of the camera is as discussed in section 4.3.2.

All intersections were also appropriately named at the beginning of each video and a 5 seconds break was introduced between intervals of successive videotapes to separate each video one from another. Eight (8) videos constitute data for intersections. Just like in segment survey, videos and rating sheets used in the survey were translated to Spanish to enhance effective participation. Viewing of intersection videos takes about 3 minute while actual viewing of all videos (segments and intersections) takes 10.6 minutes. The first section on socio-economy and experience of cyclists was estimated to take about 5 minutes, making a total survey time of 16 minutes. The author believes this served as motivation for participation in the survey. Earlier studies used employed staff as participants (Landis, 1996) or some free cinema tickets to motivate participants (Jensen, 2007).

4.6. Intersection LOS variables

4.6.1. Volume of cyclists (VOC)

The scope of study makes it difficult for data to be collected for 15 minutes per intersection. The very nature of some neighbourhoods with safety issues and complicated network system further compound this challenge. However, observation from video clips is used to obtain data on the volume of cyclists that crosses an intersection at survey time. Since the author had 3 or more fieldwork assistants, the same assumption is applied in deciding volume. A score of 1 is assigned to an intersection if there are 2 or more cyclists crossing (excluding team members) at the time of survey, 0 otherwise.

4.6.2. Conflicts with pedestrian/cyclists (CPC)

Conflicts with other cyclists, pedestrians and other wheeled tricycles impede cyclist's ability to cross intersections and thus affect their satisfaction. Video tapes from field observations reveal this as a problem in Bogota. The study therefore considers a value of 1 for ≥3 conflicts, 0 otherwise. This data is observed from collected video clips.

4.6.3. Safety and risk (SAR)

However subjective this factor may seem, it is thus an issue that affect bicycle use in Bogota. Data on security was difficult to assess, but oral interview with some residents reveal great risk and safety concerns mostly in the southern part of the city. The variable would not be considered separately for lack of data, more so that it has been considered by participants during rating.

4.6.4. Road signs and markings (RSM)

Road signs and markings inform bicyclists, pedestrians, and motorists alike on their rights, the absence of which generate user conflicts resulting in accidents and thus deteriorating level of satisfaction. The study assigns a score of 1 for clear road/traffic signs and markings, 0 otherwise.

4.6.5. Total intersection legs (TIL

The number of intersection legs has a relationship with the width of crossing, though they may be few exceptions, thus the level of service of that road infrastructure. If intersection has 3 legs, 1 is assigned, 0 otherwise.

4.6.6. Crossing width of intersection (CWI)

The very nature of the lack of special design to accommodate bicyclists at intersection makes its width an influential factor in level of satisfaction. Intersections with ≤ 12 feet are assigned 1, 0 otherwise.

Other useful variables such as motorised traffic volume (right turning and left turning in opposite direction) prove to be a useful variable in intersection studies (Carter et al., 2007). This could not be included in survey due to the limited scope for this study and the enormous number of intersections in the study area. This notwithstanding, it is expected that other variables proved adequate to estimate our model. A comprehensive variable description for both segments and intersections is attempted in table 4.6. It thus includes perception ratings as well as other geometry, physical and operational characteristics of Bogota transport system. It forms the basis of analysis at all levels of LOS estimation using the prescribed methods.

4.7. Data analysis techniques

The LOS model is a macroscopic model which has relationship between space, walking speed and flow. Different methods exist in literature on how inputs into the model can be solved to generate LOS. Logit regression analysis of non-motorised commuting was used in the United States to predict specific form of NMT commuting such as working at home, walking to work and cycling to work (Plaut, 2005). Jensen (2007) applied the ordinary generalised linear models (GLMs), cumulative logit models (CLMs), and ordinary probit models (OPMs) to develop bicycle and pedestrian models in his Copenhagen study. Hankey et al. (2012) on the other hand employed both ordinary least square (OLS) and maximum likelihood estimation (MLE) of the regression statistics to estimate models of bicycle and pedestrian traffic in Minneapolis. Pearson correlation analysis was used to estimate models and predict pedestrian LOS in Landis et al. (2001) study of 'modelling the roadside walking environment: pedestrian level of service' in Pensacola, Florida. In developing pedestrian level of service for sidewalk D. Tan, Wang, Lu, and Bian (2007) applied Pearson correlation coefficient to measure linearity between variables of interest to obtain coefficients which are used in their model. Similarly, Providelo and da Penha Sanches (2011) used the method of successive interval to define traffic characteristics based on priority of users and potential users to evaluate bicycle infrastructure in Brazilian medium-sized cities. These studies and much other form the background for our choice of statistical techniques for this study whose assumptions are met by our data set as it is justified below.

In other to evaluate the level of satisfaction of bicyclists in the study area, a statistical method with the capabilities for choice ordered modelling involving ordered discrete data of the form A-F is needed. Multinomial logit model from the traditional multinomial discrete-outcome models is however a possibility, but reveals weakness in their inability to order the nature of data. In other words, A is better than B; B is better than C; C is better than D; and so on and therefore may result in loss of efficiency in parameter estimation according to Amemiya (1985). Other possibilities include models for binary outcomes and other exponential distributions such as Poisson, negative binomial and so on (Nelder & Wedderburn, 1972). However, ordered probability method is appropriate for modelling choice and by extension satisfaction (Greene & Hensher, 2009; Washington, Karlaftis, & Mannering, 2011). Using the

Table 4.5 Variable description

Variable	Variable description
Dependent variable	Perceived satisfaction rating of the cicloruta (for segment and intersection surveys) based on six-point likert ranging from 1 as highly satisfied to 6 as highly dissatisfied
Participant's personal characteristics	Gender (1=Male; 0=Female) Age (1= ≥35; 0=>36) Localidad (1=Barrios Unidos; 2=Teusaquillo; 3=Puente Aranda; 4=Los Martires; 5=Antonio Narino; 6=Tunjuelito; 7=Rafael Uribe; 8=Candelaria; 9=Santa Fe; 10=Suba; 11=Usaquen; 12=Chapinero; 13=Kennedy; 14=Engativa; 15=Fontibon; 16=Bosa; 17=San Christobal; 18=Usme; 19=Sumapaz; 20=Cuidad Bolivar) Housing type (5=Detached; 6=Terraced; 7=Flat; 8=Student hostel; 9=Other) Bicycle ride in Bogota city (1=Yes; 0=No) Number of bicycle trips undertaken (1=<5; 2=5-10; 3=10+) Number of km/week with bike (5=<10; 6=10-15; 7=16-29; 8=30-45; 9=46+)
Experience	Experience in riding (1=Experienced; 0=Inexperienced) If yes, how many km do you ride to work/school; shopping; recreation; and other? What percentage of your riding is done in major roads; residential streets; cicloruta; sidewalks; and other road facilities?
Environmental characteristics	Does weather affect you decision to use bicycle? (1=Yes; 0=No) If yes; rain; drizzle; steady rain; heavy rain; fog; hot weather (1=Yes; 0=No)
Segment variables	Bicycle lane width (BLW): 1=>2m; 0=<2m Wide outside lane (WOL): 1=<10ft; 0=>10ft Pavement condition of lane (PCL): 1=Good; 0=otherwise Side path separation (SPS): 1=present; 0=otherwise Number of through lanes (NTL): 1≤2 lanes; 0=otherwise Vehicle speed (VS): 1≤30mi/hr; 0=otherwise Motorised traffic volume (MTV): ≤600cars/15min; 0=otherwise Conflicts with pedestrian (CWP): 1=≤10 conflicts; 0=otherwise Tree and benches (TB): 1=trees/benches/grasses; 0=otherwise Daylight: 1=daytime; 0=otherwise
Intersection variables	Volume of cyclists (VOC): 1=≥2 cyclists; 0=otherwise Conflicts with pedestrian/cyclists (CPC): 1=≤3 conflicts Road signs and markings (RSM): 1=signs/markings present; 0=otherwise Total intersection legs (TIL: 1=3leg; 0=otherwise Crossing width of intersection (CWI): 1≤12ft; 0=otherwise

Genlin procedure in SPSS, ordered probit logit were fitted in the generalized linear models (GLMs), as this allows the fitting of ordinal outcomes, such as perception of LOS as rated by our survey participants based on video experiment. It is an extension of ordinal least squares regression that generalizes linear regression and thus allows the linear model to be related to the response or dependent variable (in our case the overall rating of segments/intersection). It is a multinomial probability distribution with cumulative logit as link function. We can therefore define an unobserved variable, z, to derive ordered probabilities which enable us to define our BLOS rankings. These rankings exist as a linear function with an observation, n, in which:

$$z_n = \boldsymbol{\beta}\mathbf{X}_n + \varepsilon_n \qquad 4.1$$

where n is the number of participants' rating, in this case, 1360 ratings of 16 segments and 680 ratings of 8 intersections from 85 survey participants; X is defined as a vector variable used to determine LOS; β is a vector of parameters estimate; and ε is an independent random disturbance term. When we remove the subscript n from equation 4.1 to simplify it and convert LOS to numerical scale (i.e., from A-F to 1-6), the estimate for the probit model implies that:

$$
\begin{aligned}
&y = 1 \text{ if } z \leq 0\\
&y = 2 \text{ if } 0 < z \leq \mu_1\\
&y = 3 \text{ if } \mu_1 < z \leq \mu_2\\
&y = 4 \text{ if } \mu_2 < z \leq \mu_3\\
&y = 5 \text{ if } \mu_3 < z \leq \mu_4\\
&y = 6 \text{ if } z \geq \mu_4
\end{aligned}
\tag{4.2}
$$

where μ = estimable parameters (thresholds) used to categorise observed variable y and estimate μ & β jointly. If ε in equation 4.1 satisfy the assumption of independent normal distribution in all observations with 0 & 1 mean and variance respectively, an ordered probit model results with the selection probabilities below:

$$
\begin{aligned}
&P(y = 1) = \Phi(-\boldsymbol{\beta}\mathbf{X})\\
&P(y = 2) = \Phi(\mu_1-\boldsymbol{\beta}\mathbf{X}) - \Phi(-\boldsymbol{\beta}\mathbf{X})\\
&P(y = 3) = \Phi(\mu_2-\boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X})\\
&P(y = 4) = \Phi(\mu_3-\boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X})\\
&P(y = 5) = \Phi(\mu_3-\boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_3 - \boldsymbol{\beta}\mathbf{X})\\
&P(y = 6) = 1 - \Phi(\mu_4-\boldsymbol{\beta}\mathbf{X})
\end{aligned}
\tag{4.3}
$$

where $\Phi(.)$ is defined as the cumulative distribution function of standard normal distribution or simply represents the usual probit function.

Since 16 and 8 observations for segments and intersection respectively, are generated by each of the 85 participants, there is therefore likelihood for these observations to share unobserved effects. This violates the independent disturbance assumption in equation 4.1. We therefore adopt the traditional random effects to address this effect. It is where an individual-specific term φ_i included in other to rewrite equation 4.1, thus:

$$z_n = \boldsymbol{\beta}\mathbf{X}_{ic} + \varepsilon_{ic} + \varphi_i \tag{4.4}$$

where subscript I denotes the index of individual participant; subscript c as index of video clips; while all other terms are as earlier defined (L. Kang et al., 2013; Shafizadeh & Mannering, 2006; A. Tan & Irfanoglu).

In this study, a generalised random parameter approach is preferred to the traditional random effect. This is because of the very subjective nature of satisfaction or comfort, in which our rating data is obtained. In this sense, the model is generalised for each of the 85 participants to have its own β_i. Traditional random effect method would have assumed participants get their own constant but constrained to have values in β the same. For each respondent participant therefore, i, β_i is estimated as a random and fixed term, written as:

$$\boldsymbol{\beta} = \boldsymbol{\beta} + w_i \tag{4.5}$$

where $\boldsymbol{\beta i}$ is a vector of specific individual parameters, w_i is disturbance term for the random distribution. However, maximum likelihood estimation using Halton draws can be used to estimate this random parameters, and has been proved to be an efficient sampling method (Bhat, 1999; Fridstrøm, Ifver, Ingebrigtsen, Kulmala, & Thomsen, 1995; Greene & Hensher, 2009; Qi, Smith, & Guo, 2007; Washington et al., 2011). Indeed, one of the advantages of GLMs is that the structure of the linear predictor is the familiar structure of a linear model' (Nelder & Wedderburn, 1972).

4.8. Bicycle level of service model

4.8.1. Segment Bicycle Level of Service (BLOS)

Initial development and calibration of BLOS was at the roadway segment level. The methodology for the various operations as already discussed in previous sections is summarised in figure 4.8. According to the HCM (2000) 'the segment levels of service for a given direction of travel are combined into an overall

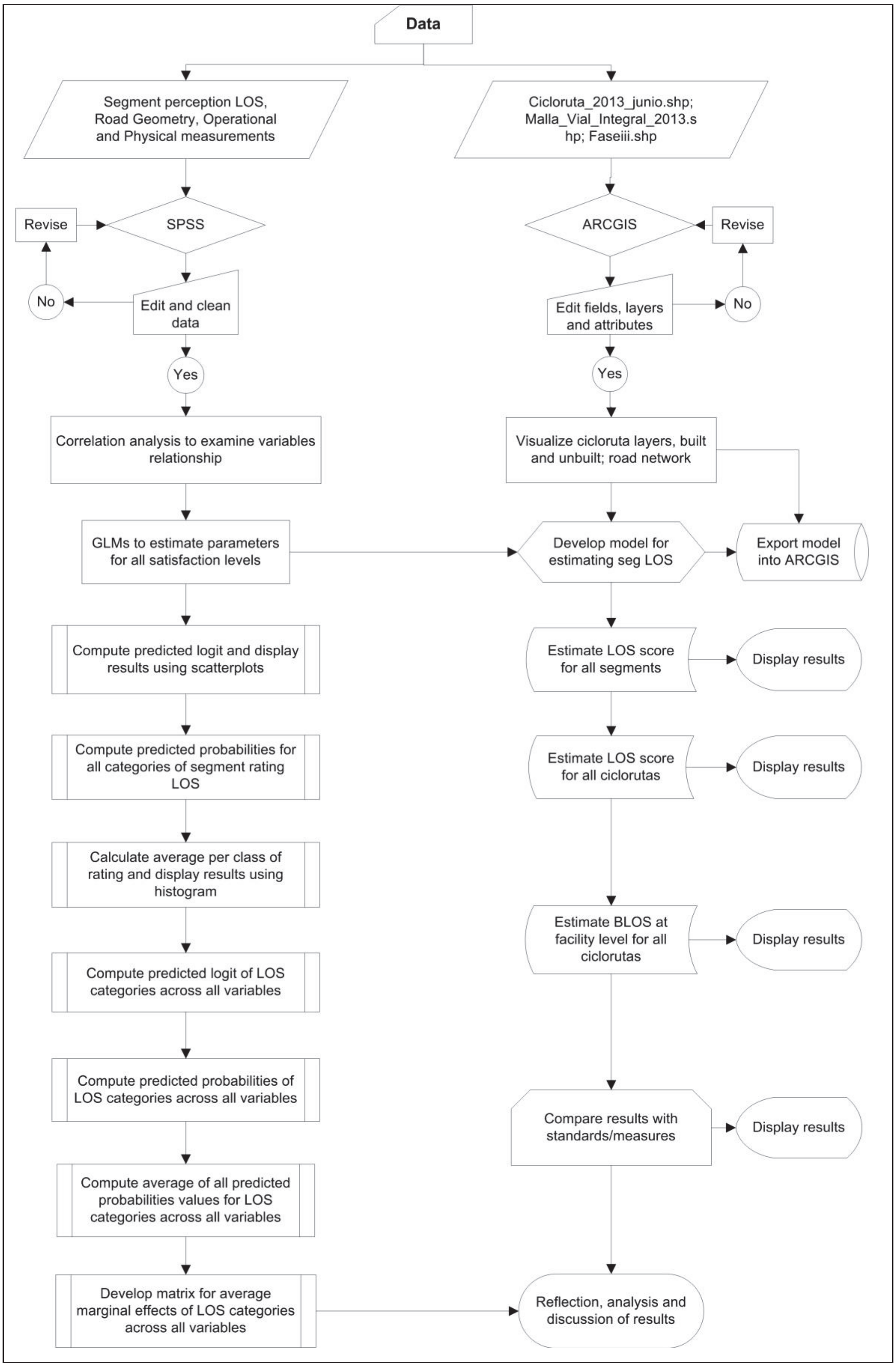


Figure 4.8 Flowchart of methodology for segment LOS estimation

directional level of service for the study section of street by taking a length weighted average of the segment levels of service for the analysis direction'. Our segment LOS is defined as BLOS score for every named segment. The estimated model (1) is used to calculate LOS score for each segment and cicloruta in ArcGIS.

A matrix for average marginal effects of the influence of individual variable on the probability of level of service by cicloruta users is generated. We further aggregate our segment BLOS (about 584 segments) into ciclorutas (71) based on their name ID. The various steps involved in this approach are summarised in figure 4.9. It is important to note that different segments of the cicloruta share similar names irrespective of their categorisation. To make our scores amenable for facility BLOS therefore, we averaged all scores of similar ciclorutas using:

$$AVBLOS_{segment} = \sum BLOS_{segment}\ 1 + 2, \ldots, n/N \qquad 4.7$$

where AVBLOSsegment = average BLOS score for cicloruta sharing similar name ID; n = referring to nth number of ciclorutas; and N = total number of segments.

4.8.2. Intersection BLOS

In other to have estimation that more readily reflect true bicycle transport conditions in Bogota, the study also examined the impact of intersection on ciclorutas. Some studies that estimated bicycle level of service exists (Carter et al., 2007; Dowling, 1994; Landis et al., 2003; L. Zhang & Prevedouros, 2003). Not many studies have considered joint estimation of intersection and segment. Carter et al., 2007 developed an intersection safety index for North Carolina using the generalised linear models, while Landis et al., 2003 developed a methodology for estimating intersection level of service for the Florida Department of Transportation (FDOT) using Pearson correlation and factor analysis. Therefore, similar methodological approach as in segment analysis is used to estimate level of service scores for intersections.

4.8.3. Facility LOS

In other to achieve the objective of this study, LOS score is estimated at facility level. This is because current transportation planning programs emphasizes LOS at facility level since roadway segments are not independent of the entire network. For example, the Florida Department of Transport (FDOT, 2009) and Highway Capacity Manual (HCM, 2000) developed a BLOS model that aggregates individual segment bicycle analyses into a facility analysis. This is particularly important in view of the fact that there is hardly any continuity in paved shoulder/bicycle track existence over the entire road facility. Some portions may offer reasonably good facilities while others will not, to the extent of discouraging bicyclist. The nature of cicloruta is not consistent to any particular pattern and therefore makes it imperative to make adjustments to earlier formulated theory on estimation of LOS at facility level. The final estimation is carried out thus:

$$BLOS_{facility} = \frac{\sum BLOS_{segment}}{n} + \frac{\sum BLOS_{intersection}}{n} / 2 \qquad 4.8$$

where $BLOS_{facility}$ is bicycle level of service score at facility level (defined as all cicloruta sharing similar name identity irrespective of their categorisation; $\sum BLOS_{segment}$ is bicycle level of service score at segment level; n is the number of segments in that facility; and $\sum BLOS_{intersection}$ is bicycle level of service score at intersection level. The procedure for this estimation is illustrated in figure 4.10.

Estimation of LOS at all three levels is matched against LOS scores shown in table 4.9. This is as contained in highway capacity manual, a modification of Landis et al., (1994, 2003). This is in view of the fact that our initial rating values and other measurement data are now converted into parameter estimates and coefficients. At facility level therefore, about 71 ciclorutas have their BLOS estimated to provide methodology for future estimation and facility maintenance and upgrade (see table 4.10).

Figure 4.9 Methodology for estimating intersection LOS

Table 4.9 LOS scores (after HCM, 2012)

LOS	Score	Description
A	≤ 2.00	Excellent
B	> 2.00 – 2.75	Very good
C	> 2.75 – 3.50	Good
D	> 3.50 – 4.25	Fair
E	> 4.25 – 5.00	Poor
F	> 5.00	Very poor

Table 4.6 Ciclorutas and their segments

s/n	Name of cicloruta	No. of seg	Width class	Pav_con	Landuse	Built	Category
1	AC 63 (AV. JOSE CELESTINO MUTIS)	8	4	GOOD	OU	YES	HS
2	ACJAS	2	0	BAD	OU	NO	HD
3	AEROPUERTO EL DORADO	1	0	BAD	OU	NO	HD
4	AUTOPISTA NORTE	30	4	GOOD	OU	YES	HS
5	AV 1 DE MAYO	5	4	GOOD	OU	YES	MS
6	AV BOSA	1	0	BAD	OU	NO	HD
7	AV CL 19	3	0	BAD	OU	NO	HD
8	AV DE LA CONSTITUCIËN	5	0	BAD	OU	NO	HD
9	AV DE LA HORTUA	1	0	BAD	OU	NO	HD
10	AV EL CENTENARIO	4	0	BAD	OU	NO	HD
11	AV EL TABOR	1	0	BAD	OU	NO	HD
12	AV FERNANDO MAZUERA	5	3	GOOD	OU	YES	AS
13	AV FERROCARRIL DEL SUR	4	4	GOOD	OU	YES	AS
14	AV FUCHA	2	0	BAD	OU	NO	HD
15	AV GENERAL SANTANDER	1	0	BAD	OU	NO	HD
16	AV JORGE GAITÁN CORTÉS	6	0	BAD	OU	NO	HD
17	AV KR 9 - AV CL 92	1	4	GOOD	U	YES	HD
18	AV LA VICTORIA	3	0	BAD	U	NO	HD
19	AV LAS AMÉRICAS	2	0	BAD	OU	NO	HD
20	AV LONGITUDINAL DE OCCIDENTE	5	0	BAD	OU	NO	HD
21	AV MANUEL CEPEDA VARGAS	1	0	BAD	OU	NO	HD
22	AV MARISCAL SUCRE	6	0	BAD	U	NO	HD
23	AV SAN BERNARDINO	1	4	GOOD	OU	YES	HS
24	AV TINTAL - PORVENIR	19	4	GOOD	OU	YES	HS
25	AV. AGOBERTO MEJIA	9	4	GOOD	OU	YES	HS
26	AV. CIRCUNVALAR - AV. LOS CERROS	3	0	BAD	OU	NO	HD
27	AV. CL 134	5	4	GOOD	OU	YES	HS
28	AV. CL 6	1	4	GOOD	OU	YES	MS
29	AV. JIMENEZ - AV. AMÉRICAS	18	4	GOOD	OU	YES	MS
30	AV. LAUREANO GÓMEZ	4	0	BAD	OU	NO	HD
31	AV. PEPE SIERRA	3	4	GOOD	OU	YES	MS
32	AV. SUBA	16	3	GOOD	OU	YES	AS
33	AV. VILLAVICENCIO	16	5	GOOD	OU	YES	HS
34	AVENIDA BOYACA	38	4	GOOD	OU	YES	MS
35	AVENIDA CALLE 127	6	4	GOOD	OU	YES	MS
36	AVENIDA CARACAS	8	0	BAD	OU	NO	HD
37	AVENIDA CIUDAD DE CALI	35	4	GOOD	OU	YES	HS
38	AVENIDA DEL SALITRE	2	0	BAD	OU	NO	HD
39	BANDERAS - PATIOBONITO	9	4	GOOD	OU	YES	HS
40	BANDERAS - PORVENIR	2	4	GOOD	OU	YES	MS
41	CANAL MOLINOS	4	4	GOOD	OU	YES	MS
42	CANAL RÍO FUCHA	12	4	GOOD	OU	YES	MS
43	CANAL SALITRE - JUAN AMARILLO	17	3	GOOD	OU	YES	AS
44	CANAL TORCA - AV 19	16	5	GOOD	OU	YES	HS
45	CIRCUITO TUNAL	15	5	GOOD	OU	YES	HS
46	CIUDAD SALITRE	16	4	GOOD	OU	YES	MS
47	CL 100 - AV 68	27	4	GOOD	OU	YES	AS
48	CL 170	7	4	GOOD	OU	YES	MS
49	CL 48 R SUR	1	4	GOOD	OU	YES	MS
50	CL 6	11	4	GOOD	OU	YES	MS
51	CL 80	10	4	GOOD	OU	YES	MS
52	ENGATIVÁ - HUMEDAL JABOQUE	9	5	GOOD	OU	YES	HS
53	HOSPITAL SAN CARLOS	3	4	GOOD	OU	YES	MS
54	KR 11 - 13	18	2	GOOD	OU	YES	AS
55	LA CANDELARIA	1	0	BAD	OU	YES	HD
56	LA FLORIDA	1	0	BAD	OU	NO	HD
57	LAS AGUAS - AV. EL DORADO	13	4	GOOD	U	YES	HS
58	MEISSEN	1	5	GOOD	OU	YES	HS
59	NQS	23	4	GOOD	OU	YES	MS
60	PARQUE CL 42 SUR KR 72I	1	3	GOOD	OU	YES	AS
61	PARQUE EL TIMIZA	2	4	GOOD	OU	YES	MS
62	PARQUE LA AURORA II	2	4	GOOD	OU	YES	MS
63	PARQUE LOS FUNDADORES	1	0	BAD	OU	NO	MD
64	PARQUE TERCER MILENIO	11	5	GOOD	OU	YES	HS
65	PARQUE TOBERÍN	1	1	GOOD	OU	YES	AS
66	PARQUE VILLA ALSACIA	27	3	GOOD	OU	YES	MS
67	RÍO BOGOTÁ - LA GAITANA	5	5	GOOD	OU	YES	HS
68	RIO NEGRO CASTELLANA	3	4	GOOD	OU	YES	AS
69	RIO TUNJUELO	8	0	BAD	OU	NO	HD
70	SIMÓN BOLÍVAR	13	5	GOOD	OU	YES	HS
71	SIMÓN BOLÍVAR (CIRCUITO)	3	5	GOOD	OU	YES	HS

Width class: 1=<2m; 2=2-2.25m; 3=2.25-2.5m; 4=2.25-3m; and 5=3+m

5. ESTIMATING BLOS FOR THE CICLORUTA

In this chapter, the level of service for the cicloruta is estimated based on the percieved level of satisfaction. This is derived from rating (use experience) of the video clips on segments and intersections and enables us to estimate the bicycle level of service score based on the perception of survey participants. Other geometry, physical and operational characteristics of transportation in Bogota were acquired, observed and measured during field survey. They all formed major components in the estimation of the models for estimating satisfaction based on the use of the cicloruta. Two models were developed using a combination of socio-economic data of participants, rated resposes from participants, environmental factors, road geometry, physical measurements/observations and traffic operational characteristics. Ordered choices were modeled using statistical techniques in SPSS and ArcGIS environments.

5.1. Study demographics

Analysis of the influence of socioeconomic characteristics of research participants reveals no positive relationship on rating of satisfaction level at 0.05 level of significance for both segments and intersections. However, individual socioeconomic variable like gender and experience of cyclists show great tendencies. For example female tend to rate segments and intersections lower than their male counterparts; while experienced cyclists revealed higher satisfaction in their rating of both segments and intersections than inexperienced cyclists (table 5.1). The influence of age of participant differs in segments and intersection. For example, in segment rating, participants younger than 35years showed lower satisfaction than those aged above 35. The sample size may account for this as more of the participants were young persons. On the other hand, their level of satisfaction is higher for intersection.

Participants for the survey represented different locations ('localidad') of the study area (figure 5.1). However, for as much as localidad did not form the basis of participation in the survey, it was not unexpected that many localidad would be represented as different socio-economic and age groups were sampled. Data in figure 5.1 revealed about 12 localidad or 60 per cent representation of participants across the city. Usaquen constitute the highest percentage of 28.4. This can be attributed to chance as every localidad had equal chances of having residents participate in the survey. Some (7) localidad were not represented in the survey. They include: Bosa, Cuidad Boliva, Los Martires, Puente Aranda, Rafeal Uribe Uribe, Sumapaz, Tunjuelito and Usme.

Similarly, there is more males' (63.5 per cent) participation in the survey than female (36.5 per cent), while across age distribution, the data revealed a very high (84.7 per cent) participation of 18-35 years. This may be explained by the choice of Universities as preferred areas for survey due to the enabling environment they provide including classroom equipped with projectors and willingness of students to participate without any form of material motivation, reward or lack of time as expressed by some staff in many government ministries who were approached for this survey. In figure 5.2, more participants fall within ages of 18-35 in both male (88.9 per cent) and female (77.4 per cent) while bicycle ridership also revealed more riders in male (75.9 per cent) than in female (58.1 per cent). Overall bicycle ridership in the study area showed that 69.4 per cent ride bicycle in the city while 30.6 per cent do not.

A chi-square statistics of these relationships above shows an X^2 value of 1.281[a], 2 degree of freedom and a p-value of 0.734 which is however greater than our confidence level of 0.05 for gender and ridership (table 5.2). We therefore conclude that the null hypothesis should be accepted, that there is not enough evidence to suggest that any differences between gender use of bike in Bogota is for any reason other than chance

5.1 Satisfaction rating by research participants for segments and intersections

s/n	Group of participants	Segment ratings		Intersection rating	
		Number rating	Rating average	Number rating	Rating average
1	All participants	1,360		680	
2	House type				
	Detached	192	2.80	96	4.63
	Terraced	192	2.74	96	4.71
	Flat	800	2.51	400	4.87
	Student hostel	112	2.78	56	4.73
	Other	32	1.81	16	5.29
3	Age				
	Equal or less 35yrs	1184	2.68	592	4.78
	Greater than 35yrs	176	1.99	88	5.05
4	Gender				
	Female	496	2.77	248	5.20
	Male	864	2.54	432	4.58
5	Number of trips				
	<5 trips/week	944	2.63	472	4.80
	5-10	144	2.28	72	4.51
	10+	256	2.71	128	5.03
6	Bike use/week				
	0	288	2.79	144	5.40
	1-2days	256	2.54	128	4.53
	3-5	528	2.58	264	4.78
	6+	256	2.54	128	4.48
7	Number of km bike/week				
	<10 days/week	560	2.69	280	5.10
	10-15	160	2.73	80	4.11
	16-29	144	2.44	72	4.24
	39-45	80	2.48	40	4.69
	46+	368	2.57	184	5.0
8	Effect of weather on bike use				
	No effect	208	2.60	104	5.20
	Yes effect	1152	2.61	576	4.72
9	Experience in cycling				
	Inexperienced	976	2.20	488	4.65
	Experienced	320	2.67	160	5.18

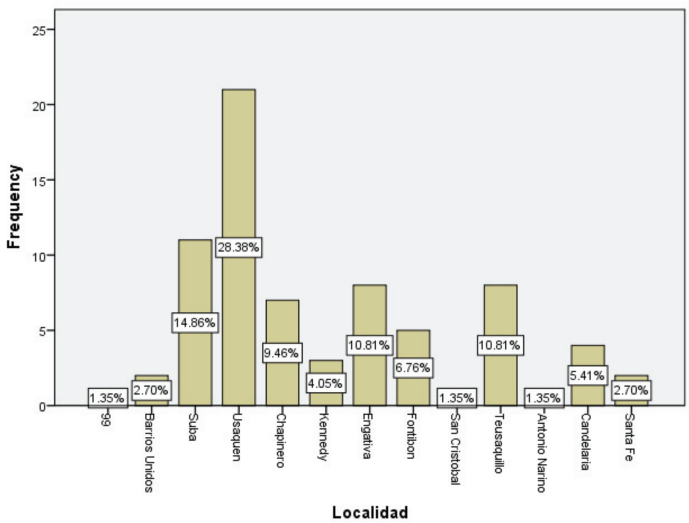


Figure 5.1 Distribution of survey participants across Localidad

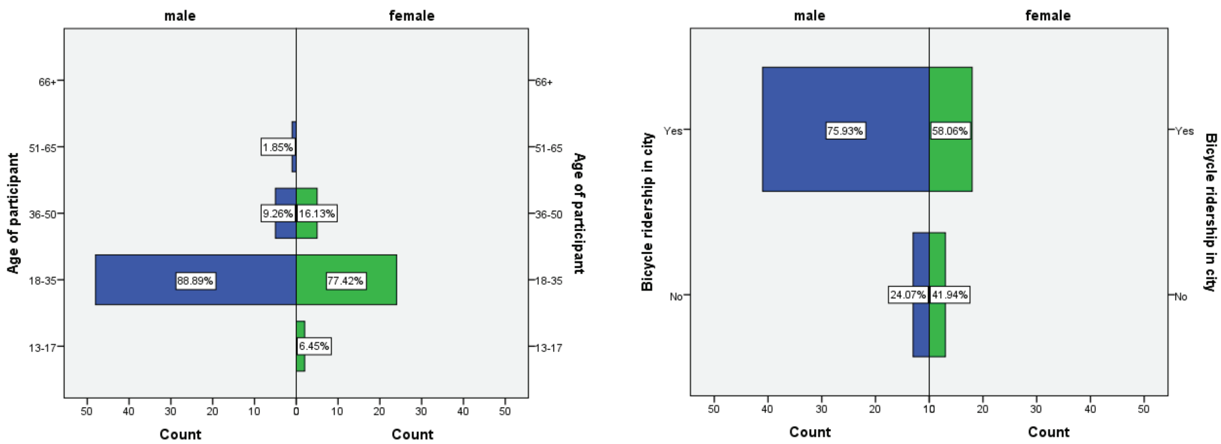


Figure 5.2 Graph of gender and age of participants; gender and experience in bicycle ridership

5.2 Chi-Square tests of bicycle ridership in the city, age and gender of research participants

Gender of participant		Value	df	Asymp. Sig (2-sided)
Male	Pearson Chi-Square	2.140[b]	2	.343
	Likelihood Ratio	3.536	2	.171
	Linear-by-Linear Ass.	1.884	1	.170
	N of Valid Cases	54		
Female	Pearson Chi-Square	3.758[c]	2	.153
	Likelihood Ratio	3.836	2	.147
	Linear-by-Linear Ass.	1.797	1	.180
	N of Valid Cases	31		
Total	**Pearson Chi-Square**	1.281[a]	2	.734
	Likelihood Ratio	1.524	2	.677
	Linear-by-Linear Ass.	.001	1	.974
	N of Valid Cases	85		

(example, sampling error and so on). These findings also hold true for independent male and female bicycle ridership with p-value of 0.343 and 0.153 respectively, which are both greater than our confidence value of 0.05. We conclude that despite observed differences in this data, there is not sufficient evidence to prove its occurrence other than chance probably due to sampling error.

The experience of cyclists in the city was also investigated. While the best cycling conditions are desirable by all cyclists irrespective of how long one has been riding, the author observed that this give an indication of high level of confidence exhibited by cyclist at worst case scenarios and not necessarily the level of experience. This is more so that even those who responded as not using bike in the city also answered question on experience. For example, while about 69.4 per cent of the study population uses bike in the city, figure 5.3 shows that 71.8 per cent of the entire study population (not of bike users) are inexperienced while 23.5 per cent indicated that they could ride under worst conditions and 4.7 per cent was without response. Moreover, of these inexperienced cyclists, 43.5 per cent and 28.2 per cent are males and females respectively (figure 5.3). Expectedly, 17.6 and 5.9 per cent represent experienced males and female respectively, which is reflective of the distribution of our sample size (63.5 and 36.5 per cent male and female respectively) and not necessarily true in Bogota even though it has been observed that males and active population have the likelihood to endure difficult bicycle riding conditions.

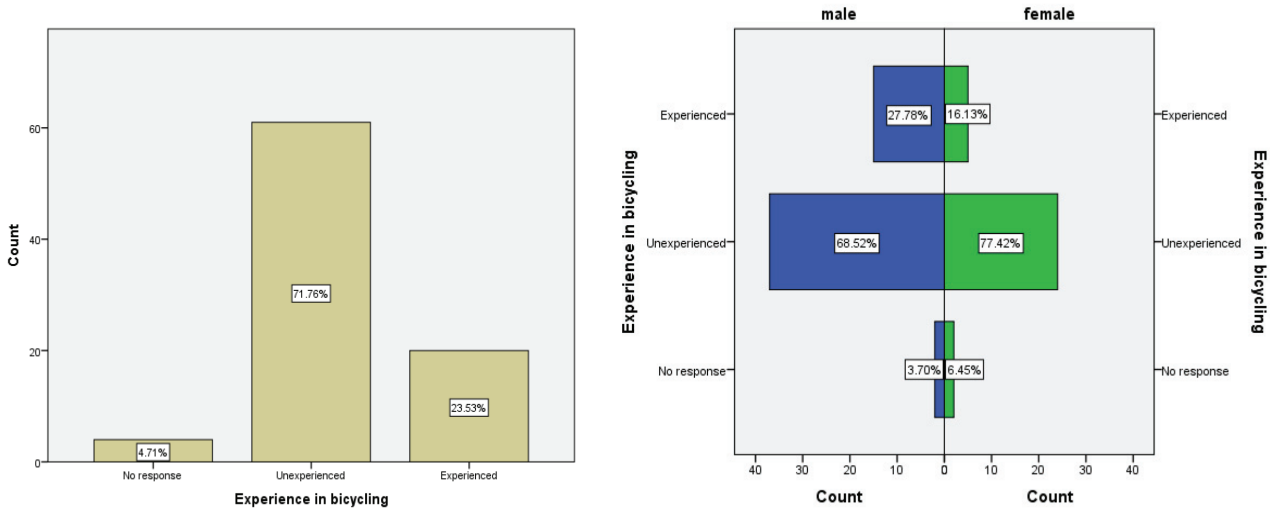


Figure 5.3 Bicycle riding experience of participants; and experience by age of participants

5.2. Perception bicycle level of service

A six-point rating system ranging from 1 as highly satisfied to 6 as highly dissatisfied was used to assess the LOS score for perceived level of satisfaction of participants. This was based on video clips of 16 sampled segments and 8 intersections whose choices were based on criteria discussed under methodology. These segment videos were produced to represent a wide range of physical, operational and geometric characteristics of the cicloruta such as width of cycle lane/track, separation from the curb lane, availability of trees/grasses/benches, vehicular volume and speed in adjacent arterial, pedestrian flow, and so on. A total of 2,040 scores were obtained for both segments and intersections by 85 participants across different variables that define in qualitative terms the level of satisfaction as viewed in the video. Segments constitute about 1,360 ratings while intersections constitute 680 (table 5.3). Data in the table shows that while average percentages for level of satisfaction in segments decreases downwards from highly satisfied to highly dissatisfied, the reverse is the case for average intersection rating.

A cross section of sampled segments for this study is shown in figure 5.4 and thus reveals different categorisation in terms of quality, land use and physical conditions of the cicloruta. Participants rated Calle 26 (Las Aquas-Av. El Dorado) with a high LOS score (table 5.4). It has a width of about 2.25-2.50m, looks more or less like a trail with trees and reasonably separated from the highway with barriers. Participants also considered the security advantage the location of this cicloruta provides, moreso that it is saperated from pedestrian use unlike many other ciclorutas. Major challenge of this cicloruta is the lack of access and egress since it is sandwiched between an 8-lane highways. Three samples were drawn from this cicloruta, including, cicloruta (bike path), ciclovia (Sunday bike lane) and tunnel. They all scored differently and therefore average score is obtained (1.71). Centro Internacional (Canal Salitre-Juan Amarillo-S) was also rated highly unlike Canal Arzobispo (Canal Salitre-Juan Amarillo-N), an average LOS score is also obtained (2.69). The high satisfaction level is not unexpected as the infrastructure is new and located around the CBD with potential for high use. The LOS rating of Canal Arzobispo reveals participants' expression of little satisfaction from the use of this cycle lane. Figure 5.4 shows an elevated (about 50cm) cycle lane located between an arterial and a deep gutter pan. Carrera 7 (KR 11-13-S) was given a high rating unlike Carrera 13 (KR 11-13-N), thus giving an average LOS of 3.03. In the same vein, Puente Avenida 68 Americas (NQS H/way (roadway) on the other hand, is a stretch that links two ciclorutas, calle 13 and the Americas (collectively called NQS). This is not a cicloruta, but was deliberately

5.3 Response satisfaction rating for 16 road segments and 8 intersections

Nominal scale	Ordinal scale	Segments (Count & %)	Intersections (Count & %)	Total (Count & %)
1	Highly satisfied	326 (25.5)	1 (0.2)	327
2	Moderately satisfied	352 (27.5)	31 (4.8)	383
3	A little satisfied	235 (18.4)	102 (15.9)	337
4	A little dissatisfied	126 (9.9)	145 (22.7)	272
5	Moderately dissatisfied	129 (10.1)	181 (28.3)	310
6	Highly dissatisfied	110 (8.6)	180 (28.1)	290
	Missing		40 (5.9)	
Total		1360 (100)	680 (100)	2040

5.4 Distribution of segments that constitute study area and their average perception LOS scores

s/n	Segment (survey) name	Cicloruta name	No of seg	Av.LOS	Description
1	Calle 13	Av. Jimenez-Americas	18	4.27	AD
2	Carrera 7	KR 11-13	1	1.79	HS
3	Cicloruta Av. El Dorado	Las Aquas-Av. El Dorado (tunel)	13	2.01	HS
4	Calle 26	Las Aquas -Av. El Dorado (ruta)	13	1.43	HS
5	Calle 26 (ciclovia)	Las Aquas -Av. El Dorado (c-via)	13	1.71	HS
6	Canal Arzobispo	Canal Salitre-Juan Amarillo (n)	17	3.27	MS
7	Paerque Simon Boliva	Simon Boliva (trails)	13	1.87	HS
8	Calle 53	Cl 100-Av 68 (trail)	27	1.7	HS
9	Carrera 50 (ciclocarril)	Avenida Boyaca	38	3.77	MS
10	Carrera 13	KR 11-13 (norte)	18	4.11	AD
11	Centro Internacional	Canal Salitre-Juan Amarillo (s)	17	2.1	MS
12	Avenida Pepe Seirra	Avenida Pepe Seirra	3	2.0	HS
13	Alameda El Porvenir	Av. Tintal Porvenir	19	1.75	HS
14	Carrera 71d	Av. Agoberto Mejia	9	4.48	AD
15	Av. Americas Costado-N	NQS	23	2.63	MS
16	Puente Av. 68xAmericas	NQS H/way (roadway)	23	5.42	MD

included in the survey to expose the apparent dangers that cyclist are confronted with by the frequent cicloruta dead ends. An average LOS score 4.85 is obtained, having considered the rating of Avenida Americas Costado Norte (NQS).

Based on these perception ratings by participants, it was possible to extrapolate satisfaction across all 70 ciclorutas. This was done by comparing the basic infrastructure (physical) characteristics of sampled segments with other ciclorutas. These physical characteristics include width of cycle lane, location of lane, kind (lane, track or trail) and urban place (CBD as urban or other urban). Measurements, physical observations during field work and relevant street maps provided the author useful insight into major characteristics of ciclorutas (see author's field work trajectory in figure 4.3). Since there was no rating as highly dissatisfied, all non-constructed ciclorutas were assigned the rating. This is also based on author's experience (see figure 4.6) as the satisfaction level from these ciclorutas is obviously the lowest. Table 5.5 shows these categories based on level of satisfaction, which then enables us to apply model 1 on the data set in an ArcGIS environment. A constant value of 1 is used when segment satisfy variable best condition and 1.5 when it does not. This is based on the 6 point likert where the lowest value represents the best condition and highest value otherwise (in this case 1, 1.1…., 1.5). This helps to give individual segment an LOS score based on its characteristics, before averages at cicloruta level are solved.

In terms of intersections, three classes were identified where average LOS for multiple, 4 and 3legs intersections included 4.6, 4.5, and 4.4 respectively (table 5.6). The intersection level of service rating of

5.5 Ciclorutas according to level of satisfaction

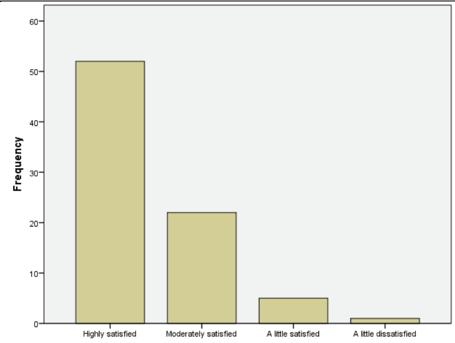
HS	MS	AS
LAS AQUAS-AV.EL DORADO	CANAL SALITRE-JUAN AMARILLO	KR 11-13
CL 100-AV 68 (TRAIL)	AV 1 DE MAYO	AV FERNANDO MAZUERA
AV. TINTAL PORVENIR	AV. CL 6	AV FERROCARRIL DEL SUR
SIMON BOLIVA (TRAILS)	AVENIDA BOYACA	AV. SUBA
AVENIDA PEPE SEIRRA	AVENIDA CALLE 127	PARQUE TOBERÍN
AC 63 (AV. JOSE CELESTINO MUTIS)	BANDERAS - PORVENIR	PARQUE VILLA ALSACIA
AUTOPISTA NORTE	CANAL MOLINOS	RIO NEGRO CASTELLANA
AV SAN BERNARDINO	CANAL RÍO FUCHA	
AV. CL 134	CIUDAD SALITRE	
AVENIDA CIUDAD DE CALI	CL 170	
BANDERAS - PATIOBONITO	CL 48 R SUR	
CANAL TORCA - AV 19	CL 6	
CIRCUITO TUNAL	CL 80	
ENGATIVÁ - HUMEDAL JABOQUE	HOSPITAL SAN CARLOS	
MEISSEN	PARQUE EL TIMIZA	
PARQUE TERCER MILENIO	PARQUE LA AURORA II	
RÍO BOGOTÁ - LA GAITANA	AV KR 9 - AV CL 92	
SIMÓN BOLÍVAR (CIRCUITO)		
AV. VILLAVICENCIO		
AD	**MD**	**HD**
AV. JIMENEZ-AMERICAS	NQS	ACJAS
	AV. AGOBERTO MEJIA	AEROPUERTO EL DORADO
	LA CANDELARIA	AV BOSA
	PARQUE CL 42 SUR KR 72I	AV CL 19
		AV DE LA CONSTITUCIËN
		AV DE LA HORTUA
		AV EL CENTENARIO
		AV EL TABOR
		AV FUCHA
		AV GENERAL SANTANDER
		AV JORGE GAITÁN CORTÉS
		AV LA VICTORIA
		AV LAS AMÉRICAS
		AV LONGITUDINAL DE OCCIDENTE
		AV MANUEL CEPEDA VARGAS
		AV MARISCAL SUCRE
		AV. CIRCUNVALAR - AV. LOS CERROS
		AV. LAUREANO GÓMEZ
		AVENIDA CARACAS
		AVENIDA DEL SALITRE
		LA FLORIDA
		PARQUE LOS FUNDADORES
		RIO TUNJUELO
Total		**71**

5.6 Average score of sample lane intersections of the cicloruta

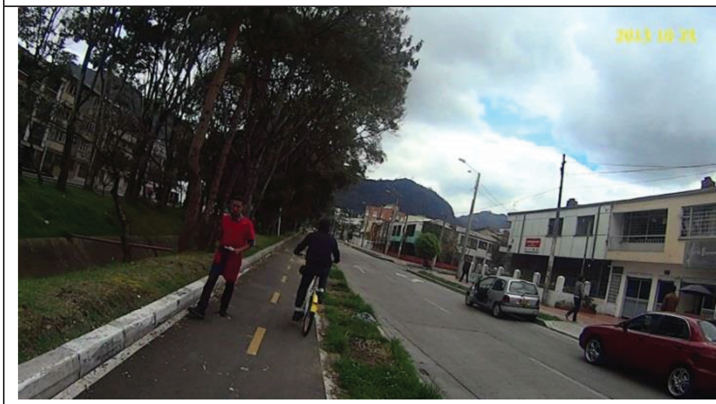
S/n	Sample intersection	Average score	class	Class average	%	Description
1	Carrera 80 by Calle 38c (M-L)	4.16	3	4.64	37.5	Moderately dissatisfied
2	Carrera 7 by Calle 19 (M-L)	4.2				
3	Carrera 71d by Calle 3s (M-L)	4.21				
4	Carrera 13 by Calle 54 (4-L)	4.47	4	4.50	37.5	Moderately dissatisfied
5	Carrera 13 by Calle 34 (4-L)	4.52				
6	Carrera 24 by Calle 53 (4-L)	4.65				
7	Carrera 13 by Calle 51 (T-L)	4.88	5	4.44	25	Moderately dissatisfied
8	Carrera 19 by Calle 13 (T-L)	4.0				

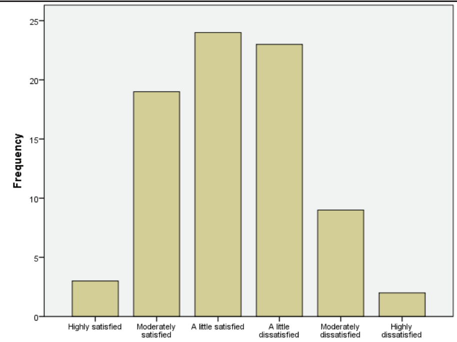
participants shows that average satisfaction of intersection is low. This however suggests that an average intersection in the study area possess similar challenges to cyclists whereas safety and security levels may vary across different neighbourhoods. Figure 5.5 presents a graphic illustration of some of these intersections and their accompanying average perception LOS scores. Field observations also revealed that some segments were not defined necessarily by intersection but by other factors such as a complete cycle

Pictures of sampled segments in study area	**Histogram showing rating of particants' perception (satisfaction)**

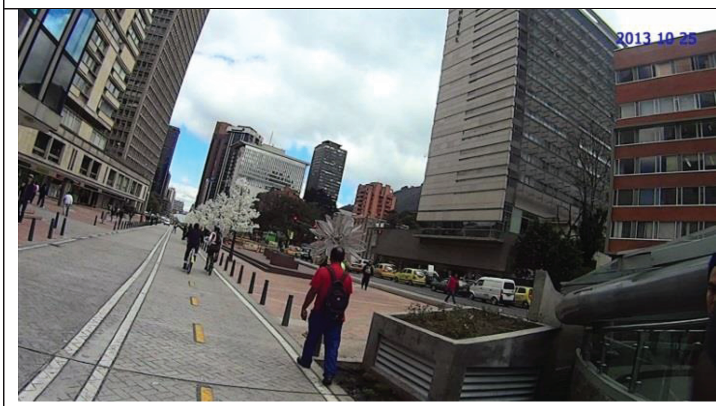


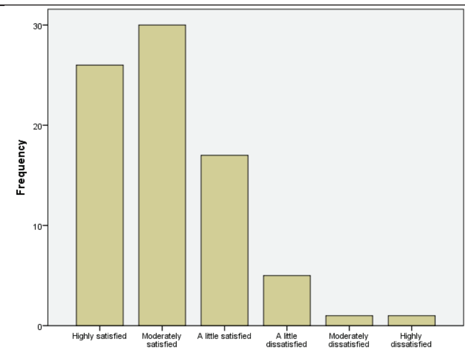
Calle 26 with an average perception LOS=1.4



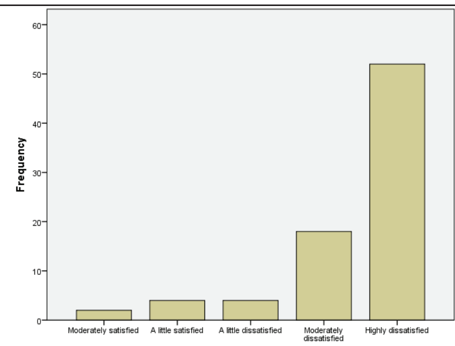


Canal Arzobispo with an average of LOS=3.3





Centro Internacional with average LOS=2.1



Puente Avenida 68 Americas with LOS=5.3

Figure 5.4 Some sampled segments of the cicloruta

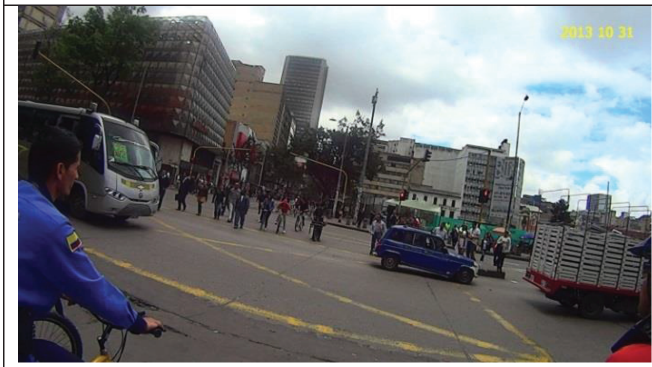
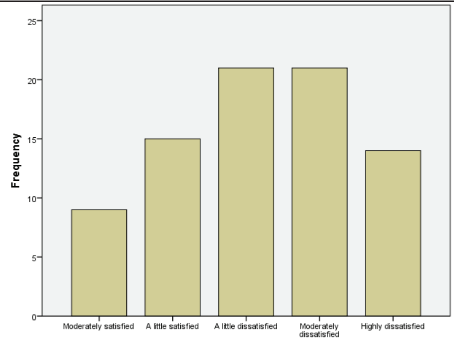
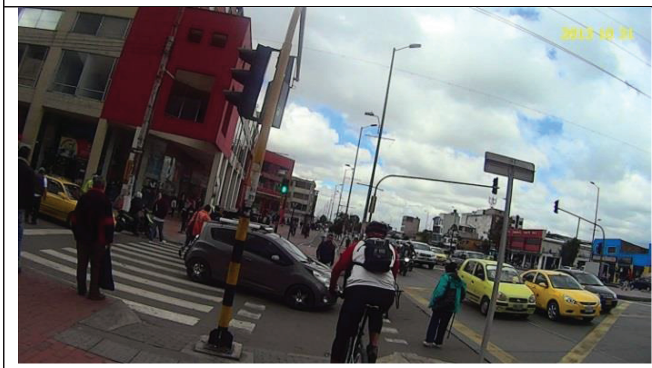
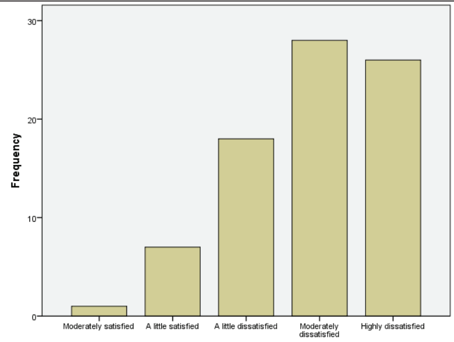
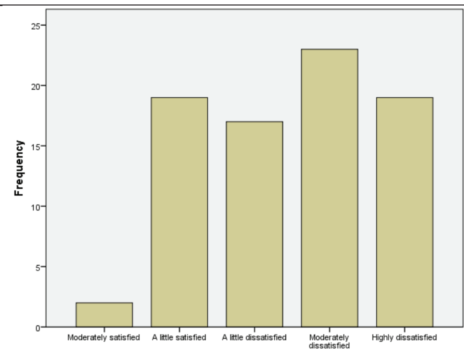
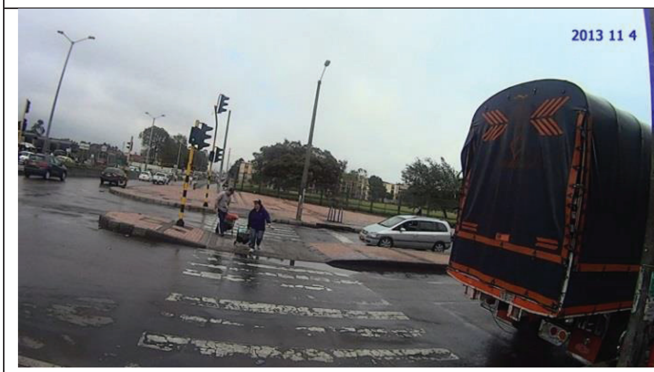
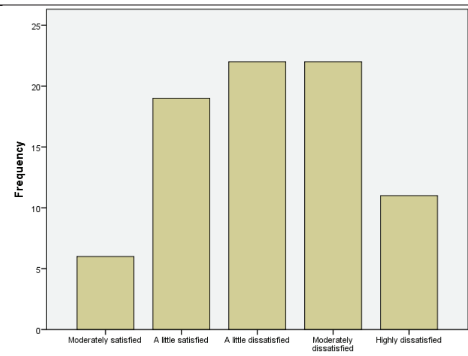
Pictures of sampled intersections in study area	Histogram rating of particants' perception
	 Carrera 7 x Calle 19 (4-lane) with LOS=4.2
	 Carrera 19 x Calle 13 with an average LOS=4.9
	 Carrera 13 x Calle 34 with LOS=4.5
	 Carrera 80 x Calle 38c with LOS=4.2

Figure 5.5 Examples of intersections used as study samples

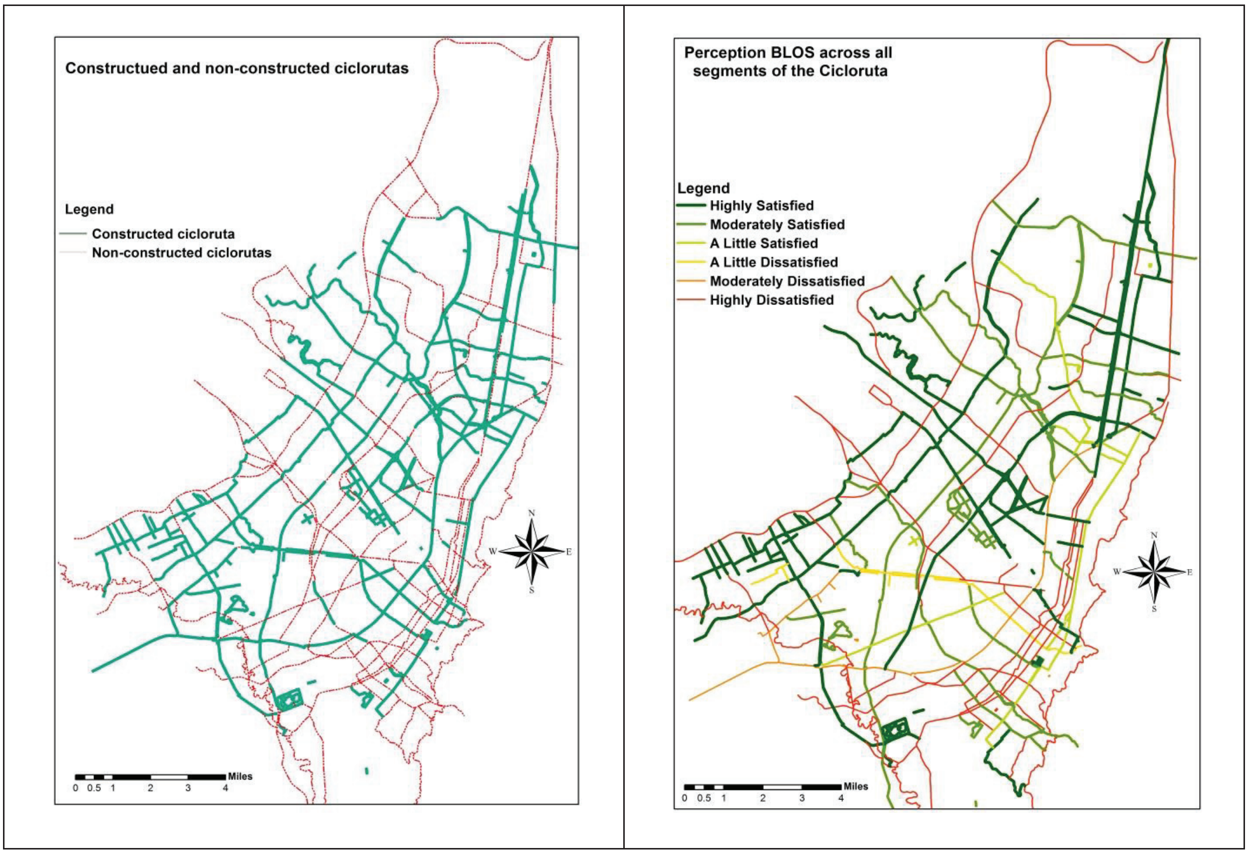


Figure 5.6 Constructed and non-constructed ciclorutas; perception BLOS across the study area

of trail, termination of constructed cicloruta, and so on. The result may not be unconnected with the fact that survey was mostly during peak period and the level of dissatisfaction participants already have about intersections prior to the survey. Similar approach in segment BLOS estimation is adopted for intersection BLOS estimation. Based on our video survey and extrapolation of data across the study area we thus obtain our perception BLOS as shown in figure 5.6. This enables us to substitute satisfaction levels in the equation to estimate our BLOS.

5.3. Estimation results of model 1

Preliminary investigations showed a strong correlation between dependent variable and independent variables at 0.05 level of significance. About 1,360 ratings were used in the estimation process. The deviance (1.085) and Pearson Chi-Square (2.309) with 1,635 degree of freedom at 0.05 level of significance shows that our model provides a better fit of the data. This is because deviance is close to the value of 1 and shows a low difference from Pearson, therefore, the model is a good fit. The Omnibus test in our model compares the intercept only model to the fitted model. Likelihood Ratio Chi-Square value of .000 reveals that the fitted model is significantly different from the intercept only model, thus suggesting that the random parameter model provides a superior statistical fit than traditional random effects with over 99.99% confidence. Using equation 4.5, we therefore estimated parameters for each observation or variable. This result shows that parameters vary across participants. Results of the random parameters ordered probit model are shown in table 5.7. They were obtained from 1,360 ratings from 16 segment videos rated by 85 participants. Positive parameters in table 5.7 means that unit change would leads to a higher probability that LOS F will be perceived, while negative parameters on the other hand means unit change in the variable leads to a higher probability that LOS A will be perceived by participants. The validity of these estimates to confirm they did not occur by chance or result of sample error was tested at

5.7 Random parameters ordered probit model of bicyclists perceived level of service (segments)

Variable description	B (Parameter est.)	Exp (B) (Variance of est.)	Wald Chi-Square	Sig.
Threshold 1	.187	1.205	1.925	.165
Threshold 2	1.024	2.784	55.647	.000
Threshold 3	1.601	4.957	129.666	.000
Threshold 4	1.973	7.189	190.072	.000
Threshold 5	2.435	11.416	279.138	.000
Threshold 6	2.955	19.196	395.655	.000
BLW (1=<2m ;0 >2m=)	-.126	.882	.487	.485
WOL (1=<10ft; 0=>10ft)	-.451	.637	.189	.663
PCL (1=Good; 0=otherwise)	-.114	.893	.012	.914
SPS (1=present; 0=otherwise)	.605	1.831	29.946	.000
NTL (1≤2 lanes; 0=otherwise)	.726	2.066	.486	.486
VS (1≤30mi/hr; 0=otherwise)	.717	2.049	49.859	.000
MTV (≤600cars/15min; 0=otherwise)	-.381	.683	10.976	.001
CWP (1=≤10 conflicts; 0=otherwise)	1.173	3.231	156.831	.000
TB(1=trees/benches/grasses; 0=otherwise)	-.038	.963	.105	.746
DAYLIGHT (1=daytime; 0=otherwise)	.473	1.605	9.700	.002
RAIN (1=Rain; 0=otherwise)	-.026	.974	.180	.671
RIDE (1=Ride in city; 0=otherwise)	.118	1.125	3.466	.936
EXPERIENCE (1=Yes; 0=otherwise)	.005	1.005	.006	.063
GENDER (1=Male; 0=Female)	-.262	.769	18.219	.000
AGE	.473	1.604	27.064	.000
Number of observations	1,360			
Log likelihood chi-square	4.55.322 (.000)			
Deviance	1773.484 (1.085)			
Scaled Deviance	1773.484			
Pearson Chi-Square	3774.940 (2.309)			
Scaled Pearson Chi-Square	3774.940			
Log likelihood	-1257.919			
Akaike's Information Criteria (AIC)	2557.839			
Finite Sample Corrected AIC (AICC)	2558.529			
Bayesian Information Criteria (BIC)	2667.359			
Consistent AIC (CAIC)	2688.359			

Dependent variable responses are integers ranging from 1-6 for A-F (highly satisfied-highly-dissatisfied)

0.05 level of significance. Some of the parameters found to vary across respondents (random) included side path separation (SPS), vehicle speed (VS), motorised traffic volume, motorised traffic volume (MTV), conflicts with pedestrian (CWP), daylight, gender, and age. They are normally distributed with standard deviation significantly different from zero. We therefore conclude that they provide a more superior statistical fit to the data even though other variables are considered for random parameters, they provide inferior statistical fit. Akaike's Information Criteria (AIC), Finite Sample Corrected AIC (AICC) and Bayesian Information Criteria (BIC) are useful statistics to compare models. Since we adopted the interaction approach in our model estimate, it is therefore not relevant to do any comparison.

Recall that our satisfaction levels ranges from 1 for highly satisfied to 6 for highly dissatisfied. Therefore in our estimated parameters (table 5.7), the probability to rate or derive a HS level increases the ordered logit by 0.187 or is exponentiated at 1.205 less likely than other levels of satisfaction. The same cannot be said about other levels of satisfaction as there are statistically significant at 0.05 confidence interval, where AS, MS, MD, AD and HD are respectively exponentiated at 2.789, 4.957, 7.189, 11.416 and 19.196 less likely than other levels of satisfaction. We therefore develop our estimation model using our parameters and factors that are statistically superior in their contribution to the level of satisfaction rating (box 1). About 15 variables comprising of 13 factors and 2 covariates were initially used in the estimation while only 7

Box 5.1: Model 1

$$\text{BLOS}_{\text{segment}} = \left\{\begin{array}{l} \text{HS} = 0.187 \\ \text{MS} = 1.024 \\ \text{AS} = 1.601 \\ \text{AD} = 1.973 \\ \text{MD} = 2.435 \\ \text{HD} = 2.955 \end{array}\right\} + 0.605.\mathbf{SPS} + 0.717.\mathbf{VS} - 0.381.\mathbf{MTV} + 1.173.\mathbf{CWP}$$

where
HS = highly satisfied;
MS = moderately satisfied;
AS = a little satisfied;
AD = a little dissatisfied;
MD = moderately dissatisfied;
HD = highly dissatisfied;
SPS = side path separation;
VS = vehicle speed;
MTV = motorised through volume; and
CWP = conflicts with pedestrian and other cyclists.

were statistically superior to fit the model at 0.05 confidence interval (table 5.7). This includes 4 measurement variables (SPS, VS, MTV and CWP), 1 environmental variable (daylight), and 2 socio-economic variables (age and gender). Hybrid parameter estimation with a Maximum Fisher Scoring Iterations at 1 was carried out using Wald statistics. In estimating our model therefore, only the 4 statistically significant variables were used. These include: side path separation (SPS), vehicle speed (VS), motorised traffic volume (MTV), and conflicts with pedestrian (CWP). Gender and age showed statistical significance but could not be used in the model as there are used as covariate in the estimation process.

Daylight however statistically significant could not be used as it is an environmental variable whose changes are obvious, day and night. This result however underscore the preferred time of cycling in the study area which may not be unconnected with safety issues. This result does not imply that they are not other important factors in considering the level of participants' satisfaction as marginal effects has proved otherwise. In figure 5.7 results of the BLOS estimation at segment and cicloruta (facility) level are displayed. Not much difference can be observed since scores and aggregated to grades. Most ciclorutas adjoin the Avenida El Dorado in the west just as others in the north and south west are revealed to score B grade. No cicloruta secured an 'A' grade in both results, which may not necessarily mean that no cyclist derives highest satisfaction level from use of specific segments of the cicloruta, except that averages are used in the estimate.

In other to effectively apply equations 4.2 and 4.3 to estimate our predicted probabilities, initial logit scores for each category of response as well as each variable for all participants was predicted using the following scripts in SPSS (also see appendix):

*COMPUTE Predicted_LogitHS = 0.187 + (-.126*BLW) + (-.451*WOL) + (-.114*PCL) + (.605*SPS) +(.726*NTL) + (.717*VS) +(-.381*MTV) + (1.173*CWP) + (-.038*TB) + (.473*DAYLIGHT) + (-.026*RAIN) + (.118*RIDE) + (.005*EXPERIENCE) + (-.262*GENDER) + (.473*AGE).*
EXECUTE.
:
*COMPUTE Predicted_LogitHD = 2.955 + (-.126*BLW) + (-.451*WOL) + (-.114*PCL) + (.605*SPS) +(.726*NTL) + (.717*VS) +(-.381*MTV) + (1.173*CWP) + (-.038*TB) + (.473*DAYLIGHT) + (-.026*RAIN) + (.118*RIDE) + (.005*EXPERIENCE) + (-.262*GENDER) + (.473*AGE).*
EXECUTE.

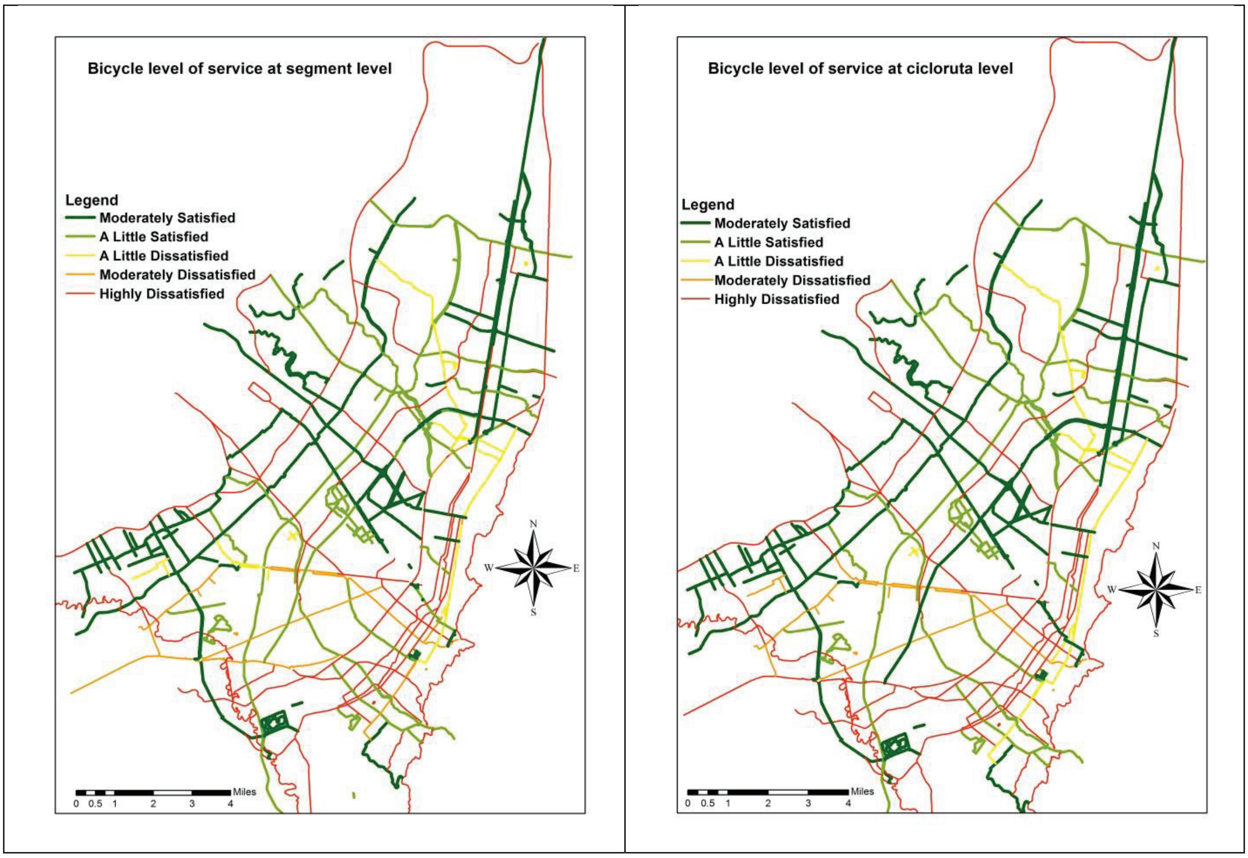


Figure 5.7 Estimated BLOS at both segment and cicloruta levels

And,
*COMPUTE Predicted_LogitHS_BLW = 0.187 + (-.126*BLW).*
EXECUTE.
:
*COMPUTE Predicted_LogitHD_AGE = 2.955 + (.473*AGE).*
EXECUTE.

This initial procedure of the computation of predicted logit produced a sigmoid-curve scatter plot across all BLOS category responses which is somewhat like the s-shape curve in logistic regression (figure 5.8). It reveals satisfaction level of participants based on unit changes in our all variables combined. The outcome of predicted probabilities of each discrete variable across all LOS response categories given one unit change in variable is discussed in details in chapter 6. Predicted probabilities were estimated based on the principles contained in equation 4.3. The probabilities are observed to change as unit changes are recorded about characteristics (x), this is however the force of the regression model. Haven predicted the logit, we therefore predict the probability of changes in category satisfaction resulting from unit changes in variable. We substitute equation 4.3 using Euler's number, 2.7 1828 1828 thus:

COMPUTE Predicted_ProbabiltiesMS_BLW =
*(2.718281828**Predicted_LogitMS_BLW)/(1+2.718281828**Predicted_LogitMS_BLW) - 0.2355.*
EXECUTE.
:
COMPUTE Predicted_ProbabiltiesHD_AGE =
*(2.718281828**Predicted_LogitHD_AGE)/(1+2.718281828**Predicted_LogitHD_AGE).*
EXECUTE.

To validate the outcome of our BLOS segment model, we compared the perception ratings with estimated scores as shown in figure 5.8. It reveals similar pattern of rating except that the estimated scores do not produce an 'A' rating. In an ideal situation for Bogota cicloruta, the model seems tenable for evaluation of the cicloruta infrastructure.

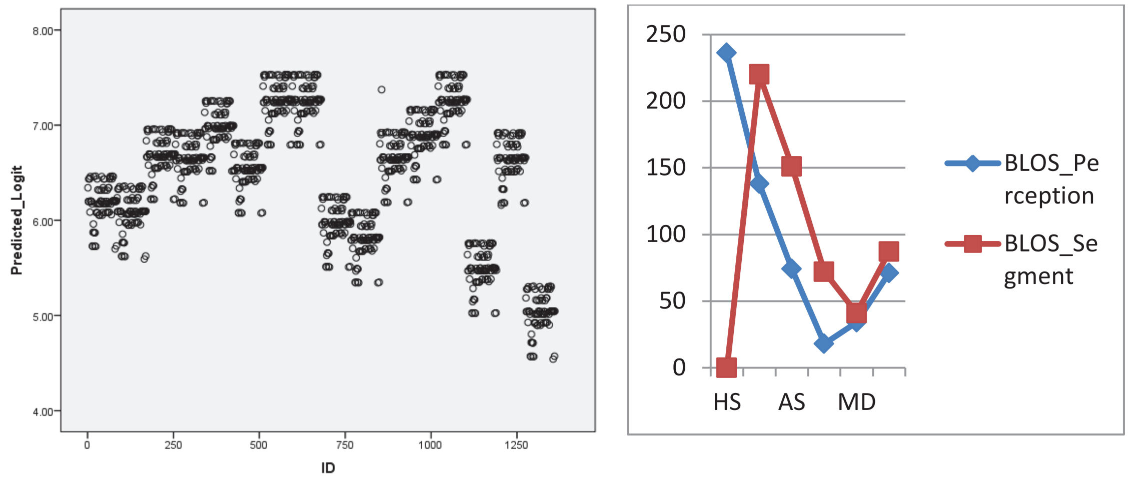


Figure 5.8 Predicted logit across all responses; and comparison between rated satisfaction and estimated scores

5.4. Estimation results of model 2

Similar statistical procedure for estimating segment BLOS was adopted for intersection BLOS. About 680 perceptions of satisfaction ratings from 85 participants were used in the estimation of this model. Other geometry, physical and traffic operational characteristics were also used. They included volume of cyclists, conflicts with other cyclists and pedestrian at intersections, road signs/markings at intersections, total intersection legs, and crossing width of intersections (table 5.9). Experience and bicycle ridership in the city by participants were used as covariates in the estimation process. An insignificant difference in deviance and Pearson Chi-Square (0.044) and Log likelihood chi-square of .000 suggests that our model provides a better fit of the data. Therefore based on the significance level of our variables, selection is made of those with statistically superior contribution to our model and thus estimates derived (box 2).

Box 5.2: Model 2

$$BLOS_{intersection} = \left\{ \begin{array}{l} HS = -2.960 \\ MS = -1.568 \\ AS = -0.680 \\ AD = 0.017 \\ MD = 0.792 \\ HD = 2.024 \end{array} \right\} + 1.116.\mathbf{VOC} + 1.048.\mathbf{CPC} - 0.365.\mathbf{TIL}$$

where
VOC = volume of cyclists;
CPC = conflicts with pedestrian and other cyclists; and
TIL = total intersection legs
HS, MS, AS, AD, MD, and HD are as previously defined.

Since level of experience is subjective based on feeling and understanding of the question on this variable, it was decided to exclude it from the model just as gender that was used as covariate, even though they were statistically significant at a confidence interval of 0.05. We have earlier observed our perception intersection BLOS as 'E' for all three kinds of intersections (table 5.6). The model in box 5.2 is used in ArcGIS to demonstrate estimation of intersection BLOS. Earlier results of parameter estimates (table 5.9) reveal three variables as making superior contribution to the model using 0.05 level of significance. They include volume of cyclists, conflicts with pedestrian and other cyclists; and total intersection legs.

5.8 Random parameters ordered probit model of bicyclists perceived level of service (intersections)

Variable description	B (Parameter est.)	Exp (B) (Variance of est.)	Wald Chi-Square	Sig.
Threshold 1	-2.960	0.052	53.719	.000
Threshold 2	-1.568	0.209	39.848	.000
Threshold 3	-0.680	0.506	8.110	.004
Threshold 4	0.017	1.017	0.005	.944
Threshold 5	0.792	2.208	10.955	.001
Threshold 6	2.024	7.565	65.240	.000
VOC (1=≥2 cyclists crossing;0=otherwise)	1.116	3.053	46.354	.000
CPC (1=≤3; 0=otherwise)	1.048	2.851	59.851	.000
RSM (1=RSM present; 0=otherwise)	0.079	1.082	0.123	.726
TIL (1=3legs; 0=otherwise)	-0.365	0.694	5.221	.022
CWI (1=≤12 feet; 0=otherwise)	-0.111	0.895	0.291	.590
EXPERIENCE (1=Yes; 0=otherwise)	-0.465	0.628	25.934	.000
RIDE (1=Ride in city; 0=otherwise)	0.160	1.174	3.293	.070
AGE	0.022	1.022	0.033	.856
GENDER (1=Male; 0=Female)	-0.534	0.586	38.093	.000
Number of observations	860			
Log likelihood chi-square	131.619 (.000)			
Deviance	371.496 (.820)			
Scaled Deviance	371.496			
Pearson Chi-Square	351.348 (.776)			
Scaled Pearson Chi-Square	351.348			
Log likelihood	-363.679			
Akaike's Information Criteria (AIC)	757.358			
Finite Sample Corrected AIC (AICC)	758.081			
Bayesian Information Criteria (BIC)	825.189			
Consistent AIC (CAIC)	840.189			

Dependent variable responses are integers ranging from 1-6 for A-F (highly satisfied-highly-dissatisfied)

Volume of cyclists was observation measurement of the number of other cyclists crossing in the same direction during field data collection. No specific consideration was given to either peak or off-peak, however data was collected during all traffic periods. Where 2 or more cyclists crosses an intersection, a value of 1 is assigned since this is seen as measure of safety feeling, and zero when only one cyclist crosses at a given time. This time is called the 'effective green time to signal cycle length ratio' defined as 'composed of the sum of the time of the green (G), yellow (Y) and all red (R) ball signal indications minus the sum of the start-up and clearance lost times' (HCM, 2012). Collection of this data was subjective to the extent of the scope of this research while future research can measure all effective green time at every signalised intersection.

Conflicts with other cyclists and pedestrian is also an observed data collected as author and field assistants rode across different segments and intersection of the network. Several conflicts were observed at many intersections around the CBD and other high density residential areas in the south. Based on author's experience therefore, a value of 1 is coded to conflicts of 3 or less and zero if more than 3. Whereas presence of more cyclists may increase the feeling of safety amongst cyclists, crossing an intersection at opposite direction with pedestrian and cyclists alike causes a lot of accidents and thus dissatisfaction.

Total intersection legs is a measure of the number of through lanes in an intersection. It also correlates strongly with width of intersection. It was statistically more superior in its contribution than crossing width itself perhaps due to the nature of intersection design in Bogota (Figueira, Ehrgott, & Greco). Design does not incorporate cycling round a roundabout to adjoining segment, rather the use of pedestrian cross over (Figueira et al.). Where intersection has three crossing legs (T-junction), we assign a value of 1, otherwise zero. This to an extent is subjective as data was collected from observation and relevant street maps. It was difficult to define which intersection is 3, 4 or multiple legs since all motorised and non-motorised modes affect cycling.

In other to demonstrate our methodology, we sampled 33 intersections from 3 ciclorutas namely Avenida Boyoca, Avenida Ciudad De Cali and Las Aquas-Av El Dorado. Model 2 is used in ArcGIS to estimate both intersection BLOS and facility BLOS in accordance with equations 4.7 and 4.8. Average intersection scores for all three ciclorutas included 3.0912, 3.1759 and 2.9325 respectively. Figure 5.9 shows intersection BLOS in the cicloruta network and road network (major arterials). The effectiveness of this methodology is expressed in figure 5.10 with sampled segments showing level of satisfaction derived from use of every intersection across a give path. The second map in the figure reveals BLOS score at facility level. This is given as average BLOS plus Average intersection BLOS divided by two (equation 4.8). Avenida Boyoca with AvBLOS score of 3.3492 has $BLOS_{facility}$ of 3.2202 equivalents to grade 'C. Avenida Ciudad De Cali on the other hand with 2.33 AvBLOS has 2.7529 $BLOS_{facility}$ or 'C' grade. This underscores the weakness of the grading system as this cicloruta is only 0.0529 points away from its earlier 'B' grade. Moreover, Las Aquas-Av El Dorado also scored 'C' grade or 2.7616 $BLOS_{facility}$ from its earlier AvBLOS score of 2.5907.

Some earlier methodologies incorporated right turn through traffic and left turn opposite traffic. Other variables include specific design of intersections and length of segments between intersections. The scope of this study could not consider these variables in the model more so that some including operational variables are already considered in segment BLOS. This methodology is therefore confirmed to be effective in view of the complex nature of intersections in the study area, whose design is considered not safe for cycling in many parts of the city.

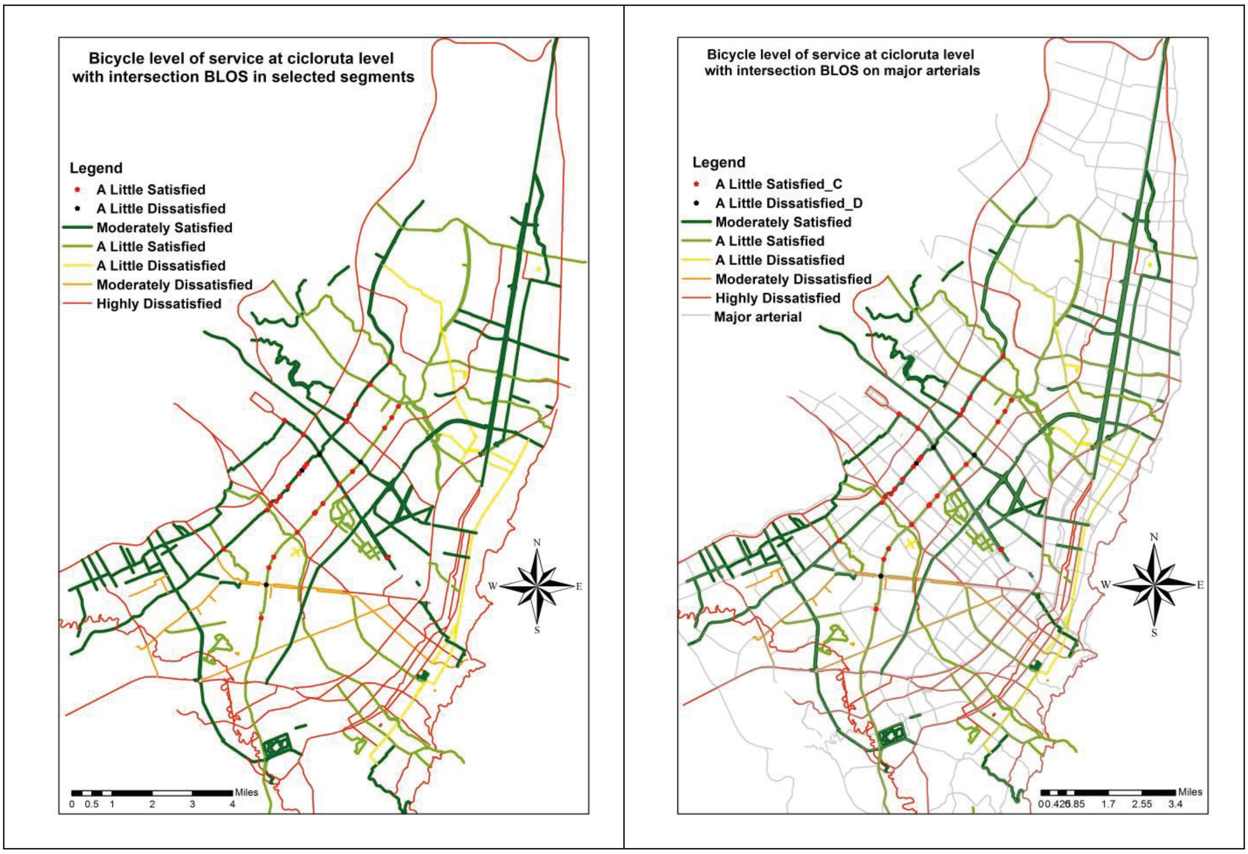


Figure 5.9 Intersection BLOS in cicloruta network; and in road network across the study area

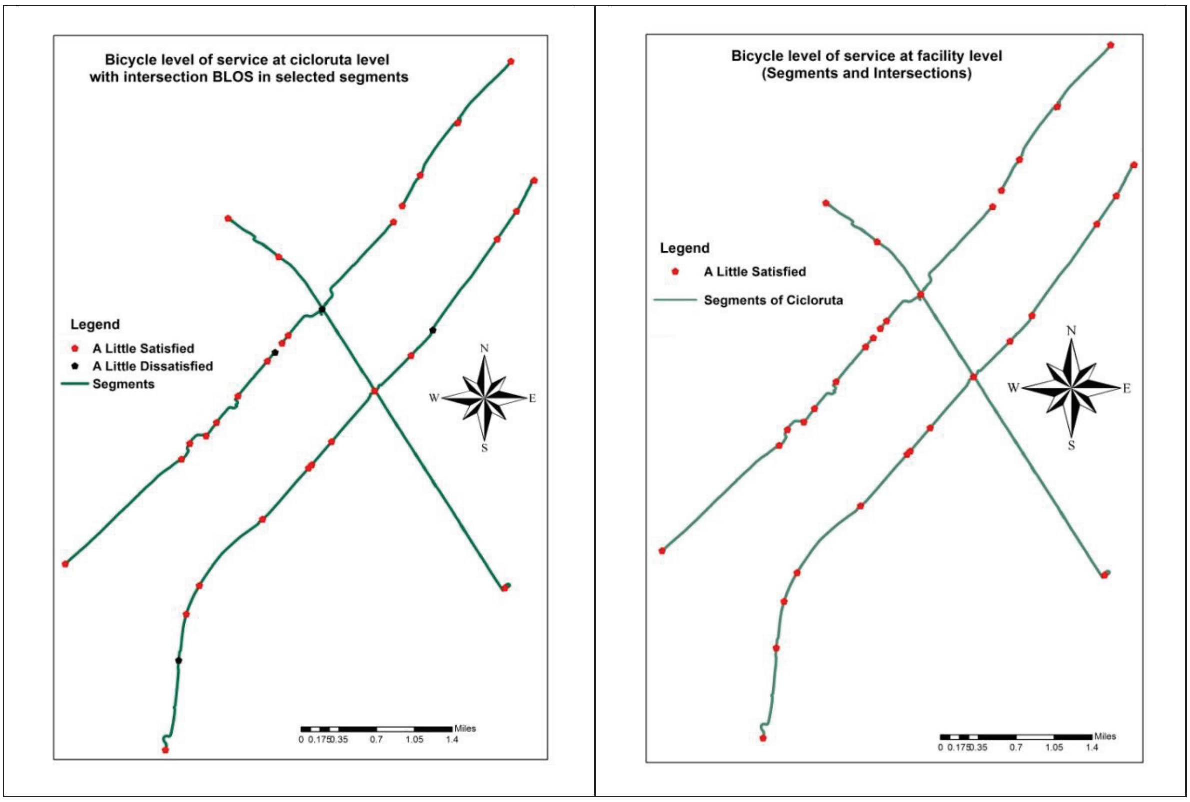


Figure 5.10 Intersection BLOS at segment level; and BLOSfacility for sampled streets

6. DISCUSSION OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

This chapter focuses on the findings of the research and compares them with earlier researches on the subject matter. Fundamental to these findings is the development of a methodology leading to model formulation for the estimation of BLOS in Bogota. This is discussed along methodological approaches adopted by this research in comparison to others and results of findings both for BLOS (segment and intersection). Concluding remarks and recommendations were also presented in this chapter.

6.1. Discussion of findings

Major findings of this research included the estimation of $BLOS_{segment}$ models using parameter estimates for satisfaction levels and coefficients for side path separation (0.605.**SPS**), vehicle speed (0.717.**VS)**, motorised through volume (– 0.381.**MTV**) and conflicts with pedestrian and other cyclists (1.173.**CWP)**. Most important is the determination of factors that affect bicyclists LOS and the ability to quantify these effects across different variables. Table 6.1 shows the marginal effects for participants perceived level of satisfaction in the model.

Bicycle lane width is obtained as 1 if it is greater than 2 meter wide, otherwise it is coded zero. This data was obtained from secondary sources and field work measurements carried out for validation. Estimation in table 6.1 shows that a unit increase in bike lane would increase participants' perceived satisfaction such that the probability of becoming highly satisfied is 0.5192, higher than all other satisfaction levels. On the other hand, the probability for a highly dissatisfied rating from participants due to a unit change in width is lowest at 0.0739.

Curb lane (wide outside lane) was measured in terms of the class of arterial adjoining the segment. Generally, segments adjoining highway were scored zero since such roads are observed to be wider than 10 feet. Were the adjoining road is an arterial, the segment is awarded a score of 1. Since less width is score 1, therefore, any unit reduction in the width of curb lane would have the least probability for highly dissatisfied satisfaction level, while as expected the probability of highly satisfied is 0.4906 as the highest.

Pavement condition of bicycle lanes was observed to be generally satisfactory as many segments of the ciclorutas are second and third generation constructed in 2005 and 2010 respectively. This probably accounts for the non-statistical relevance of this important variable in the model. Good conditions observed by author were assigned a value of 1 and zero otherwise. However, the probability of a highly satisfied rating from a unit improvement in the quality of pavement is 0.5200 and decreases sharply to 0.0741 as highly dissatisfied. Subsequent models may have its contribution statistically validated depending on its overall quality across the network.

Side path separation is defined generally as physical separation of cicloruta from motorised arterial either by tress, grasses or raised shoulder. Where any of these exist, a value of 1 is assigned, zero otherwise. A unit improvement of this variable indicates a high (0.6447) probability value for a highly satisfied rating. The same cannot be said of highly dissatisfied as the probability score is low, 0.0739. Therefore, the more side path separation facilities are incorporated in the design of bicycle paths, the higher the probability for a high satisfaction rating from users. This is also consistent with the findings of (Jensen, 2007), that

6.1 Matrix of average marginal effects for the perceived LOS (segment) model

s/n	Variable	HS y=1	MS y=2	AS y=3	AD y=4	MD y=5	HD y=6
1	BLW	0.5192	0.4782	0.3222	0.1886	0.1343	0.0739
2	WOL	0.4906	0.4522	0.3020	0.1725	0.1228	0.0664
3	PCL	0.5200	0.4789	0.3228	0.1891	0.1347	0.0741
4	SPS	0.6447	0.4782	0.3872	0.1886	0.1680	0.0739
5	NTL	0.6197	0.5511	0.3728	0.2269	0.1604	0.0903
6	VS	0.6395	0.5650	0.3822	0.2339	0.1652	0.0933
7	MTV	0.4873	0.4501	0.3007	0.1716	0.1223	0.0661
8	CWP	0.7335	0.6234	0.4201	0.2616	0.1836	0.1046
9	TB	0.5395	0.4947	0.3342	0.1979	0.1408	0.0780
10	DAYLIGHT	0.6522	0.5765	0.3909	0.2409	0.1699	0.0963
11	RAIN	0.5442	0.4983	0.3369	0.2000	0.1422	0.0789
12	EXPERIENCE	0.5470	0.5157	0.3493	0.2094	0.1487	0.0831
13	RIDE	0.5668	0.5005	0.3385	0.2012	0.1431	0.0795
14	GENDER	0.5051	0.4660	0.3130	0.1814	0.1292	0.0706
15	AGE	0.6447	0.5711	0.3872	0.2379	0.1680	0.9662

the more separated bike paths are away from curb lanes and pedestrian walkway, the more likelihood for high satisfaction levels. Garrard et al. (2008) also used multinomial logistic regression statistics to examine the impact of gender on the use of cycle paths with different separation paths, and found out the preference of female cyclists to off-road paths over non-bicycle paths with an odd ratio of 1.43 at 0.05 confidence interval. They also observed female preference for off-road paths to cycle lanes with an odd ratio of 1.34.

Number of through lanes refers to the number of through lanes adjoining bicycle paths. One of the challenges of bicycle use in Bogota is the location of cycle paths in mainly arterials and highways. Interviewed users decry the non-continuity of paths especially in residential neighbourhoods as this according to them discourages home-based associated trips with the bicycle (figure 6.1). Many segments end abruptly with or without posted signs. Many ciclocarrils are also rated low as the level of safety owing to collision with motor cars is high (figure 6.1). Measurement of this variable was by use of relevant street maps and field work validation to assign a value of 1 to cycle paths with equal to or less than 2 adjoining motorised lanes, zero otherwise. Therefore, the location of cycle paths in motorised arterials of less than 2 through lanes predicts higher level by 0.6197 or 62 per cent and highest dissatisfaction with a low probability of 0.0903 or 1 per cent probability.

Vehicle speed highly correlates with number of through lanes. In most observed cases in the study area, the number of through lanes increases the speed and volume of traffic along that arterial or highway. However, there were not observed posted speed limits in the city. In view of the Highway Capacity Manual (2012) definition of vehicle speed as good in urban areas if equal to or less than 35 miles per hour and observed traffic conditions in the study area, we therefore defined good vehicle speed as 1 if less or equal 30 mi/hr and bad if greater, therefore zero value assigned. Expectedly, the highest probability score of 0.6395 predicts highest satisfaction for users and decreases progressively to 0.0933 for highly dissatisfied. The high correlation between these two variables may offer a valid explanation for the exclusion of one (NTL) in the model. This corroborates some of the findings in Jensen (2009), about the significant impact of speed on satisfaction level of bicyclists. In his model, speed had a coefficient of 0.000421. Other variables also considered in his model of similar contribution in our model include the 'width of buffer area between facility and drive lane on the nearest roadside (LBUF = -2.3895).

Figure 6.1 Typical ciclocarril been contested by cars other non-motorised mode; signage warning cyclists of segment termination

Motorised traffic volume was based on secondary data obtained from Movilidad (2013) traffic census. Based on estimated averages across the city network, a value of 1 is assigned to traffic volume of equal or less 600 cars/15mins, zero if greater. The probability that users would derive highest satisfaction level when motorised traffic volume is less than 600 cars/15mins is 0.4873. The impact of motorised traffic volume remains an important consideration for level of satisfaction for cyclist in view of vehicle-bicycle related accidents. A unit reduction in the volume of traffic has a low prediction for highly dissatisfied. However, this findings corroborates research results earlier carried out on the attractiveness of bicycle paths in Germany (Bohle, 2000).

Trees and benches provide important elements in any cycling network as they provide shade, aesthetics and a feeling of safety to cyclists. They were observed across the network and where they exist or the presence of a raised shoulder we assign a value of 1, otherwise zero is given. Many ciclocarrils (figure 6.1) were assigned value of zero owing to little difference the separation makes in the feeling safety among cyclists. A unit improvement in this variable strongly predicts highly satisfied (0.5395), whereas, highly dissatisfied is 0.0780.

Daylight, rain, experience, and ride all exhibits a strong probability for highly satisfied level of service. Cycling during the day for instance is desirable by cyclists than night cycling. Sample was drawn from a segment video filmed at night during a ciclopeaso event. In addition, daylight was assigned 1 and zero for night. The probability that cyclists will be highly satisfied cycling during the day is 0.6522 compared to 0.0963 for highly dissatisfied. Rain also records a greater probability for highly satisfied (0.5442) than for highly dissatisfied (0.0789). Higher riding experience also predicts the high perception of satisfaction (0.5668) than in-experienced cycling with 0.0831 probabilities for highly dissatisfied. This has a relationship with the confidence level of cyclist as a measure of their cycling experience. A measure of this experience was exhibited by members of Bogota Humana cycling agency that participated in some field surveys, as they could ride through perceived unsafe and un-built ciclorutas at such great speed that kept the author gasping for breath. In terms of gender, since male was coded 1 and female 0, the result therefore suggest that being a male increases the probabilities of higher satisfaction perception than female. The table 5.8 reveal 0.5051 highly satisfied probability rating and 0.0706 highly dissatisfied levels. An interesting result was obtained for age. The data was coded 1 for ages equal or less 35 years, zero otherwise obtained from participants. The probabilities decrease from 0.6447 for HS through 0.5711, 0.3872, 0.2379 and 0.1680 for MS, AS, AD, and MD respectively. The probabilities score for HD suddenly rose to 0.9662. This can be explained by an apparently large young age group 17-35 providing such a mix in perception of satisfaction that is difficult to predict. In most cases, younger population are less sensitive to level of satisfaction.

6.2. Comparison with other studies

The results of this study are relevant for comparison with three studies drawn from Europe, Asia and America. Jensen, 2007 developed a methodology to evaluate pedestrian and bicyclist level of service on roadway segments in Denmark using video data obtained from filming of segments, other geometry, physical and operational characteristics of traffic. Table 6.2 shows the variables that each one of these studies used. All studies defined variables that seem important or measurable in their study. For example, Jensen (2007) adopted and defined variables that satisfy the scope of his study and thus reflect the Danish local traffic and socio-cultural characteristics. On the other hand, Lowry, et al., adopted the HCM standards with some modifications, just as Kang, et al., (2012) developed and defined variables to satisfy assumption of their analytical method. This underscores the fact that there is no generally acceptable method for evaluating bicyclists' level of satisfaction. This is not unconnected with the subjective nature of the concept of satisfaction and different traffic characteristics in different cities. However, a closer look at table 6.2 reveals common variables across all four studies even though there are defined differently.

Different approaches are also adopted in the collection of these data. This is because not all traffic data is available in most cities just as the choice of data collection is dependent on scope, convenience and affordability. For example, Jensen used rated survey from video data in addition to measured traffic characteristics; Lowry, et al., used an already maintained data set of about 10 variables from the communities he sampled and validated data using sensitivity analysis; a six-point questionnaire was used to collect research data by Kang, el at., while this study employed the use of video data in combination of other measured and observed traffic characteristics.

All four studies in table 6.2 adopted a 6-point classification in the rating of satisfaction, ranging from 'A' for highly satisfied to 'F' for highly dissatisfied. However, different statistical approaches were adopted in the analysis of data. For instance, Jensen (2007) used ordinary generalised linear model set up in SAS software to estimate BLOS model in box 6.1. In his model, both interaction and main effects were used to evaluate the effect of variables on BLOS. His findings that many variables influence level of satisfaction of cyclists and specifically the presence of and width of cycling facilities corroborate earlier studies. This is also in line with the findings of this study that cycling is mostly carried out along the cicloruta network, the lack of which discourages the use of bicycle.

Lowry et al., on the other hand weighted 10 attributes as adjustment factors which they combined to produce the following equation in box 6.2. This equation produces scores which are then compared with HCM standards ranging from <2 as 'A' to >5 as 'F'. The choice of this measure/standard is the same with our study. This is because 6-pouint rating scale was adopted and all other variables defined as modifications from HCM to reflect local transport infrastructure circumstance of Bogota. Lowry et al., developed a methodology to validate which variable should be estimated more accurately in any given road class. For example, accurate estimates for the percentage of on-street parking and heavy vehicles is critical for estimating BLOS for arterials as the resulting LOS ranges from A-F; vehicle volumes for collector streets; while for local streets geometry accuracy may not be important given low traffic volume, since all perturbations produce A or B BLOS grade. An 'F' BLOS grade as expected for all arterials without bicycle path is corroborated by the findings of this study where all un-built ciclorutas scored 'F'.

Using ordinary least square regression, ordered logit and probit models and multinomial logit, Kang et al., developed three BLOS models for South Korean cities from user's perspectives. Models 1 estimated threshold values which were compared with HCM standard ranging from ≤0 for 'A' to >2.57 for 'F' score. In this model, their results revealed that 'the bicycle road width, the total number of vehicle lanes on the approach to the intersection, the number of access and egress points on the bicycle road corridor, 6.2 Variables used in different studies

Jensen, 2007	Lowry, et al. 2012	Kang, et al. 2012	Present study 2014
Average annual daily traffic (AADT)=	Width of lane 12	Bicycle rd width 1.3-3.5m	BLW (1=<2m ;0 >2m=)
500 to 30,000 on urban roads and	Width of bike lane 5	Sidewalk width 0-8.5m	WOL (1=<10ft; 0=>10ft)
1,500 to 13,000 on rural roads;	Width of shoulder 9.5	Bicycle rd type 0-1	PCL (1=Good; 0=otherwise)
Motorized traffic per 40 s =	ppk_onstreet parking 0.2	Bicycle volume 1-72	SPS (1=present; 0=otherwise)
0 to 31 on urban roads and	Vehicle traffic vol. 940	Pedestrian volume 0-148	NTL (1≤2 lanes; 0=otherwise)
1 to 15 on rural roads;	SR_vehicle speed 33	No. of encounters 0-100	VS (1≤30mi/hr; 0=otherwise)
Average speed of motor vehicles =	Phv_%heavy veh. 0.08	No. of overtaking 0-34	MTV(≤600cars/15min;
27 to 59 km/h on urban roads and	Pavement conditions 2	Intersection cross dist. 8-35	0=otherwise)
48 to 86 km/h on rural roads;	c_presence of curb lane 1	Total number of lanes 1-5	CWP(1=≤10Conflicts;
Speed limit = 30 to 80 km/h;	Nth_no. of tru lanes 2	No. of access and egress 2-8	0=otherwise)
Sidewalk width = 0.8 to 4.5 m;			TB(1=trees/benches/grasses;
Bicycle track width = 1.7 to 2.5 m;			0=otherwise)
Bicycle lane width = 1.4 to 1.7 m;			
Paved shoulder width = 0.9 to 1.6 m;			
Width of outer drive lane=2.8 to 6.0m			

Box 6.1: Adapted from (Jensen, 2007)

$$\text{Logit}(p) = \alpha \begin{pmatrix} \text{Very satisfied} = -1.3652 \\ \text{Moderately satisfied} = 0.3741 \\ \text{A little satisfied} = 1.5512 \\ \text{A little dissatisfied} = 2.4805 \\ \text{Moderately dissatisfied} = 3.8449 \end{pmatrix} + \begin{pmatrix} \text{residential} = 0.4871 \\ \text{shopping} = 0.5385 \\ \text{mixed} = -1.6349 \\ \text{rural fields} = 1.2380 \\ \text{rural forest} = 0.5122 \end{pmatrix}$$

-0.0005585.MOT - 2.3895.LBUF + 0.0004691.MOT.LBUF – 0.0958.SPEED + 0.000421.SPEED^2 – 0.000002913.MOT.SPEED + 0.0402.LBUF.SPEED + 0.000002446.MOT.LBUF.SPEED – 0.001623.PED + 0.0000008309.PED2 – 0.09416.PARK + 1.7782.PATH + 1.3938.ULAN + 2.5196.RSHO + 0.2413.DBL – 0.2593.RBUF + 1.2694.SW – 0.6988.BUS + 0.6821.LANE

where
logit(p) = utility function of the cumulative logit model,
á = intercept parameter of the response level of satisfaction,
AREA = type of roadside development or landscape,
MOT = motor vehicles per hour in both directions,
LBUF = width of buffer area between bicycle facility and drive lane on the nearest roadside (m),
SPEED = average motor vehicle speed (km/h),
PED = passed pedestrians per hour on nearest roadside at 20 km/h riding speed,
PARK = parked motor vehicle on nearest roadside per 100 m,
PATH = width of bicycle path/track on nearest roadside (m),
ULAN = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in urban areas (m),
RSHO = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in rural areas (m),
DBL = width of nearest drive lane including bicycle lane/paved shoulder of less than 0.9 m width (m),
RBUF = width of buffer area between sidewalk and bicycle facility/drive lane (m),
SW = sidewalk dummy, sidewalk on nearest roadside = 1, no sidewalk = 0,
BUS = bus stop dummy, bus stop on roadway = 1, no bus stop = 0,
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0.

Box 6.2: adapted from (Lowry & Callister, 2012)

BLOSscore = 0.760 + F_w + F_v + F_s + F_p

where
F_w = width adjustment factor;
F_v = vehicle volume adjustment factor;
F_s = vehicle speed adjustment factor; and
F_p = pavement condition adjustment factor

the pedestrian volume and the number of encounters were statistically significant factors' for the BLOS (Kang et al, 2012). However, the BLOS tend towards 'A' with increasing width of lane. Model 2 of their study adopted 3 rating levels (satisfied, fair and dissatisfied) to however confirm bicycle width as a statically significant factor in bicyclists' satisfaction. Model 3 which seek evaluate satisfaction based on bicycle road type indicates a strong correlation (-0.8776) between type of bicycle road and cyclist volume. Another correlation coefficient of 0.8541 indicates a statistical relationship between bicycle road type and the number of access and agrees points on the route. The study further concludes that if 'bicycle road width increases by one unit, the probability of obtaining 'A' increases by 27.1% while that of 'B' and 'C' decreases by 10.77% and 16.94% respectively. In comparison with our finds, the probability of highly satisfied (A) rating is 0.5192 or 51.92% for every unit increase in the bicycle lane width and 0.0739 or less than 1% for a grade of 'F'.

In terms of intersection, the study compares with 'bicyclist intersection safety index (ISI) developed by Carter et al., 2007. Video data had extensive coverage of the following variables: 'traffic control, number of intersection legs, one-way or two-way, number of lanes, crossing width, crosswalks (presence and type), right-turn curb radius sizes, on-street parking, street lighting, surrounding development type, right-turn-on-red allowance, sight distance, and number of driveways on the main street' (Carter et al., 2007). Generalized linear models were used to analyse both 'observed behavioural data (avoidance manoeuvres) and subjective intersection safety ratings (expert survey)'. Three models were developed for through, right turn and left turn movement (box 6.3). This study underscores the significance of the feeling of safety of bicyclist in their level of satisfaction. Whereas, the models in this study are independent of segment BLOS (standalone), our study considered separate methodology which is somewhat an addendum to segment BLOS to aggregate BLOS at the facility or corridor level. Both studies adopted the GLMs in analysis approach to estimate parameters and coefficients thus estimating probabilities. The statistical significance of total intersection legs in our model supports their inclusion of number of traffic lanes for cyclists to cross to make a left turn (LTCROSS).

Whereas, no two studies on LOS can be identical, a review of methodological approaches adopted especially in recent times points to the application of probabilistic statistics to predict the satisfaction level of respondents. Also worthy of note from above comparison is the fact that different variables can be used almost elsewhere, but not without modification based on local circumstances. Therefore different LOS studies are recommended for different cities to serve their peculiar bicycle transportation needs.

6.3. Limitations of study

The aggregation of participants' ratings across of 16 videos representing 574 segments of 71 ciclorutas may not reflect actual perception level across the study area. This is in view of the small sample size which the scope of this study accommodates. Further studies may validate perception of bicyclists using larger sample size to examine levels of satisfaction. The sample size of participants comprising over 70 per cent student participants and overall age of participants as over 80 per cent less than 35 years has the tendency to influence our rating of satisfaction level as many studies have posited. For example, (Moudon et al., 2005) study of cycling and built environment, a US perspective' revealed that 'Middle-aged and young adults tend to bicycle more than older adults' and by extension have more experienced thus tolerating difficult cycling environments than older people. K. Kang and Lee (2012) also revealed a high tolerance level for congestion by people younger than 25 years and therefore increases their likelihood to perceive pedestrian facilities as being A, B, or C than older people. For as much as it was desired that participants be drawn to reflect all socioeconomic background, it might not be feasible in real life, and also considering the limited time for this research.

Box 6.3: adapted from (Carter et al., 2007)

Though:
ISI = 1.13 + 0.019MAINADT + 0.815MAINHISPD + 0.650TURNVEH + 0.470(RTLANES*BL) + 0.023(CROSSADT*NOBL) + 0.428(SIGNAL*NOBL) + 0.200PARKING
Right turn:
ISI = 1.02 + 0.027MAINADT + 0.51TRCROSS + 0.151CROSSLNS + 0.200PARKING
Left turn:
ISI = 1.100 + 0.025MAINADT + 0.836BL + 0.485SIGNAL + 0.736(MAINHISPD*BL) + 0.380(LTCROSS*NOBL) + 0.200PARKING

where
ISI = safety index value
BL = bike lane presence
CROSSADT = cross street traffic volume
CROSSLNS = number of through lanes on cross street
LTCROSS = number of traffic lanes for cyclists to cross to make a left turn
MAINADT = main street traffic volume
MAINHISPD = main street speed limit ≥35 mph
NOBL = no bike lane present
PARKING = on-street parking on main street approach
RTCROSS = number of traffic lanes for cyclists to cross to make a right turn
RTLANES = number of right turn traffic lanes on main street approach
SIGNAL = traffic signal at intersection
TURNVEH = presence of turning vehicle traffic across the path of through cyclists

Undertaking the scope of this study in a completely new environment was quite a daunting task. Most challenging was the Spanish language spoken by the generality of the populace. Field assistant was able to help in this regard to the best of his ability.

The concept of bicyclists' level of satisfaction is not rigorously defined in this study and therefore it is expected that perception of satisfaction would vary considerably across all participants. It is in view of this uncertainty regarding the concept of satisfaction that this research opted for a statistical approach that deals with probabilities. The ordered probit model as used in this study captures the heterogeneity between individual participants and their perception of satisfaction. This data is limited to Bogota and cannot be applied elsewhere copiously, except with modifications to reflect local transportation circumstances. The choice of a six-point rating scale is due to the LOS measurement earlier developed by Landis (1994) and modified by Highway Capacity Manual (HCM, 2000) as one of the most acceptable standard for comparing satisfaction levels. It cannot completely be said to be advantageous as Kang et al., (2012) has proved when they developed a three-point rating scale for level of satisfaction.

This model does not incorporate crash data in its estimation which is observed to have related strongly with BLOS performance evaluation as shown in the Gainesville study. The crash statistics in the Gainesville study indicate that accidents are concentrated at congested central, commercial or high activity centres. Further studies are recommended in this respect.

These limitations notwithstanding, the study has provided an empirical methodology for estimating the level of satisfaction that bicyclists derive from the use of the cicloruta, and by extension made contribution to the existing body of literature on the subject matter. The methodology is suitable for application in many countries with modification on scoring of variables. The findings confirm the validity of the use of video data in combination with other geometry, physical and operational traffic characteristics as opposed to Epperson (1994) suggestion that video simulation alone can be used to simulate LOS model.

6.4. Concluding remarks

Some important findings can be found in the estimation of the two models not just in terms of contributor variables to satisfaction but also in the empirical findings of the magnitude of these effects across study population. Important element includes the significance of side path separation in the perception of safety of cyclists. The findings suggest that adequate attention be directed at planning for physical separation of cycle paths from motorised traffic. Such facilities like raising of curb shoulder, planting of trees and grasses and use of physical barriers like it is been experimented in Carrera 7 (KR 11-13) unlike the use of plastic reflectors to separate bicycle lanes from motorised roadways in all ciclocarrils. Secondly, vehicle speed also has a significant impact on the satisfaction of bicyclists. This is not unrelated with cases of vehicle and bicyclists collisions as explained by many interviewed residents. The lack of posted speed limits let alone an effective policy to regulate speed in the city corroborates bicyclists' fears. This research suggest the display of posted speed limits as it is obtainable in many cities of the world as a first step towards enforcing speed limit in the city. This it is believed will help restore the feeling of safety of cyclists from vehicle related accidents. Thirdly, motorised traffic volume affects the safety feeling of bicyclists. The variable odd ration value is negative meaning that a unit increase in the MTV increases the probabilities for a higher level of satisfaction. This can be explained by the feeling of safety and security of property that bicyclists enjoy as many areas of the city are said to be unsafe for cycling. Finally, conflicts with pedestrian and other cyclist, physical barriers separating lanes and other non-motorised four-wheeled modes affect the level of cyclists' satisfaction. For as much as some of the four-wheeled modes provides employment opportunities for residents (especially in the south of the city), enforcing the regulation of its use can help encourage cycling.

6.5. Policy recommendations

From an engineering standpoint, the results of this research suggest the redesign of intersections to accommodate cyclists. Secondly, it is also important to contemplate the completion of most dead-ends of the network as well as extend the network beyond major arterials to residential neighbourhoods. Regulating the speed of motor vehicles and other associated road surface hazards would increase perceived levels of cyclists' safety and thus greater likelihood for bicycle use.

In terms of education, much is needed to be done to enlighten cyclists on safety issues such as speed, phone use and other form of conversations that has the tendencies to detract cyclist while on the road. Motorists should be made aware of the right of the cyclist especially in shared lanes like the ciclocarrils while programmes that highlight the dangers of speed should also be emphasized. Bicycle use amongst children of school going age should be encouraged to inculcate in the young people the culture of cycling. In this regard therefore, there should be an improved effort to develop suitable programmes in school curriculum that highlights some of these issues among road users irrespective of age, sex and income. Enlightenment programmes should also be directed at all urban residents on the need to respect traffic separation. This is in view of the frustration cyclist face with regular conflicts with pedestrian and other modes almost across the entire network.

The estimated BLOS model can provide traffic and other infrastructure planners the ability to rate the level of satisfaction of cyclists in Bogota. This is in a view to achieving better plans and designs of bicycle network that optimizes national and local budgets. The model also provides an evaluation tool for existing ciclorutas, so planners can undertake specific improvement measures for respective segments in the network. Already existing improvement plans on the cicloruta can be compared with the result of this research to prioritise investment on high priority areas of the network. Specifically, along the Av. El Dorado, a deliberated plan to introduce some access and egress into the network is recommended.

Facility inventory, efficiency and improvements can also be measured using this model. It can also be used to determine minimum LOS standards along specific ciclorutas as well as set targets, given road type, posted speed limits, land use type, pavement quality, path separation as well as cyclist characteristics. For example, higher BLOS standards such as 'B' should be targeted at ciclorutas around school areas, hospital, government ministries and so on.

The proposed model therefore represents a BLOS methodology for evaluating bicycle infrastructure in Bogota. This represents an alternative solution which seeks encouragements for cycling mode of transport. It is however believed that this model would be useful not only in Bogota but also in South America and indeed elsewhere in the world as an effective tool for bicycle infrastructure planning. An expansion and further improvement is possible to reflect peculiar transport circumstances. Further testing for the significance of model variables such as side path separation, vehicle speed, motorised traffic volume and conflicts with pedestrian is also possible. The output of this research can become vital components of data for routing of ciclorutas along slope, best route and shortest path along good ciclorutas and so on. Future studies would have to enlarge the scope of this study to fully understand the satisfaction level of cyclist and potential users on the quality of infrastructure for bicyling. Other methods that seek to focus on different profile of bicyclists are recommended. However, based on the methodology and result of this research, further studies on accessibility on cicloruta and associated land uses can be carried out.

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7. APPENDICES

Appendix 1: BICYCLE LEVEL OF SERVICE (BLOS) STUDY IN BOGOTA

SECTION A: questionnaire of bicyclists' socio-economy/experience

1. Sex: Male_____ Female_____
2. Age:
13-17___ 18-35____ 36-50____ 51-65____ 66+_____
3. Indicate which localidad you reside in the city______________________________________
4. Indicate your kind of residence:
Detached housing___
Terraced housing___
Flat housing___
Student hostel____
Other____
5. Do you ride bicycle in the city? Yes____ No____
If yes indicate by how many times in a week bearing in mind that the total should be 10:
Work or school___
Shopping___
Recreation/exercise/tourism____
Other____
6. On which of the following do you ride bearing in mind that the total should be 10?
Major Road___
Residential streets____
Cicloruta___
Sidewalks____
Other____
7. How many trips do you make on bicycle in a week (a trip is going from origin to a destination; for instance, moving from your office is one trip, returning back is another)?
<5___ 5-10____ >10____
8. How many days do you ride in a week_____?
9. How many kilometres do you ride in a week:
<10____ 10-15_____ 16-29_____ 30-45_____ >40_____
10. Do you ever choose not to ride due to weather condition? Yes____ No_____
If yes, under what condition (tick as appropriate)?
Rain threat___ Drizzle___ Steady rain___
Heavy rain___ Fog___ Hot weather____
11. Rate your riding experience below?
______I feel comfortable riding under any traffic conditions including major streets with busy traffic and higher speeds
Or
______I feel comfortable riding on streets with less traffic and lower speeds, on bicycle lanes, or on sidewalks.
12. How many kilometres are you always willing to ride to the following facilities:
Bus station with parking facility_______
School/work________
Shopping_________
Recreation__________

BICYCLE LEVEL OF SERVICE (BLOS) STUDY IN BOGOTA

SECTION B: Video/field survey rating scale

1 = highly satisfied
2 = moderately satisfied
3 = a little satisfied
4 = a little dissatisfied
5 = moderately dissatisfied
6 = highly dissatisfied

Name: **Date:**

Segment no.	Ratings				
	Volume of cars	Speed of cars	Cycle lane/track	Environment (safety/secu)	Overall
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

INTERSECTION LEVEL OF SERVICE (IntBLOS) STUDY IN BOGOTA

SECTION C: Video/field survey rating scale

Video survey form-intersection
1 = highly comfortable
2 = moderately comfortable
3 = a little comfortable
4 = a little comfortable
5 = moderately comfortable
6 = highly comfortable

Name: **Date:**

Intersection no.	Ratings				
	Conflicts	Exposure	Signs/markings	Environment	Overall
1					
2					
3					
4					
5					
6					
7					
8					