TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: T01/078

Modeling Pedestrian Level of Service for Crosswalks at Signalized Intersection in Kathmandu Valley

by

Aadarsha Ram Shrestha

A THESIS

SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN TRANSPORTATION

ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

LALITPUR, NEPAL

DECEMBER,2023

COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

The undersigned certify that they have read and recommended to Institute of Engineering for acceptance, a thesis entitled "**Modeling Pedestrian Level of Service for Crosswalks at Signalized Intersection in Kathmandu Valley"** submitted by Aadarsha Ram Shrestha in partial fulfillment of the requirement for degree of Master of Science in Transportation Engineering.

…………………………………………………………

Supervisor: Mr. Anil Marsani

Department of Civil Engineering

Institute of Engineering

…………………………………………………………

External Examiner: Mr. Saroj Kumar Pradhan

National Road Safety Council

…………………………………………………………

Committee Chairperson: Mr. Anil Marsani

Coordinator: MSc in Transportation Engineering

Department of Civil Engineering

Date:……………………..

ABSTRACT

Modeling pedestrian level of service (PLOS) provides valuable insights into the quality of the pedestrian environment and can serve as a basis for establishing standards for pedestrian facilities and thus helps in planning, designing and maintaining pedestrian facilities. This research aimed to create an appropriate model for PLOS at signalized intersection crosswalks in Kathmandu Valley and this study considered pedestrians' perspectives on it. The data were collected from five crosswalks of Kathmandu valley through a videographic survey which also captured the details from 1205 individuals along with traffic characteristics entering the signalized intersection via the crosswalk. A questionnaire survey of 408 individuals was also carried out onsite to understand perceptions regarding PLOS. To identify the significant elements impacting the PLOS score, the Pearson's correlation test was employed. Using the perceived PLOS score from the questionnaire as the dependent variable and the significant factors as independent variables, a stepwise regression analysis was conducted to establish the most suitable predictive model. The threshold values of the PLOS ranges were established by k-means clustering for six categories ranging from A to F. The intervals were set as follows: Scale A spanned values from 10 to 16.76, Scale B from 16.76 to 23.69, Scale C from 23.69 to 29.65, Scale D from 29.65 to 36.59, Scale E from 36.59 to 44.06, and Scale F from 44.06 to 50.

Keywords: Pedestrian, Pedestrian Level of Service, Pedestrian Delay, Crosswalk, Signalized Intersection

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to all the people who supported and guided me throughout this research project. Their valuable contributions and encouragement have been instrumental in making this study possible. I am thankful to my supervisor, Mr. Anil Marsani, and faculties, Dr. Rojee Pradhananga and Dr. Pradeep Kumar Shrestha, for providing valuable insights and feedback that significantly improved the quality of this work. Additionally, I extend my thanks to my friends and family for their unwavering support and understanding during the entire duration of this project. Their collaboration, encouragement, and insightful discussions have contributed significantly to the development and refinement of my ideas. This research journey has been both challenging and rewarding, and I am grateful to everyone who played a part in it.

In addition to my academic mentors, I extend my thanks to all the participants and respondents who willingly shared their time and insights, contributing to the robustness of this research. Their willingness to participate has been integral to the success of this study.

Lastly, I want to express my gratitude to the countless other individuals, colleagues, and acquaintances who, in one way or another, offered their support, assistance, and inspiration during this pursuit. Each contribution, no matter how small, has played a significant role in shaping the outcome of this research.

Name: Aadarsha Ram Shrestha

Roll No: 078/MSTrE/001

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C	Compliance of signal
CT	Crossing time
G	Green Phase
L	Length of crosswalk
LT	Left Turning traffic
N	Number of lanes
NC	Non-compliance of signal
NG	Non-green phase
P	Average pedestrian volume
PCU	Passenger Car Unit
PS	Pedestrian Speed
RT	Right Turning traffic
T	Through Traffic

LIST OF ABBREVIATION

AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
DoR	Department of Roads
HCM	Highway Capacity Manual
HMIS	Highway Management Information System
LOS	Level of Service
PCU	Passenger Car Unit
PLOS	Pedestrian Level of Service
SPSS	Statistical Package for Social Sciences

CHAPTER 1: INTRODUCTION

1.1 Background

As a result of swift urban growth in Nepal, road traffic is experiencing a significant upsurge. For quite a while, the enhancement of vehicular transit systems has been the focal point for transportation planners and engineers. To this day, priority is predominantly given to motorized transport systems over those catering to non-motorized users like cyclists and pedestrians. Yet, recent years have seen a shift toward embracing multimodal strategies to improve pedestrian facilities and operations, addressing the hurdles of traffic congestion, air pollution, safety enhancement, and quality of life improvement. It is increasingly encouraging for researchers to contribute to refining traffic behavior in all its dimensions.

The diversity of traffic on Nepalese city streets is striking, with vehicles exhibiting a broad spectrum of static and dynamic characteristics. All types of vehicles, irrespective of its type, use the same road space without segregation, and can occupy any part of the road based on the availability of space at that moment, often disregarding lane discipline. Under such unregulated traffic conditions, pedestrian spaces are steadily shrinking, making them increasingly susceptible to accidents.

Pedestrian activity forms an integral part of most individuals' daily commutes. A study conducted by JICA in 2012 revealed that 40.7% of trips in the Kathmandu Valley were completed on foot. Despite the fact that pedestrians cover shorter distances compared to other road users, they constitute a significant proportion of road fatalities in Nepal. Pedestrians and cyclists combined account for 26% of all road-related deaths (WHO, 2018). This is a grave issue that necessitates immediate attention and solution.

Traffic intersections are among the most challenging spots on any road network due to their inherent nature of accommodating vehicles moving in different directions who desire to occupy the same area simultaneously. Not only vehicles, but pedestrians also seek to utilize these spaces for crossing, adding to the potential for conflict between different road users at the intersections. The need to improve pedestrian facilities is driven by issues such as the difficulty in navigating heavily trafficked crossings, vehicles interrupting pedestrians' paths during green signals, clashes between pedestrians and motorized vehicles, physical obstacles, low visibility, and poor design of accessible ramps for the differently-abled. In Nepal, the infrastructure at many signalized intersections lacks dedicated pedestrian crossings and signals, and where such facilities do exist, they are often found to be non-operational. An effective solution would be to devise a method for gauging the level of difficulty users encounter while crossing these intersections. The development of a Pedestrian Level of Service (PLOS) model could serve as an effective technique to evaluate the complexity of intersection crossings, and thus assess the quality of pedestrian facilities.

The construction of a Level of Service (LOS) model for pedestrian crosswalks at signalized intersections could offer valuable insights into optimal pedestrian travel accommodations. PLOS reflects the quality of the pedestrian environment and could help shape standards for pedestrian facilities. The formulation of PLOS at intersections could lead to a better understanding of how to design intersections that safely and effectively accommodate pedestrian movement.

Such an evaluative tool would facilitate the integration of pedestrian facility planning into the broader framework of transportation planning, design, and implementation. The LOS for pedestrians at crosswalks could be used to establish a minimum LOS standard, which would define the least acceptable LOS required to adequately facilitate pedestrian movement.

1.2 Problem Statement

As Kathmandu Valley continues to urbanize, the increase in vehicular traffic combined with the traditional pedestrian-centric culture of the region presents significant challenges to transportation planning. Ensuring a safe, efficient, and comfortable pedestrian experience at signalized intersection crosswalks is a key aspect of sustainable urban development. However, the existing methods used to model pedestrian levels of service at signalized intersection crosswalks in the valley often fail to capture the unique characteristics of pedestrian behavior and traffic patterns in this particular context. Thus, there is a need to develop a PLOS model for the context of crosswalks that fits our traffic nature. PLOS serves as an effective approach for assessing pedestrian facilities at intersections, which can inform future enhancements, better design, and construction initiatives.

While Pedestrian Level of Service (PLOS) can guide the development of standards for pedestrian facilities, most existing LOS standards originate from developed countries, where traffic conditions and pedestrian facilities differ significantly from those in Nepal. Consequently, the direct application of these standards may not accurately reflect Nepalese conditions. This problem is further heightened by the lack of adequate pedestrian infrastructure, poor traffic discipline, and increased rate of traffic-related accidents involving pedestrians in Kathmandu Valley.

Given the current design approaches to road construction in Nepal, the needs of non-motorized users, such as pedestrians, are often overlooked in favor of motorized transport systems. The Nepal Road Standard (2070) references LOS for roads but offers little information regarding LOS of pedestrian facilities. This deficiency results in pedestrian traffic experiencing difficulties and being at risk of conflicts with road traffic, which ultimately disrupts overall road traffic flow as well. Implementing PLOS as a standard for developing pedestrian facilities in Nepal could aid in integrating pedestrian facility planning into overall traffic design, planning, and construction efforts. This would ensure a more comprehensive and inclusive approach towards managing and improving Nepal's transportation infrastructure. Moreover, such a model would contribute significantly to the literature and provide insights applicable to other rapidly urbanizing areas globally.

1.3 Objective of the study

The main objective of this study is to develop PLOS model for crosswalks at signalized intersection. The specific objectives are as follows:

- To identify the factors affecting pedestrian level of service
- To propose a suitable method for estimating a PLOS model
- To categorize PLOS scores into an appropriate PLOS scale

1.4 Scope of the study

The scope of the study are as follows:

- Focused on the selected signalized intersection in the Kathmandu valley only.
- The study of current pedestrian infrastructure and signals at the selected signalized intersection.
- Videographic method to determine the pedestrian flow at the signalized intersection for a period of 1 hour at each crosswalk.
- Videographic method to determine the vehicle traffic count entering the signalized intersection
- Questionnaire survey in order to find out the perceived PLOS of the crosswalks.

1.5 Limitation of the study

The limitations of the study are as follows:

- This study was only focused on the selected signalized intersections in the Kathmandu Valley only.
- The level of service was focused on the perception of the pedestrians using the crosswalks.
- Surveys and sample studies faced low participation rates which led to low representative data.

1.6 Organization of Report

The report consists of the following chapters:

Chapter 1: Introduction; This chapter deals with the background, problem statement, objectives of the study, scope of the study, and limitations of the study.

Chapter 2: Literature Review; It includes the present context of pedestrian crosswalks of Nepal, a description of the general facilities and factors that were used for the study, and past studies that have been done on the subject of PLOS.

Chapter 3: Methodology; This chapter includes the framework of the research design, methodologies to find out different variables used for the study and the PLOS model for the signalized intersections crosswalks.

Chapter 4: Analysis and Design; This chapter includes the analysis and interpretation of the results.

Chapter 5: Conclusion and Recommendation; It provides summary of the study, and recommendation.

CHAPTER 2: LITERATURE REVIEW

2.1 Present condition of Nepal

The lack of sufficient pedestrian infrastructure in Nepal is a significant issue. While governmental efforts have focused on extending the road network to reach remote areas, pedestrian safety and accessibility have received inadequate attention. This has led to unorganized road infrastructures, insufficient pedestrian facilities, non-presence of crosswalks markings, poor maintenance of existing facilities, and either a lack of traffic signals or poorly calibrated signal timings. These issues expose pedestrians to risk of accidents.

With many intersections designed predominantly for vehicular traffic, pedestrians often struggle to safely navigate these crossings. Absent or insufficient sidewalks, pedestrian crossings, and signals have contributed to a high rate of pedestrian accidents and fatalities. The concept of Level of Service (LOS) should be crucial in Nepal's road network planning, ensuring infrastructure is designed and maintained to certain standards. But pedestrian facilities have been overlooked in this regard. As pedestrians are among the most vulnerable road users, they deserve safe and accessible facilities. Given the high rates of pedestrian-related accidents and fatalities in Nepal, it's imperative that the government takes definitive steps to tackle this issue.

From a pedestrian’s perspective, majority of intersections are not safe. Providing safe, accessible pedestrian facilities isn't just about convenience—it's a social issue. Everyone, regardless of their mode of transport, should have access to safe, efficient infrastructure. The government needs to invest in enhancing pedestrian infrastructure to ensure all road users, can navigate the road network safely and efficiently. This could include the development of a PLOS rating system for pedestrian facilities, which would guarantee that pedestrian infrastructure meets the required standards. Such a system would also help prioritize investments in pedestrian facilities, making sure they're not overlooked in road network development planning.

2.2 Pedestrian Level of Service

The Level of Service (LOS) concept was first introduced in the Highway Capacity Manual in 1965. It was utilized to qualitatively describe the performance, operation, and facilities provided for traffic movement. LOS offers a qualitative analysis of the operational conditions for vehicle and pedestrian traffic, informed by service indicators such as speed, travel time, maneuverability, traffic interruptions, comfort, and convenience.

Pedestrian Level of Service (PLOS) provides a measure of the quality of service extended to pedestrians as they traverse through different environments, such as footpaths, crosswalks, stairs, etc. The assessment is based on various factors including the quality of crosswalks, pedestrian signals, street lighting, and other amenities that affect pedestrian comfort and safety. PLOS serves as a critical tool for gauging the walkability and pedestrian-friendliness of an area. It considers the pedestrian experience and delivers a quantitative evaluation of the comfort and convenience of walking in a specific area. Enhancing PLOS can incentivize walking as a transport option, improve access to services, reduce traffic congestion, and foster healthier, more sustainable communities.

To evaluate LOS, a LOS score must be computed. Many studies categorize the six service levels, ranging from A to F, as outputs from a mathematical model based on various performance measures or each individual service measure. LOS A signifies the optimal operational condition, while LOS F signifies the least favorable. The PLOS score is a mathematical function of various factors that influence pedestrian movement. These factors can be grouped into two broad categories: geometrical parameters and traffic parameters.

Geometrical parameters include urban infrastructure or road furnishings, along with road geometrical features such as segment length, road width, lane width, sidewalk width, and crosswalk length. These parameters directly impact walking in terms of speed and comfort, and can influence the amount of space available per pedestrian. As a result, they heavily affect the number of pedestrians per unit of time and length. Traffic parameters might include traffic composition, such as the percentage of different transportation modes. These parameters provide context for how pedestrian movement is affected by the surrounding vehicular traffic and other transport modalities.

PLOS has been categorized into six levels ranging from A to F. According to Indo-HCM, the PLOS has been categorized according to pedestrian delay (in seconds). Table 2-1 shows the classification of PLOS according to Indo-HCM (Indo, 2017).

Table 2-1: PLOS classification according to Indo-HCM

LOS	Pedestrian delay (in seconds)
A	<= 5
B	5-10
C	11-25
D	26-45
E	46-80
F	>80

2.3 Pedestrian facilities

Pedestrian facilities refer to infrastructure and amenities designed specifically for pedestrians to enhance their safety, convenience, and accessibility. These facilities are built to accommodate and facilitate pedestrian movement, making walking a viable and comfortable mode of transportation. Pedestrian facilities can vary in design and features depending on the context and purpose, but their primary goal is to prioritize the needs and well-being of pedestrians.

2.3.1 Uninterrupted-flow Pedestrian Facilities

Walkways and Sidewalks

Sidewalks and walkways are designated solely for pedestrian use, prohibiting both motorized and non-motorized vehicles. They are essential components of urban and suburban environments, designed specifically for pedestrian use. Sidewalks are typically constructed alongside roads and streets, adjacent to the curb or at a distance from vehicular traffic. They are typically made of concrete or asphalt and provide a dedicated space for pedestrians separate from vehicles. Sidewalks often feature smooth surfaces, ensuring ease of movement for individuals of all abilities. They may also incorporate curb ramps or tactile paving to enhance accessibility for people with disabilities.

Walkways, on the other hand, are broader in scope and can be found in various settings such as parks, campuses, shopping centers, or recreational areas. They serve as paths or trails connecting different areas within a particular space or connecting multiple destinations. Walkways can be constructed using a range of materials, including concrete, asphalt, pavers, or natural elements such as gravel or compacted earth, depending on the intended use and aesthetic preferences.

Both sidewalks and walkways are designed with pedestrians' safety and convenience in mind. They often include features such as crosswalks, pedestrian signals, and signage to guide individuals and promote orderly movement. Lighting is another crucial element, particularly for sidewalks in urban areas, ensuring visibility during nighttime hours and enhancing overall safety.

These pedestrian pathways not only facilitate movement but also contribute to the overall livability and walkability of communities. They encourage active transportation, promote physical activity, and reduce reliance on motor vehicles, leading to numerous benefits such as improved public health, reduced traffic congestion, and decreased environmental impact.

2.3.2 Interrupted-flow Pedestrian Facilities

In case of interrupted flow, the impact of motorized vehicles on pedestrian movement is taken into consideration.

Signalized Intersection

A signalized intersection refers to an intersection or junction where traffic movements are regulated by traffic signals or traffic lights. These intersections are equipped with a set of traffic signals that control the flow of vehicles, pedestrians, and sometimes bicycles. Traffic lights commonly show red, yellow, and green indicators to signal when vehicles should halt, move carefully, or go freely. Signalized intersections are designed to improve traffic safety and efficiency by assigning specific time intervals or phases to different traffic movements. For example, the traffic signals may allow vehicles from one direction to proceed while others are stopped, and then switch to allow traffic from another direction to move. Pedestrian signals are often included to provide a designated time for pedestrians to cross the intersection safely.

A signalized intersection with pedestrian signals refers to an intersection equipped with traffic signals that specifically cater to pedestrian movements. In addition to the regular traffic signals for vehicles, pedestrian signals are included to regulate and facilitate the safe crossing of pedestrians. Pedestrian signals are typically displayed in the form of icons or symbols, such as a walking person or a hand, to indicate when pedestrians can cross the intersection and when they should wait. The signals may be located at eye level for pedestrians or positioned on poles or overhead structures. The timing of the pedestrian signals is coordinated with the traffic signals to ensure the safe interaction between pedestrians and vehicles.

The behavior of pedestrian crossing a signalized intersection is a very tedious affair. Pedestrian movement on signalized intersections includes sidewalk flows as well as crossing the street. It also includes the queuing behavior which changes according to the change of signal. Pedestrian delay factor should also be considered in this aspect.

2.4 Pedestrian Delay

Pedestrian delay at a signalized intersection refers to the amount of time pedestrians have to wait before they can safely cross the street. When a pedestrian arrives at a signalized intersection, they must wait for the “Walk” or green signal in the pedestrian phase to appear, indicating that it is safe to cross. However, there is a delay between the time the pedestrian phase is green. Various reasons can contribute to this delay, such as the time it takes for the signal to cycle through all the phases, the length of the crosswalk, and the volume of the traffic. The delay time can vary depending on the intersection and the time of the day. During peak traffic periods, the pedestrian delay may be longer due to the higher volume of vehicles and longer signal cycles. Pedestrian delay can also be impacted by the physical layout of the intersection, such as the number of lanes, width of the road, and presence of medians. Excessive pedestrian delay can be a safety concern as pedestrians may become impatient and attempt to cross the street before it is safe to do so, leading to accidents. The pedestrian delay is sub-divided into delay in green and non-green phases. Delay can be calculated by subtracting the average crossing time from the difference of arrival time of the pedestrian at the crosswalk and the completion time of crossing the crosswalk.

2.5 Compliance of signal

Compliance with traffic signals at signalized intersections is crucial for ensuring road safety and smooth traffic flow. These signals provide clear guidance to pedestrians about when it is safe to cross or wait for vehicles. Pedestrians in general tend to follow traffic signals and wait for the "walk" signal before crossing. This compliance can be attributed to factors like well-established traffic regulations, effective enforcement measures, public awareness campaigns, and a culture of obeying traffic rules. However, in Nepal, the enforcement of such regulations is inadequate. Studies have shown that pedestrian delays are approximately 22% lower than predicted if complete compliance with signals was observed (Virkler, 1998). As a result, a significant number of pedestrians do not adhere to the signal. Therefore, it is important to consider the non-compliant behavior of pedestrians if pedestrian delay model is determined.

2.6 Past Studies

Lautso and Murole pioneered research on Level of Service (LOS) to assess how environmental factors affect pedestrian facilities. Their work laid the foundation for future studies, which have further enriched the understanding and calculation of pedestrian LOS by adding various important elements. (Murole, 1974).

Sarkar put forth a technique to evaluate the pedestrian level of service (LOS) by taking into account six factors: safety, security, convenience and comfort, continuity, system coherence, and attractiveness. However, the method is qualitative, which means that the attributes of pedestrian environments are described without being quantified. In practice, measuring each factor is challenging, and several of the factors are interdependent since it is a qualitative approach (Sarkar, 1993).

Khisty created a method for calculating the level of service (LOS) for pedestrians using criteria similar to those proposed by Sarkar. This method provides a numerical measurement of LOS, but interpreting the results can be challenging. There is a question about whether these measurement systems accurately reflect the experiences of pedestrians and whether they agree with these scales (Khisty, 1994).

Dixon's method for evaluating pedestrian LOS incorporates various factors and uses a point scale from 1 to 21. The scores are then categorized into six levels, ranging from A to F, providing a quantifiable approach to the assessment (Dixon, 1996).

Virkler conducted a study to examine how much delay pedestrians can reduce by violating pedestrian signals. The study found that pedestrians experienced delays that were 22% lower than what was predicted if they had completely complied with the signal (Virkler, 1998).

Miller developed a scale-based method to assess the pedestrian level of service, which included recommendations for improving existing conditions. They also utilized 3-D visualization to calibrate the proposed model.(Miller et al., 2000)

In a study by Muraleetharan (2004), an index called "overall LOS" was introduced as a way to combine multiple factors that affect the pedestrian level of service (LOS). The researchers used a conjoint technique to integrate these factors and create an overall value for pedestrian LOS.

Landis et al put forth a mathematical model that relies on five variables lateral separation of pedestrians from motor vehicle traffic, presence of physical barriers and buffers, outside lane traffic volume, motor vehicle speed, and vehicle mix (Landis et al., 2001). The model is focused on evaluating a particular section of a roadway and does not take into account the conditions at intersections, although the authors acknowledge that intersections are crucial to pedestrian safety and that a measure should be developed to address this. Moreover, this model is limited by environmental aspects and doesn't consider other components like the flow rate of path users and their space needs.

Li et al. have formulated a pedestrian delay model that is appropriate for signalized intersections in developing urban areas (Li et al., 2005). The model was created based on a field study that was carried out in Xi'an, China. After analyzing the findings of the study, certain assumptions were made concerning the correlation between the average delay experienced by pedestrians and their arrival subphases. Using this information, a new model was developed to estimate the amount of delay pedestrians are likely to experience at signalized intersections which is shown in equation (2-1).

$$d = d_G + \frac{k_{NU}K\, R_E{}^2}{2C} \qquad (2\text{-}1)$$

Where,

d_G = average pedestrian delay during green phase (s)

k_{NU} =adjustment factor for nonuniform arrival rate, and

R_E = effective red time (s)

The factors evaluated. that affect LOS at crosswalks include corner space, crossing infrastructure, turning vehicles, signal delay, and pedestrian-bicycle interaction(Muraleetharan et al., 2005). The space at the corners includes both the holding area and the circulation area. This research aided in evaluating the factors that influence the LOS for pedestrians at intersections and was employed to ascertain the LOS for pedestrians at signalized intersections under mixed traffic scenarios. This takes into account the operations (i.e. Signalization and delay) as well as comfort and safety (i.e. Perceived exposure and conflicts).

A LOS model was modeled that precisely reflected the views of pedestrians when crossing at intersections with signals (Petritsch et al., 2005). This model incorporated perceived safety and comfort (i.e., perceived exposure and conflicts) and operations (i.e., delay and signalization).

Chilukuri and Virkler sought refinements to the Highway Capacity Manual (2000) equation concerning pedestrian delay at signalized intersections, operating under the assumption that pedestrians approach an intersection in a random manner (Chilukuri & Virkler, 2005).

Traffic conflicts, crossing facilities, and delays were three potential aspects that Bian et al. took into consideration when determining pedestrian LOS at crosswalks(Bian et al., 2009). This study assessed pedestrians' perceptions of safety and comfort when crossing signalized junctions to ascertain how well intersections can accommodate them.

The Highway Capacity Manual (2010) provides standards for pedestrian level of service (LOS) at intersections with signals, considering factors like pedestrian delay, circulation area, and vehicular traffic attributes.

Nagraj and Vedagiri created a pedestrian level of service (LOS) framework specifically tailored for crosswalks at signalized intersections in Mumbai, India. Their approach involved incorporating pedestrians' perceptions of different factors that impact their movement. The crucial elements taken into account while formulating the model were the presence of turning and through traffic, the volume of pedestrians, and the amount of delay experienced by pedestrians. The development of the pedestrian delay model for Indian scenarios involved taking into account factors such as nonuniform arrival rate and signal non-compliance behavior. By considering the perceived level of service (LOS) as the dependent variable and identifying significant independent variables, a stepwise regression approach was used to create a model that accurately represented urban mixed traffic conditions.(Nagraj & Vedagiri, 2013)

Ye et. al also identified the factors affecting the PLOS at signalized intersection crosswalks under mixed traffic conditions in China and developed a model for estimating PLOS. In this study too, the important factors influencing PLOS at crosswalks were: turning traffic, through traffic, number of pedestrians, and pedestrian delay like the study done in Mumbai, India. (Ye et al., 2015). The study employed perceived LOS as the dependent factor. Both Pearson correlation analysis and linear regression methods were utilized to identify the key elements influencing LOS. To address the shortcomings of linear regression methods, cumulative logistic regression was applied to create a model suitable for mixed traffic scenarios in China. The findings indicated that the cumulative logistic model was a better match for the survey data compared to the linear regression model.

The Highway Capacity Manual (HCM) categorizes facilities into six levels of service (LOS), ranging from A to F. Threshold values for each category are determined using either a step function or medium value method. However, this approach has limitations, as it can be challenging to achieve a Rating A or Rating F due to user perceptions. Additionally, rigid threshold values restrict the subjective and quantitative aspects of service quality. To address these limitations, researchers have turned to data mining techniques for data classification. Cluster analysis, particularly the fuzzy C-means (FCM) clustering technique, has been widely used to classify data by identifying clusters and dissimilarities among them. In the context of urban road intersections, a few researchers have applied FCM clustering to define vehicle LOS classifications. (Fang et al., 2003)

Marisamynathan & Vedagiri developed an effective approach to estimate the Pedestrian Level of Service (PLOS) model in the context of mixed traffic conditions and establish threshold values for PLOS classification at signalized intersections in Mumbai, India. At first, they investigated the standard linear regression (CLR) method for determining PLOS. But, given the constraints of CLR, they employed fuzzy linear regression (FLR) to devise a PLOS model compatible with the mixed traffic scenarios in India. The researchers validated two models and found that the FLR model provides more precise predictions of the PLOS score. Additionally, they applied k-means and fuzzy C-means (FCM) clustering techniques to classify the PLOS score and compared the results based on time complexity and field values. The assessment revealed that while the k-means approach is quicker, it falls short in consistently producing threshold values. On the other hand, the FCM method ensures higher precision and effectiveness in setting threshold values for the PLOS rating at intersections with signals in mixed traffic scenarios(Marisamynathan & Vedagiri, 2017).

Paudel estimated level of service for crosswalks at signalized intersection using stepwise multiple regression analysis to find out the PLOS model in a case study of Tinkune-Suryabinayak road. The significant variables found during the study were: crosswalk surface rating, pedestrian crossing time & pedestrian flow. (Paudel, 2014)

CHAPTER 3: METHODOLOGY

3.1 Research Design

For the proposed study, all the relevant literature is thoroughly assessed to identify the important variables to be considered. A model framework was prepared for the study, outlining the types of variables to be examined. The selection of the site was done. Four sites were selected for the purpose of model training. Both qualitative and quantitative works were conducted. Subsequently, the field survey of the sites was done and captured through the use of cameras or smartphones. First, average pedestrian delay was calculated. A questionnaire survey of the pedestrians using the crosswalks was carried out. PLOS score was determined through the questionnaire. The PLOS score was correlated with variables from the field and videographic survey. The best-fit PLOS model for PLOS was modelled through stepwise regression method. Threshold values for the PLOS scores were classified into six scales ranging from A to F. Then, validation of the PLOS model was done. The framework of methodology is shown in Figure 3-1.

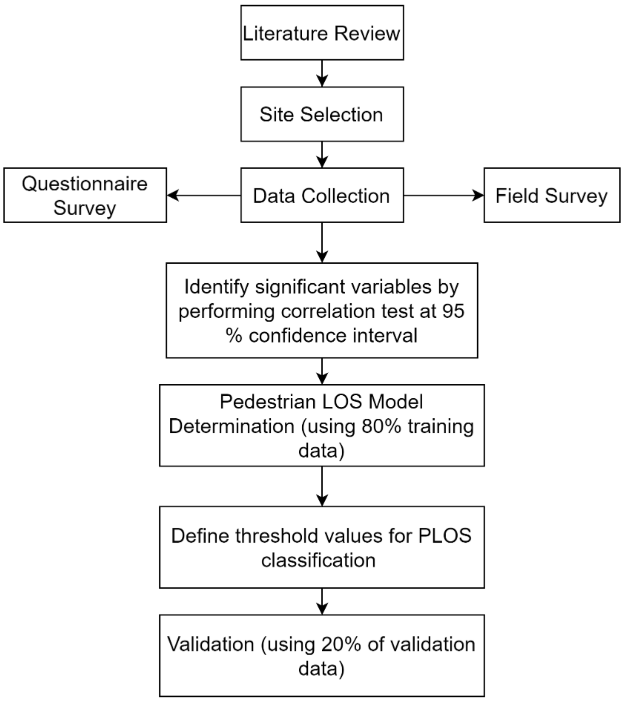

Figure 3-1: Framework of Methodology

3.2 Site Selection

The sites are to be selected that satisfies these requirements.

- Reasonable flow of pedestrians
- Presence of traffic signals for pedestrians
- Availability of crosswalks

Data was collected from five designated locations: Balkhu-Sanepa Crosswalk (Site ID: S-1), Sallahghari Crosswalk (Site ID: S-2), Balkhu-Vayodhya Hospital Crosswalk (Site ID: S-3), Balkhu-Kalanki Crosswalk (Site ID: S-4), and Balkhu-Dakshinkali Crosswalk (Site ID: S-5). The details of the sites that were taken for the study are as follows:

1. **Balkhu-Sanepa Crosswalk (Site ID: S-1)**

The first designated crosswalk location is situated at the Balkhu-Sanepa intersection, positioned to the east, approximately 200 meters away from Balkhu Bridge. This intersection falls within the Kalanki-Koteshwor section of Kathmandu Ring Road (H16) and has a four-legged configuration with pedestrian signals for safe crossing. However, the volume of left-turning traffic from entering vehicles coming from the west direction (as indicated by the arrow in the Figure 3-2) is quite low. This is due to the fact that the left-turning vehicles veer towards the service lane before reaching the intersection. This service lane connects to Sajha Petrol Pump in Balkhu which eventually leads to the adjacent-left side of the intersection. This location was chosen because it has operational traffic and pedestrian signals, with a reasonable flow of pedestrians in the area. Some information about the crosswalk is listed as follows:

- Co-ordinates of the site: 27°41'3.46"N, 85°18'6.34"E
- Length of the crosswalk: 35.8 m.
- Number of lanes:8

Site location and crosswalk site photographs are shown in Figure 3-2 & Figure 3-3 respectively.

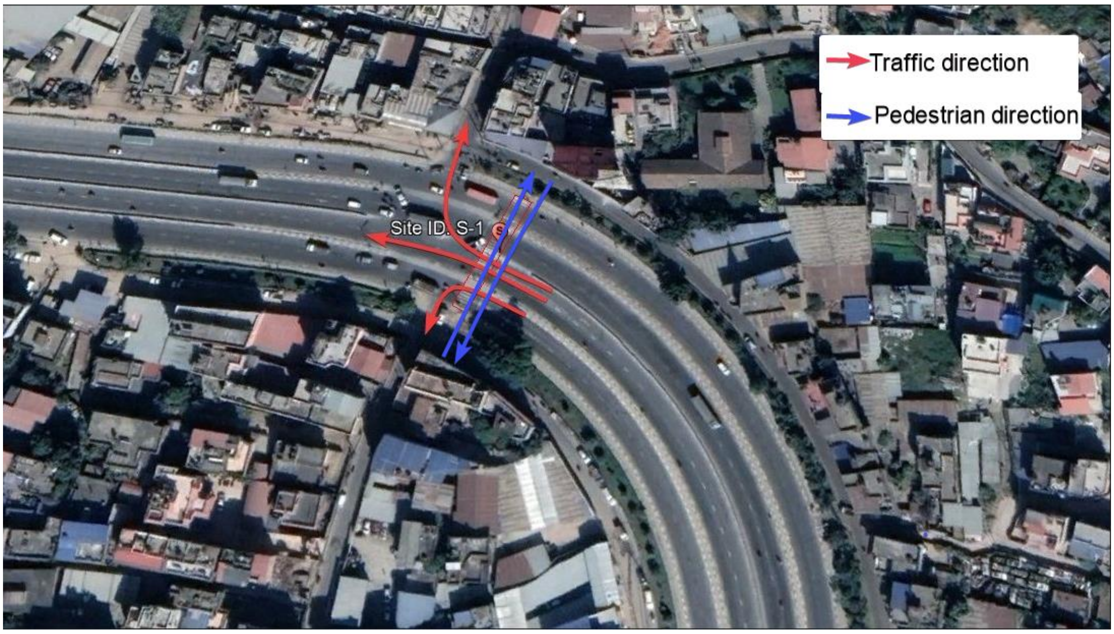

Figure 3-2: Site location of S-1 crosswalk


Figure 3-3: Site photograph of S-1 crosswalk

2. **Sallahghari Crosswalk (SITE ID: S-2)**

The Sallahghari intersection is situated in the Sallahghari section of Araniko highway (H03). It is located approximately 6 kilometers to the east of Koteshwor. The site location and crosswalk site photographs are as shown in the Figure 3-4 and Figure 3-5 respectively. As per the entering of the vehicle in the direction of travel (as shown by arrow in the Figure 3-4), traffic is diverted to through and in right direction. This intersection has a three-legged configuration. Some information about the crosswalk is listed as follows:

- Co-ordinates of the site: 27°40'17.82"N,85°24'31.01"E
- Length of the crosswalk: 22.5m
- Number of lanes:4

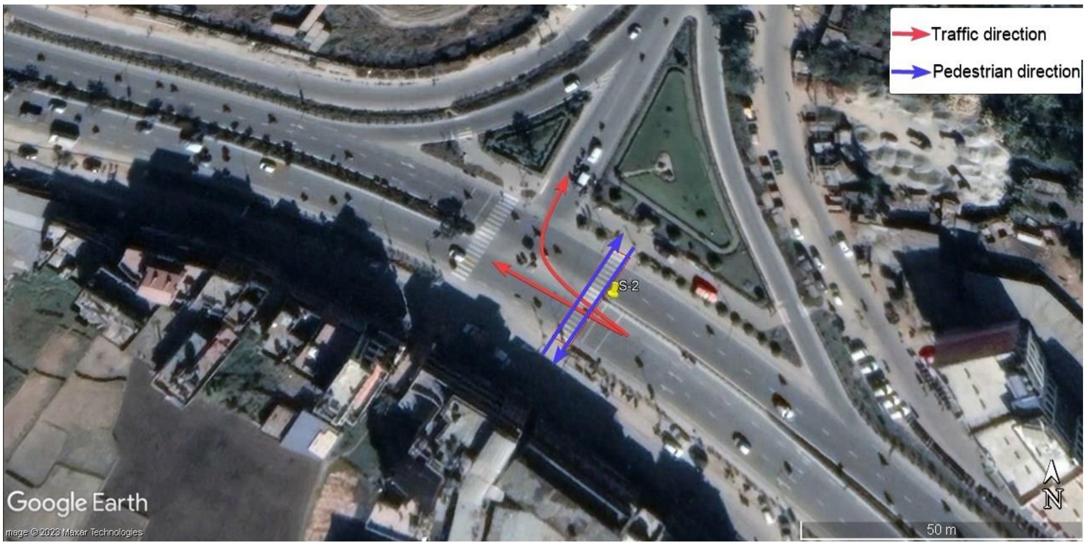

Figure 3-4: Site location of S-2 crosswalk

Figure 3-5: Site photograph of S-2 crosswalk

3. **Balkhu-Vayodhya Hospital Crosswalk (SITE ID: S-3)**

This intersection is located within the Kalanki-Koteshwor stretch of the Kathmandu Ring Road (H16). It's situated next to the western end of Balkhu bridge. Typically, there is a large number of pedestrians using this crosswalk. This characteristic had made it an ideal site for our study. The intersection is classified as a three-legged one, based on the entry routes for vehicles. Here are some details about the crosswalk:

- Co-ordinates of the site: 27°41'4.80"N,85°17'54.23"E
- Length of the crosswalk: 35.4m
- Number of lane: 8

The site location and crosswalk photograph is shown in the Figure 3-6 and Figure 3-7 respectively. This crosswalk was used for the validation of the model.

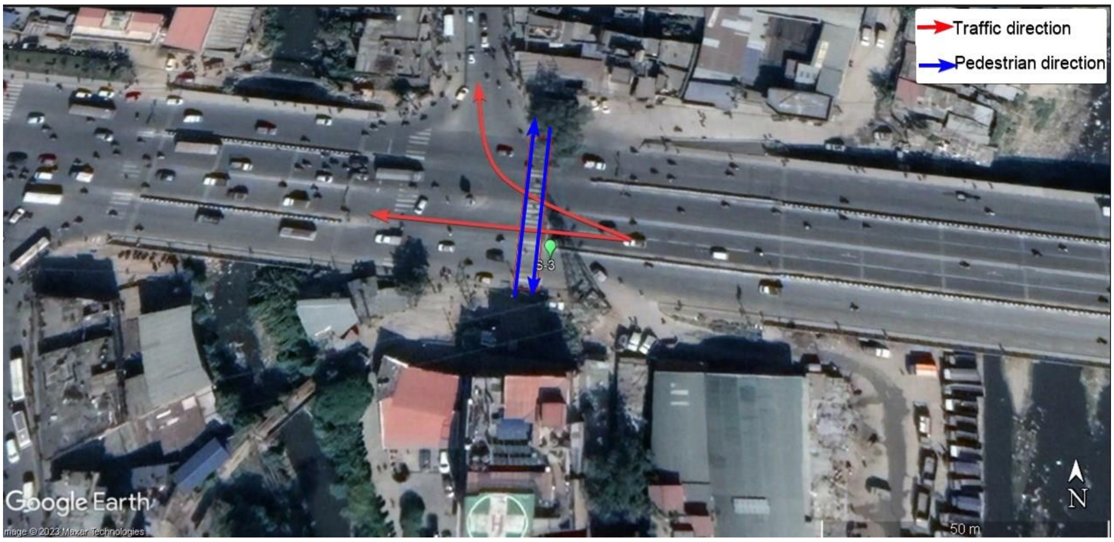

Figure 3-6: Site location of S-3 crosswalk

Figure 3-7: Site photograph of S-3 crosswalk

4. **Balkhu-Kalanki Crosswalk (SITE ID: S-4)**

The fourth crosswalk under investigation is found at Balkhu chowk, situated 150 meters to the west of Balkhu bridge. Like the previous crosswalk, this intersection is also part of the Kalanki-Koteshwor segment of the Kathmandu Ring Road. The pedestrian traffic at this crosswalk is quite high, as it is close to the bus stop for the Hetauda station. The direction of traffic considered as the entry in the intersection is as shown in the figure below. The layout of the intersection, based on the vehicles' entry directions, classifies it as a three-legged junction. Some information about the crosswalk is listed below:

- Co-ordinates of the site: 27°41'5.85''N, 85°17'49.74''E
- Length of the crosswalk: 35.8m
- Number of lanes:8

The site location and crosswalk photograph are shown in Figure 3-8 & Figure 3-9 respectively.

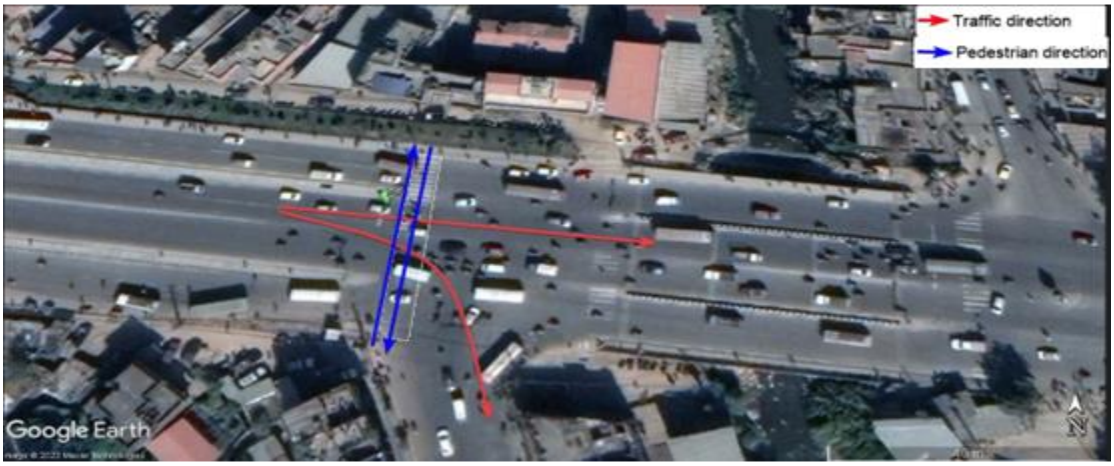

Figure 3-8: Site location of S-4 crosswalk

Figure 3-9: Site photograph of S-4 crosswalk

5. **Balkhu-Dakshinkali crosswalk (SITE ID: S-5)**

The fifth crosswalk taken for the study is Balkhu-Dakshinkali crosswalk. It lies adjacent to the S-4 crosswalk. The pedestrian traffic at this crosswalk is quite high, as it is also close to the bus stop for the Hetauda station. The direction of traffic considered as the entry in the intersection is as shown in the figure below. The layout of the intersection, based on the vehicles' entry directions, classifies it as a three-legged junction. To ensure uniformity and coherence with other study intersections, the categorization of vehicular volume incorporates the left turning volume as part of the through volume. While right turning traffic intersects with oncoming vehicles from the opposite direction, the left turning volume does not confront this oncoming traffic. This characteristic aligns it more closely with through traffic. Consequently, it has been classified under the through volume category. Some information of this crosswalk are as follows:

- Co-ordinates of the site: 27°41'4.85"N, 85°17'50.12"E
- Length of the crosswalk: 20.9 m
- Number of lanes :4

The site location and site photograph are shown in Figure 3-10 & Figure 3-11 respectively.

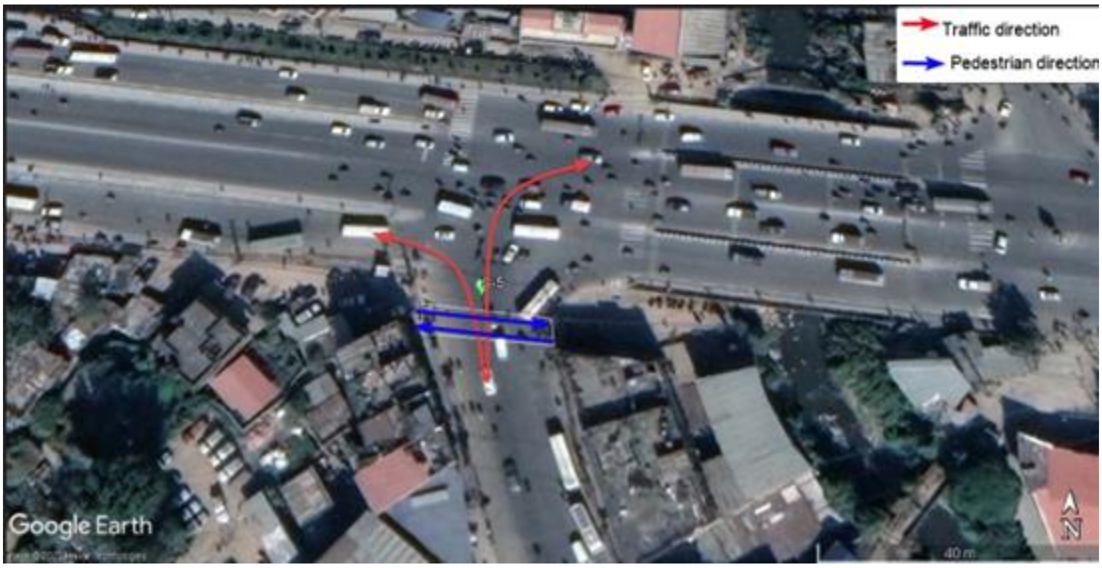

Figure 3-10: Site location of S-5 crosswalk

Figure 3-11: Site photograph of S-5 crosswalk

3.3 Method to calculate traffic volume

A manual method was used to count the traffic volume data by viewing the recorded video. The volume of the vehicles entering the intersection through the corresponding crosswalk according to various classification was done in intervals of 15 minutes.
Table 3-1 shows the vehicle types used in the traffic count and classification survey in all counting stations.
Figure 3-12 shows the typical visual representation of the vehicle types.

Table 3-1: Classification of vehicle

Vehicle Type	Vehicle Characteristics
Multi-Axle Truck	Standard / heavy trucks, trailers/articulated. (≥3 axles)
Heavy Truck	Standard / heavy trucks, trailers/articulated. (2 axles)
Mini Truck	Mid-sized trucks with single rear-axle (usually 4-wheeled,<8 tons GVW)
Big Bus	Buses having seating capacity of 35-50 seats
Mini-bus	Medium size buses having seating capacity of 20-35 seats.
Micro-bus	Small buses and vans having seating capacity of 10-15 seats.
Car	Passenger car taxis and vans (≤ 5 seats).
Utility Vehicles	Pickups or 4-wheeled vehicles with single/twin cabin and load compartment (open/hooded), Light freight vehicles

Vehicle Type	Vehicle Characteristics
Tractor	Farm tractors
Four Wheel Drive	Vehicles strictly having four-wheel gears (seating approximately 10) such as Mitsubishi Pajero, Prado etc.
Three-Wheeler	Electrical or gasoline/LPG fuelled 3-wheeled vehicles (excluding power tillers, farm tractors)
Power Tiller	Motorised four-wheel vehicles used for carrying goods and mainly driven by hands and not steering.
Motorcycle	Motorised two wheelers such as scooters and motorcycles
Bullock/Hand cart	Bullock, horse or manually driven vehicles (non-motorised)
Rickshaws	Non-motorised cycle rickshaws

Figure 3-12: Vehicle Types

Traffic data are presented in terms of Passenger Car Unit (PCU) by multiplying the total number of each type of vehicle with its equivalent PCU factor. The Passenger Car Units (PCU/veh) for different types of vehicles are presented in Table 3-2.

Table 3-2: Vehicle types and their equivalent PCU factors

SN	Vehicle Type	PCU Equivalency Factor
1	Car	1.0
2	Heavy Truck	3.0
3	Light Truck	1.5
4	Multi Axle Truck*	4.0
5	Tractor	1.5
6	Bus	3.0
7	Minibus	2.5
8	Microbus	1.5
9	Utility	1.0
10	Four Wheel Drive**	1.0
11	Motorcycle	0.5
12	Rickshaw	1.0
13	Three-wheeler (Auto Rickshaw)	0.75
14	Power Tiller***	1.5
15	Bullock Cart and horse –cart (Tonga)	8.0
Source: Statistics of Strategic Road Network (SSRN), HMIS unit, DoR (http://ssrn.aviyaan.com/) *PCU of Multi-Axle truck was taken as PCU of Heavy truck ** PCU of Four-Wheel Drive was taken as PCU of car *** PCU of power Tiller was taken as PCU of Tractor		

3.4 Method for finding out field data used for modeling

Various data were taken directly from on-site observations. The length of each crosswalk was ascertained using a measuring tape. In addition, the total number of traffic lanes at each location was manually tallied during field visits. Both vehicular traffic volume and pedestrian volume, along with the time taken for pedestrians to traverse the crosswalk, were derived from videographic surveys conducted at the intersections in 15-minute interval time period. Pedestrian speed was deduced through analysis of the collected data. PLOS score for each crosswalk was calculated through the questionnaire survey.

3.5 Method for finding average pedestrian delay

Data that were obtained were the number of pedestrians moving in both directions; downstream to upstream pedestrians, who encounter the downstream vehicle first; and upstream to downstream pedestrians, who encounter the upstream vehicle first. The use of smartphone was used for the collection of videographic data. Data of 1-h were collected for each crosswalk from 9.15 AM to 10.15 AM. At each green and non-green phase, the arrival time of the pedestrians (as shown in Figure 3-14) , the time at which the pedestrians depart from the starting end of the crosswalk (as shown in Figure 3-15) and the time at which the pedestrians reach the other end of the crosswalk (as shown in Figure 3-16) was noted. The average crossing time of the pedestrians was calculated as the time difference between the completion time and the arrival time of crossing. Along with it, the number of the pedestrians complying/ non-complying with the signals were also noted.

To find the ideal time for each crosswalk, the average time taken by the pedestrians to cross the particular crosswalk during the green phase was taken with the assumption that there were no conflicts during the green time of pedestrians. Thus, the delay was calculated as the time difference between the actual crossing time and the ideal time of crossing. Total average delay was the sum of delay during the green phase and non-green phase.

Figure 3-13: Representation of the arrival of pedestrians in the vicinity of crosswalk

Figure 3-14: Representation of the time of arrival of pedestrians at the starting end of the crosswalk

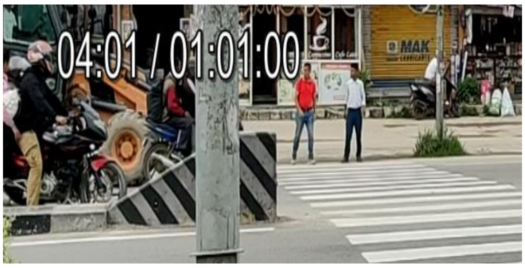

Figure 3-15: Representation of the time at which pedestrians depart from the starting end of the crosswalk

Figure 3-16: Representation of the time at which pedestrian reached the end of the crosswalk

3.6 Questionnaire

Surveys via questionnaires were conducted at the designated crosswalks. The time interval of 1 hour from 9.15 AM to 10.15 AM was subdivided into four 15-minute intervals. Questionnaire survey was done for 3-4 days at the respective crosswalks until sufficient data were collected. The one-hour duration, from 9:15 AM to 10:15 AM, was broken down into four distinct 15-minute segments. This questionnaire exercise was carried out over 3-4 days at the specific crosswalks until an adequate amount of data was collected. A representative photograph of the questionnaire survey process is shown in Figure 3-17.

Figure 3-17: Representative photograph of the questionnaire survey

The sample of the questionnaire is shown in APPENDIX A. The questionnaire was fixed in such a way that the questions could be categorized into three topics: Efficiency, Safety and Convenience. 5-point likert scale was fixed for each question in the questionnaire. The description of the categorical scale range is provided in the APPENDIX A. The design of the questionnaire was structured so that a lower score corresponded to a superior service level. This was achieved by arranging the Likert scale responses from "excellent" to "worse", assigning them values ranging from 1 to 5 in the questionnaire responses. Essentially, the more favorable the user feedback, the lower the numerical value it was assigned, making it intuitive to interpret higher quality with lower scores. Table 3-3 shows the description of the efficiency variables of questionnaire.

Table 3-3: Description of the efficiency variables of questionnaire

Grouping	Variable	ID	Type of variable	Score	Description
Efficiency (E)	Flow of pedestrians	E_1	Ordinal	1-Very low 2-Low 3-Moderate 4- Congested 5-Very Congested	It takes into account the total number of pedestrians using the crosswalk per minute basis.
	Adequacy of signal timing	E_2	Ordinal	1- More than adequate 2- Adequate 3- Satisfactory 4- Insufficient 5- Highly insufficient	Whether the signal timing is adequate or not
	Average waiting time	E_3	Ordinal	1: <10 seconds 2: 11- 25 seconds 3: 26-45 seconds 4: 46- 80 seconds 5:> 80 seconds	Average waiting time for crossing of the crosswalk.
	Crosswalk length	E_4	Ordinal	1: Very short 2: Short 3: Neutral 4: Long 5: Very long	Total width of the road section to be crossed.

Table 3-4 shows the description of the safety variables of questionnaire.

Table 3-4: Description of safety variables for questionnaire

Grouping	Variable	ID	Type of variable	Score	Description
Safety (S)	Overall Safety	S_a_1	Ordinal	1: Very Safe 2: Somewhat Safe 3: Neutral 4: Somewhat unsafe 5: Very unsafe	Overall perception of the safety at the crosswalk
	Vehicle blocking crosswalk	S_a_2	Ordinal	1: Never 2: Rarely 3: Sometimes 4:Often 5: Never	Whether the crosswalk is blocked by the vehicles
	Crosswalk marking /visibility	S_a_3	Ordinal	1: Very Visible 2: Somewhat Visible 3: Neutral 4: Somewhat invisible 5: Very invisible/non -presence	Visibility / presence of the crosswalk
	Vehicle yield	S_a_4	Ordinal	1: Always 2: Often 3: Sometimes 4: Rarely 5: Never	Whether the drivers yield to the pedestrians
	Effective traffic control	S_a_5	Ordinal	1: Very effective 2: Somewhat effective 3: Neutral	Whether the rules and signals are followed by the pedestrians and the drivers

Grouping	Variable	ID	Type of variable	Score	Description
				4: Somewhat ineffective 5: Very ineffective	
	Presence/ size of refuge island	S_a-6	Ordinal	1: Excellent 2: Good 3: Adequate 4: Poor 5: Non-presence	Whether there is presence of refuge island, and present, size of refuge island

Table 3-5 shows the description of the convenience variables of questionnaire.

Table 3-5: Description of convenience variables for questionnaire

Grouping	Variable	ID	Type of variable	Score	Description
Convenience (C)	Accessibility for disabled	C_1	Ordinal	1: Very accessible 2: Somewhat accessible 3: Neutral 4: Somewhat inaccessible 5: Very inaccessible	Accessibility for disabled pedestrians
	Sidewalk Continuity	C_2	Ordinal	1: Complete continuity 2: Substantial continuity 3: Partial continuity 4: Minimal continuity 5: No continuity	Continuation of the sidewalk at the end of the crosswalk

Grouping	Variable	ID	Type of variable	Score	Description
	Footpath Condition	C_3	Ordinal	1: Excellent Protection and Elevation 2: Good Protection and Elevation 3: Adequate Protection and Elevation 4: Poor Protection and Elevation 5: No Protection and Elevation	Condition of the footpath at the ends of the crosswalks

3.7 Statistical tools

Various statistical tools were used in this study majorly for questionnaire and modeling of PLOS. Among different statistical tools, the IBM SPSS v27 software package was used for the calculations and analysis for this study.

3.7.1 Reliability test

Cronbach's alpha, named after the American psychologist Lee Cronbach, is a statistical measure used to assess the internal consistency or reliability of a psychometric test or questionnaire. It is commonly employed in various fields, including psychology, education, and social sciences, to determine the extent to which a set of items within a test are measuring the same underlying construct. The alpha coefficient ranges from 0 to 1, with higher values indicating greater internal consistency. An alpha value closer to 1 suggests that the items in the test are highly correlated and effectively measuring the same construct. Conversely, a low alpha value, closer to 0, indicates a lack of internal consistency, indicating that the items in the test may not be adequately capturing the targeted construct. Researchers and practitioners often use Cronbach's alpha to evaluate and improve the reliability of their scales or questionnaires before conducting further analyses or drawing conclusions from the data. By identifying problematic items or subscales, they can refine the measurement instrument and ensure that it provides more consistent and accurate results. Analysts frequently use 0.7 as a benchmark value for Cronbach’s alpha. At this level and higher, the items are sufficiently consistent to indicate the measure is reliable. The range of reliability and its coefficient of Cronbach’s alpha is shown in Table 3-6.

Table 3-6: Range of reliability and its coefficient of Cronbach’s alpha

Coefficient of Cronbach’s alpha	Reliability Level
More than 0.90	Excellent
0.80-0.89	Good
0.70-0.79	Acceptable
0.60-0.69	Questionable
0.50-0.59	Poor
Less than 0.49	Unacceptable

3.7.2 Correlation test

Correlation is a statistical measure that quantifies the degree of relationship or association between two or more variables. It helps to assess how changes in one variable are related to changes in another variable. It's important to note that while correlation reveals a relationship between variables, it does not imply causation. Just because two variables are correlated does not necessarily mean that one variable causes the other to change. Establishing causation requires further experimentation, research design, and statistical analysis. Correlation is a valuable tool in understanding associations in data, but careful interpretation and consideration of other factors are necessary to draw meaningful conclusions.

Pearson’s correlation often symbolized as “r”, is a widely-used statistical measure that quantifies the strength and direction of a linear relationship between two continuous variables. Developed by Karl Pearson in the early 20th century, this coefficient has become a fundamental tool in statistical analysis across various disciplines. Pearson's correlation coefficient is the covariance of the two variables divided by the product of their standard deviations. Mathematically, it is represented as shown in (3-1).

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2)]}} \tag{3-1}$$

Where, x and y are the values of the two variables.

The value of this coefficient ranges between -1 and +1. A correlation coefficient of +1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 indicates no correlation between the variables.

3.7.3 Multiple regression model

Multiple regression is a statistical method used to understand the relationship between one dependent variable and two or more independent variables. It is an extension of simple linear regression that involves more than one predictor variable.

The general form of the multiple regression model is equation (3-2).

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + ... + \beta kXk + \varepsilon \tag{3-2}$$

Where:

- Y is the dependent variable (the variable we're trying to predict or explain)
- X1, X2, ..., Xk are the independent variables (the variables we are using to predict Y)
- β0 is the y-intercept (the value of Y when all independent variables are 0)
- β1, β2, ..., βk are the regression coefficients (the change in Y for a one-unit change in the corresponding X, holding other variables constant)

- ε is the error term (the difference between the observed and predicted value of Y, assumed to follow a normal distribution with mean 0)

The β coefficients are typically estimated using a method called least squares, which minimizes the sum of the squared differences between the observed and predicted values of Y.

Each β coefficient represents the change in the mean response, E(Y), per unit change in the corresponding predictor, when all the other predictors are held constant. For example, β1 represents the change in the mean response E(Y) per unit change in X1, when X2, X3, ..., Xk are held constant.

3.7.4 Stepwise-regression model

Step-wise regression is a statistical method used to select a subset of independent variables to build a regression model. It is an iterative process that involves adding or removing variables from the model based on their statistical significance and contribution to the model's performance. It is a specific method of selecting which variables to include in a multiple regression model. It involves running multiple rounds of regression, each time adding or removing variables based on certain criteria. The algorithm starts with no variables in the model, tests the addition or subtraction of each variable using a chosen model fit criterion, adds or removes the variable if appropriate, and repeats this process until no variables can be added or removed to improve the model. Some use a combination of both methods and therefore there are three approaches to stepwise regression:

Forward selection begins with no variables in the model, tests each variable as it is added to the model, then keeps those that are deemed most statistically significant—repeating the process until the results are optimal. Backward elimination starts with a set of independent variables, deleting one at a time, then testing to see if the removed variable is statistically significant. Bidirectional elimination is a combination of the first two methods that test which variables should be included or excluded.

3.7.5 K-means clustering

K-means clustering is a widely-used unsupervised machine learning technique aimed at segmenting a dataset into distinct, non-overlapping subgroups based on inherent similarities within the data (MacQueen, 1967). The primary goal is to form clusters so that the within-cluster variation is minimized.

Procedure:

Initialization: The algorithm initiates by picking 'k' centroids, either randomly or based on a specific strategy. In our case, since the level of service scale is predefined into six levels, the value is taken as 6.

Assignment: Data points are allocated to the nearest centroid, thereby associating them with a specific cluster.

Update: Post assignment, the centroids of the newly formed clusters are recalculated.

Iteration: The assignment and update steps are reiterated until the centroids stabilize, indicating convergence.

Outcome: The final output yields 'k' clusters with each member sharing common traits.

3.8 Method for developing PLOS model

Some of the factors that might affect pedestrian LOS at a signalized intersection were as follows (Raad & Burke, 2018):

- Factors related to the pedestrian environment
    - Crossing distance
    - Number of traffic lanes
    - Crosswalk width
    - Disabled access
    - Refuge island presence
    - Crosswalk markings
    - Pedestrian signal

- Factors related to the traffic system and users
    - Turning vehicles
    - Delay
    - Pedestrian crossing time
    - Vehicle volume
    - Pedestrian speed
    - Non-compliance
    - Pedestrian volume

The factors mentioned above were thoroughly studied and incorporated into the methods for the PLOS model development. The factors taken for the model development directly are the through traffic volume, right turning traffic volume, pedestrian volume, pedestrian delay, pedestrian crossing time, pedestrian speed and crosswalk length. Other factors such as refuge island presence, crosswalk markings, pedestrian signal adequacy, compliance of signal, average waiting time, perception of safety, effective traffic control, accessibility for disabled, footpath continuity and condition were also incorporated into the model through questionnaire survey.

After selecting the important factors affecting PLOS, statistical approaches were used for filtering and determining the variables of the model. The influence of independent variables on the dependent variable and the interdependence among the independent variables can be verified, establishing correlation of various variables with the help of tests like Pearson's correlation test, and this assists in the removal of the insignificant ones. Then, the best-fit model was developed by using stepwise regression.

Questionnaire surveys were done at the selected sites. Participants were asked to rate the crosswalk based upon the questions set by the surveyor. There was a total of 13 questions of 5-point likert scale. The questions were grouped under efficiency, safety and convenience. The main objective after modeling is to find out the ranges of the LOS in appropriate scale: LOS A, excellent; LOS B, good; LOS C,average; LOS D, inferior; LOS E, poor; LOS F, terrible. The mean survey rating of LOS from the field was taken as the dependent variable.

The field survey explored the factors related to the pedestrian environment, factors related to the traffic system and users, and pedestrian delay at the signalized intersection. Videos were taken from a nearby elevated space, and the data like number of pedestrians, pedestrian arrival time, start time, completion time, turning, and through vehicle data for each 15 min interval were extracted and used for model development. The scale for PLOS were determined based on the user's responses. The ratings from 10 to 50 were subdivided into 6 parts (LOS A to F) for the study. K-means cluster analysis was used to find threshold values for the PLOS range.

CHAPTER 4: ANALYSIS AND DESIGN

4.1 General

At first, the videographic data of the sites were analyzed and extracted. The videographs were taken nearby from the corresponding crosswalk with the help of camera stand and smartphone with permission of traffic police in the vicinity. The videographs were taken for 1 hour at the time 9.15 AM to 10.15 AM for every site and the time interval for study was subdivided into 15-minute intervals. Two groups of information were extracted from the videograph. The first being the traffic characteristics which includes the number of vehicles according to their classification based upon the HMIS unit of DoR. The number of vehicles entering the intersection through the crosswalk was recorded and converted into equivalent PCU. Similarly, pedestrian data was also extracted from the videographs. Pedestrian volume and pedestrian delay during the green and non-green phases along with the separation of Upstream and downstream pedestrian movement was analyzed and noted. The pedestrian delay was calculated for both green and non-green phases. Arrival time refers to the time at which the pedestrian arrives at the starting end of the crosswalk. Start time refers to the time at which the pedestrian starts to enter the crosswalk. End time/ Completion time refers to the time at which the pedestrian reaches the other end of the crosswalk. The crossing time was first calculated by subtracting the starting time from the completion time. Also, the time difference between the arrival time and start time, as well as the difference between arrival time and completion time was calculated. Similarly, the gender and status of compliance / non-compliance of the signal for each pedestrian was noted down. The average crossing time was calculated by averaging the actual crossing time of pedestrians at the green phase at each crosswalk.

After the completion of extracting data from videographic survey, questionnaire survey was done at the corresponding crosswalk in order to find the perception of the level of service at the site. A total of 408 pedestrians participated in the questionnaire survey (217 males, 191 females) in five different crosswalk locations.

4.2 Overview of the data

The data from the sites are analyzed and extracted. Five sites have been taken for the study. The following are some of the descriptive characteristics of the pedestrian data from the videographic survey. Table 4-1 shows the characteristics of data collection of pedestrians.

Table 4-1: Characteristics of data collection of pedestrians

Parameter	Site				
	S-1	S-2	S-3	S-4	S-5
Cycle time (s)	162	140	145	145	112
Green time (s)	25	20	45	45	25
Average number of pedestrian arriving during green phase (ped/15 min)	9	3	35	33	11
Average number of pedestrian arriving during non-green phase (ped/15 min)	45	11	58	51	43
Average delay of pedestrians (s)	27.61	25.01	39.11	36.15	46.9
Signal non-compliance rate of pedestrians (%)	98	73	10	77	95
Total average crossing time in green phase (s)	27	17	27	29	17
Length of crosswalk (m)	35.8	22.5	35.4	35.8	20.9
Average Speed of pedestrians (m/s)	1.33	1.323	1.31	1.23	1.24
Average Speed of males (m/s)	1.359	1.297	1.338	1.257	1.197
Average speed of females (m/s)	1.211	1.328	1.257	1.211	1.09
Male compliance rate (%)	1	20	90	21	4
Female compliance rate (%)	4	32	59	18	7

Parameter	Site				
	S-1	S-2	S-3	S-4	S-5
Average signal noncompliance rate both direction	71%				

Pedestrian data characterized according to gender from the videographic survey is as shown in Table 4-2.

Table 4-2: Pedestrian data based upon Gender

Gender	Total	Green phase	Non-green phase	Non-compliance	Non-compliance rate (%)	Average Speed (m/s)
Male	787	245	542	365	67.34	1.29
Female	418	118	300	194	64.67	1.22

The PCU of the entry vehicles at the corresponding intersection through studied crosswalks is shown in Table 4-3.

Table 4-3: PCU of entry vehicle at the intersection

SITE ID	Time (min)	Total PCU			Average LT	Average T	Average RT
		LT	T	RT			
S-1	0-15	1	402.5	41	2.25	367.4	44.6
	15-30	4	307	48.5			
	30-45	1.5	362.5	38			
	45-60	2.5	397.5	51			
S-2	0-15	0	398.5	45	0	384.8	36.5
	15-30	0	388	25.5			

SITE ID	Time (min)	Total PCU			Average LT	Average T	Average RT
		LT	T	RT			
	30-45	0	398	35			
	45-60	0	354.5	40.5			
S-3	0-15	0	434.5	141	0	428.6	137.5
	15-30	0	413.5	132.5			
	30-45	0	361	150.5			
	45-60	0	485.5	111			
S-4	0-15	0	524.5	78.5	0	541.1	66.5
	15-30	0	577.5	59.5			
	30-45	0	575	62.5			
	45-60	0	487.5	65.5			
S-5	0-15	0	46.5	522	0	59.5	479.4
	15-30	0	50.5	487.5			
	30-45	0	67	490.5			
	45-60	0	74	417.5			

The pedestrian volume at the studied crosswalks is shown in Table 4-4.

Table 4-4: Pedestrian Volume at the crosswalks

SITE ID		Pedestrian Volume			
	Time (min)	a	b	Total	Total Average
S-1	0-15	10	51	61	54.25
	15-30	4	38	42	
	30-45	11	57	68	
	45-60	12	34	46	
S-2	0-15	2	8	10	13.5
	15-30	4	12	16	
	30-45	4	9	13	
	45-60	2	13	15	
S-3	0-15	32	38	70	92.75
	15-30	32	57	89	
	30-45	32	61	93	
	45-60	44	75	119	
S-4	0-15	23	67	90	83
	15-30	39	40	79	
	30-45	33	43	76	
	45-60	35	52	87	
S-5	0-15	31	23	54	58.5
	15-30	26	20	46	
	30-45	45	19	64	
	45-60	51	19	70	

The pedestrian data who participated in the questionnaire survey is shown in Table 4-5.

Table 4-5: Pedestrian data participating in the questionnaire survey

Location	Gender		Age (%)		
	Male	Female	<25 years	25-59 years	>60 years
S-1	49	37	37	43	20
S-2	29	35	41	31	28
S-3	49	44	44	30	26
S-4	51	38	31	38	30
S-5	39	37	37	34	29

Summary:

- Female compliance rate (35.33%) was higher than male compliance rate (32.66%).
- Average speed of male (1.29 m/s) at the intersection was higher than that of females (1.22 m/s).

4.3 Questionnaire Analysis

The data from the questionnaire were noted in excel and extracted into SPSS for further analysis. The sample of questionnaire is shown in APPENDIX A. The scoring of questionnaire is shown in APPENDIX C.

4.3.1 Descriptive Statistics:

The descriptive statistics of the overall questionnaire data is shown in Table 4-6.

Table 4-6: Descriptive Statistics of overall data

	No. of sample	Min	Max	Mean	Std. Deviation
Flow of pedestrians	408	1	5	2.66	.885
Adequacy of signal timing	408	2	4	2.88	.738
Average waiting time	408	2	5	3.41	.893
Crosswalk length	408	3	5	4.31	.951
Overall Safety	408	2	5	3.41	.909
Vehicle blocking crosswalk	408	1	5	2.62	1.206
Crosswalk marking/visibility	408	2	5	3.63	1.238
Vehicle yield	408	2	5	2.84	.925
Effective traffic control	408	2	5	3.20	1.063
Presence/size of refuge island	408	3	5	3.97	.632
Accessibility for disabled	408	4	5	4.69	.462
Sidewalk continuity	408	2	5	3.00	.770
Footpath condition	408	2	3	2.56	.497
Valid N (listwise)	408				

4.3.2 Reliability Test

Cronbach's alpha test was used to find out the internal consistency of the variables of questionnaire. By measuring reliability of all questionnaire parameters, Cronbach's alpha was found to be 0.650. After removal of the variables from reliability test from SPSS to increase the Cronbach's alpha value, the Cronbach's alpha was found to be 0.736. Since the Cronbach's alpha value is greater than 0.7, this is acceptable. The questions removed from the original questionnaire due to inconsistency of the internal variables are: E-2 (adequacy of signal timing), E-4 (crosswalk length), and S_a-6 (presence/size of refuge island). Table 4-7 shows the Cronbach's alpha after removal of the inconsistent variables.

Table 4-8 shows further analysis of what happens to the Cronbach's alpha value when further parameters are removed. However, since the Cronbach's alpha value was at the acceptable limit, no further removal has been done.

Table 4-7: Reliability statistics

Reliability Statistics	
Cronbach's Alpha	N of Items
.736	10

Table 4-8: Reliability analysis

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Flow of pedestrians	29.35	23.064	0.130	0.752
Average waiting time	28.61	26.598	-0.265	0.802
Overall Safety	28.61	20.160	0.486	0.701
Vehicle blocking crosswalk	29.39	16.028	0.774	0.635
Crosswalk marking/visibility	28.39	17.792	0.539	0.689
Vehicle yield	29.18	18.734	0.670	0.670
Effective traffic control	28.82	17.777	0.675	0.663
Accessibility for disabled	27.32	24.254	0.107	0.744
Sidewalk continuity	29.02	20.648	0.531	0.698

4.4 Pedestrian Level of Service Model

A total of 1205 pedestrians (787 males and 418 females) were surveyed at five locations through videographic survey. The average pedestrian volume and pedestrian delay was extracted from the videos. Similarly, traffic characteristics like turning vehicular volume and through vehicle volume were also extracted from the videos.

The variables that were taken for the study were: Left-turning vehicles (LT), Through vehicles (T), Right-turning vehicles (RT), Average pedestrian volume (both directions) (P), Average delay (D), Crosswalk length(L), number of lanes(N), pedestrian crossing time (CT) and pedestrian walking speed (S). Pearson's correlation test was conducted to find out the variables for model development. The correlation matrix is shown in Table 4-9. The correlation matrix shows that no. of lanes (N) and length of Crosswalk (L), no. of lanes (N) and crossing time (CT) are highly correlated with correlation values as 0.997 and 0.979 respectively.

Table 4-9: Pearson’s correlation matrix

	PLOS	LT	T	RT	P	D	L	N	CT	S
PLOS	1	-0.316	-.685**	.928**	0.497	.879**	-0.342	-0.268	-0.231	-.569*
LT	-0.316	1	0.039	-0.292	-0.053	-0.387	0.496	.498*	0.445	0.202
T	-.685**	0.039	1	-.886**	0.152	-.535*	.706**	.656**	.642**	0.384
RT	.928**	-0.292	-.886**	1	0.174	.760**	-.604*	-.539*	-.514*	-.498*
P	0.497	-0.053	0.152	0.174	1	.527*	.574*	.625**	.660**	-0.370
D	.879**	-0.387	-.535*	.760**	.527*	1	-0.272	-0.209	-0.147	-.626**
L	-0.342	0.496	.706**	-.604*	.574*	-0.272	1	.997**	.974**	0.165
N	-0.268	.498*	.656**	-.539*	.625**	-0.209	.997**	1	.979**	0.123
CT	-0.231	0.445	.642**	-.514*	.660**	-0.147	.974**	.979**	1	-0.056
S	-.569*	0.202	0.384	-.498*	-0.370	-.626**	0.165	0.123	-0.056	1
**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).										

A total of 408 pedestrians participated in the questionnaire survey at the crosswalk locations. The PLOS score ranged from 10-50 after removal of inconsistent questions from 13 to 10 with the help of reliability test using Cronbach's alpha value. PLOS score, through questionnaire, was taken as the dependent variable for the model development.

The variables that have low correlation were not considered due to their poor correlation with the dependent variable. The variables that were selected for the model development are: through traffic volume (t), right-turn traffic volume (r) , average pedestrian volume (p), average pedestrian delay (d) and number of lanes (l). For the training of the model, sites S-1, S-2, S-4 and S-5 were selected. Videographic survey of 1 hour was subdivided into 15-minute intervals. Thus, a total of 16 data sets were taken for the model development. Table 4-11 shows the data for the training of the model.

The PLOS model was then developed with the PLOS score from the questionnaire as the dependent variable and significant independent variables using stepwise regression method and is shown in equation 4-1.

$$\text{PLOS Score} = \alpha 1 * \frac{RT}{10} + \alpha 2 * \frac{P}{10} + \alpha 3 * \frac{T}{10} + \alpha 4 * D + constant \quad (4\text{-}1)$$

Where, RT = right turning vehicles (PCU/15min)

P = number of pedestrians crossing the intersection every 15 min (Ped/15 min)

T = through vehicle (PCU/15 min)

D = average pedestrian delay (sec)

Constant = Regression model constant

The PLOS model parameters are shown in Table 4-10.

Table 4-10: PLOS model parameters

Coefficient	Value	Standard error	t-statistics	p-value
constant	19.577		16.308	0
α1	0.303	1.019	10.555	0
α2	0.457	0.214	4.736	0
α3	0.08	0.253	2.98	0.01
α4	0.073	0.127	2.213	0.05

Table 4-11: Training data for the model development

ID	Time (min)	LT	T	RT	P	D	L	N	CT	S	LOS
S-1	0-15	1	402.5	41	61	33.8	35.8	8	28.21	1.27	28.29
S-1	15-30	4	307	48.5	42	25.5	35.8	8	29.50	1.21	28.24
S-1	30-45	1.5	362.5	38	68	26.5	35.8	8	29.27	1.22	27.93
S-1	45-60	2.5	397.5	51	46	24.65	35.8	8	25.34	1.41	28.75
S-2	0-15	0	398.5	45	10	33.6	22.5	4	18.00	1.25	26.27
S-2	15-30	0	388	25.5	16	22	22.5	4	16.00	1.41	25.92
S-2	30-45	0	398	35	13	21.15	22.5	4	18.00	1.25	26.28
S-2	45-60	0	354.5	40.5	15	23.3	22.5	4	18.00	1.25	25.84
S-4	0-15	0	524.5	78.5	90	36.3	35.8	8	28.27	1.27	32.53
S-4	15-30	0	577.5	59.5	79	31.25	35.8	8	29.53	1.21	32.05
S-4	30-45	0	575	62.5	76	37.95	35.8	8	28.83	1.24	32.68
S-4	45-60	0	487.5	65.5	87	39.1	35.8	8	30.19	1.19	32.57
S-5	0-15	0	46.5	522	54	40.1	20.9	4	18.36	1.14	40.71
S-5	15-30	0	50.5	487.5	46	45.5	20.9	4	17.29	1.21	40.50
S-5	30-45	0	67	490.5	64	45	20.9	4	16.71	1.25	40.76
S-5	45-60	0	74	417.5	70	57	20.9	4	18.75	1.11	40.71

Table 4-12 explains that the fourth model which is the best fit model, R value is 0.995 and R square value is 0.991. R value of 0.995 suggests a very strong positive linear relationship between the predictor variables and the response variable (PLOS Score) in the stepwise regression model. R square value of 0.991 means 99.1% of the variability in the PLOS Score is explained by the predictors included in the model.

Table 4-12: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.928[a]	0.862	0.852	2.212
2	.989[b]	0.978	0.975	0.917
3	.993[c]	0.986	0.983	0.748
4	.995[d]	0.991	0.987	0.650
a. Predictors: (Constant), Right turn volume divided by 10				
b. Predictors: (Constant), Right turn volume divided by 10, Ped vol divided by 10				
c. Predictors: (Constant), Right turn volume divided by 10, Ped vol divided by 10, Through vol divided by 10				
d. Predictors: (Constant), Right turn volume divided by 10, Ped vol divided by 10, Through vol divided by 10, Average delay				

After training the model, Site S-3 was taken for validation purposes. Table 4-13 shows the validation of the model. The mean absolute percentage error (MAPE) value of the validation model was found to be 3.09 %. Thus, the model can be concluded as a fairly accurate predictor of the PLOS of signalized intersection crosswalks of Kathmandu Valley.

Table 4-13: Validation Data

SITE ID	Time (min)	RT /10	P/10	T/10	D	Field PLOS	Predicted PLOS	%change
S-3	0-15	14.1	7	43.45	41.9	32.44	33.58	3.52
S-3	15-30	13.25	8.1	41.35	32.4	32.12	32.97	2.65
S-3	30-45	15.05	9.1	36.1	37.2	33.15	33.90	2.26

SITE ID	Time (min)	RT /10	P/10	T/10	D	Field PLOS	Predicted PLOS	%change
S-3	45-60	11.1	10.2	48.55	44.95	33.45	34.77	3.94
MAPE (%)								3.09

After the model was calibrated and validated, the objective was to categorize the range of scores into six level of service ranging from A to F. The questionnaire was modeled such that lower the scores, better the level of service. For this, k-means clustering was used for determining the threshold values. But the PLOS scores sourced from field questionnaires did not align with the anticipated minimum and maximum values of 10 and 50 at the study areas. To address this gap and derive cluster centers closer to these expected values, dummy data were introduced into the analysis.

LOS A: 10 to 16.76
LOS B: 16.76 to 23.69
LOS C: 23.69 to 29.65
LOS D: 29.65 to 36.59
LOS E: 36.59 to 44.06
LOS F: 44.06 to 50

The number of data falling in each cluster is shown in Table 4-14.

Table 4-14: PLOS range and number of data in each scale

PLOS Scale	PLOS Range	No. of data
A	10.00-16.76	21
B	16.76-23.69	23
C	23.69-29.65	145
D	29.65-36.59	108
E	36.59-44.06	76
F	44.06-50.00	27

4.5 Comparison of proposed PLOS scale with Indo-HCM scale

According to Indo-HCM, PLOS for crosswalks have been categorized according to pedestrian delay values as shown in Table 2-1. Comparison of the values of the PLOS scale of Indo-HCM and the scale defined from the analysis of this study is shown in Table 4-15. When comparing the values, it is observed that most of the PLOS scores ranged in the same scale as that mentioned in Indo-HCM . But, some values didn't range in the same scale . This is due to the fact that Indo-HCM used only the pedestrian delay (in seconds) as the sole criteria for ranging the PLOS score range. But, in this analysis, pedestrian delay is not the sole criteria for ranging the PLOS score range but other values like right turning traffic volume, through traffic volume and pedestrian volume along with the pedestrian delay is considered during the model calibration.

Table 4-15: Comparison of Indo-HCM scale and Proposed Scale

SITE ID	Time (min)	RT/10	P/10	T/10	Avg delay	Field LOS	Predicted LOS	%change	Indo-HCM Scale	Proposed Scale
Training data										
S-1	0-15	4.1	6.10	40.25	33.8	28.29	29.29	3.55%	D	C
S-1	15-30	4.85	4.20	30.7	25.5	28.24	27.28	3.37%	C	C
S-1	30-45	3.8	6.80	36.25	26.5	27.93	28.67	2.66%	D	C
S-1	45-60	5.1	4.60	39.75	24.65	28.75	28.20	1.90%	C	C
S-2	0-15	4.5	1.00	39.85	33.6	26.27	27.04	2.94%	D	C
S-2	15-30	2.55	1.60	38.8	22	25.92	25.79	0.49%	C	C
S-2	30-45	3.5	1.30	39.8	21.15	26.28	25.96	1.21%	C	C
S-2	45-60	4.05	1.50	35.45	23.3	25.84	26.03	0.71%	C	C
S-4	0-15	7.85	9.00	52.45	36.3	32.53	32.91	1.17%	D	D
S-4	15-30	5.95	7.90	57.75	31.25	32.05	31.89	0.50%	D	D
S-4	30-45	6.25	7.60	57.5	37.95	32.68	32.31	1.13%	D	D

S-4	45-60	6.55	10.90	48.75	39.1	32.57	33.30	2.23%	D	D
S-5	0-15	52.2	5.40	4.65	40.1	40.71	41.16	1.11%	D	E
S-5	15-30	48.75	4.60	5.05	45.5	40.50	40.18	0.80%	D	E
S-5	30-45	49.05	6.40	6.7	45	40.76	41.18	1.03%	D	E
S-5	45-60	41.75	7.0	7.4	57	40.71	40.17925	1.29%	E	E
Validation data										
S-3	0-15	14.1	7.0	43.45	41.9	32.44	33.58	3.52%	D	D
S-3	15-30	13.25	8.1	41.35	32.4	32.12	32.97	2.65%	D	D
S-3	30-45	15.05	9.1	36.1	37.2	33.15	33.90	2.26%	D	D
S-3	45-60	11.1	10.2	48.55	44.95	33.45	34.77	3.94%	D	D

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The development of a Pedestrian Level of Service model for signalized intersection crosswalks is not just a theoretical advancement, but a practical necessity, especially in areas like Kathmandu Valley that face complex traffic conditions and growing pedestrian demands. This model can serve as a cornerstone for transportation authorities to quantitatively evaluate and qualitatively enhance the pedestrian environment, thereby ensuring a more balanced and inclusive urban mobility landscape.

For the purpose of this study, five sites were chosen that had functional pedestrian signals and availability of crosswalks. Despite this, there was a high incidence of pedestrians disregarding the signals, leading to frequent conflicts with vehicular traffic. The study used Pearson's correlation test to determine key factors affecting PLOS scores. Using the perceived PLOS score from the questionnaire as the dependent variable and the significant factors as independent variables, a stepwise regression analysis was conducted to establish the most suitable predictive model. The formulated PLOS model reflected the perception of pedestrians at signalized crosswalks. The questionnaires were designed in such a way that higher PLOS score reflected worse level of service of the crosswalk. The factors were taken into the model through questionnaires and were identified as: flow of pedestrians, average waiting time, overall safety, crosswalk marking/visibility, vehicle blocking crosswalk, vehicle yield, effective traffic control, accessibility for disabled, sidewalk continuity and footpath condition. The PLOS model included factors of perceived safety and convenience along with functional aspects (such as delay and signalization). The information used to construct the model was gathered through field observations. The data comprises pedestrians' perception of their sense of safety, ease, and functionality as they navigate specific signalized intersections, in addition to the design and operational characteristics of these crosswalks. Upon determining PLOS scores, our aim was to ascertain the threshold values for the PLOS scale. These intervals, ranging A to F, were defined using k-means clustering. The thresholds for each scale were set as follows:

Scale A ranged from 10 to 16.76, Scale B from 16.76 to 23.69, Scale C from 23.69 to 29.65, Scale D from 29.65 to 36.59, Scale E from 36.59 to 44.06, and Scale F from 44.06 to 50.

The real promise of the PLOS model lies in its potential to become an integral part of the transportation planning and design process. With the significant variables identified for affecting PLOS of signalized intersection crosswalks as right turning traffic, through traffic, average pedestrian delay, and average number of pedestrians, city planners and traffic management authorities could prioritize intersections that are most at risk. This can be achieved by gathering information of the respective crosswalks, finding out the PLOS scores, ranking & prioritizing them for further improvements. Implementing a baseline PLOS standard for pedestrian infrastructure design ensures that pedestrian considerations are integral to intersection planning, preventing their needs from being overshadowed by vehicular priorities.

5.2 Recommendation

It is imperative to recognize the constraints and potential areas of enhancement within our study. This research specifically targeted certain signalized intersections within the Kathmandu Valley. The precision and relevance of the model are dependent on the data at hand. By integrating a more comprehensive set of questionnaire survey data and metrics related to both pedestrians and traffic from a broader range of sites, the model's robustness could be markedly elevated. A potential research trajectory might involve broadening the model's parameters to account for diverse intersection types across varied pedestrian environmental contexts. The model could benefit from an expansion of both questionnaire and on-field parameters to encompass more scenarios. Furthermore, the typical delay experienced by pedestrians at the chosen intersections presents another potential dimension for subsequent investigation.

REFERENCES

Bian, Y., Ma, J., Rong, J., Wang, W., & Lu, J. (2009). Pedestrians’ Level of Service at Signalized Intersections in China. *Transportation Research Record: Journal of the Transportation Research Board*, *2114*(1), 83–89. https://doi.org/10.3141/2114-10

Chilukuri, V., & Virkler, M. R. (2005). Validation of HCM Pedestrian Delay Model for Interrupted Facilities. *Journal of Transportation Engineering*, *131*(12), 939–945. https://doi.org/10.1061/(ASCE)0733-947X(2005)131:12(939)

Dixon, L. B. (1996). Bicycle and Pedestrian Level-of-Service Performance Measures and Standards for Congestion Management Systems. *TRANSPORTATION RESEARCH RECORD*. https://doi.org/10.1177/0361198196153800101

Fang, F. C., Elefteriadou, L., Pecheux, K. K., & Pietrucha, M. T. (2003). Using Fuzzy Clustering of User Perception to Define Levels of Service at Signalized Intersections. *Journal of Transportation Engineering*, *129*(6), 657–663. https://doi.org/10.1061/(ASCE)0733-947X(2003)129:6(657)

Indo, H. C. M. (2017). Indian Highway Capacity Manual. *Council of Scientific & Industrial Research (CSIR). India*.

Landis, B. W., Vattikuti, V. R., Ottenberg, R. M., McLeod, D. S., & Guttenplan, M. (2001). Modeling the Roadside Walking Environment: Pedestrian Level of Service. *Transportation Research Record: Journal of the Transportation Research Board*, *1773*(1), 82–88. https://doi.org/10.3141/1773-10

Li, Q., Wang, Z., Yang, J., & Wang, J. (2005). Pedestrian delay estimation at signalized intersections in developing cities. *Transportation Research Part A: Policy and Practice*, *39*(1), 61–73. https://doi.org/10.1016/j.tra.2004.11.002

MacQueen, J. (1967). *Some methods for classification and analysis of multivariate observations*. *1*(14), 281–297.

Marisamynathan, S., & Vedagiri, P. (2017). Modeling Pedestrian Level of Service at Signalized Intersection Under Mixed Traffic Conditions. *Transportation Research Record: Journal of the Transportation Research Board*, *2634*(1), 86–94. https://doi.org/10.3141/2634-13

Miller, J. S., Bigelow, J. A., & Garber, N. J. (2000). Calibrating Pedestrian Level-of-Service Metrics with 3-D Visualization. *Transportation Research Record: Journal of the Transportation Research Board*, *1705*(1), 9–15. https://doi.org/10.3141/1705-02

Muraleetharan, T., Hagiwara, T., Adachi, T., & Kagaya, S. (2005). *METHOD TO DETERMINE PEDESTRIAN LEVEL-OF-SERVICE FOR CROSSWALKS AT URBAN INTERSECTIONS*. *6*. https://doi.org/10.11175/easts.6.127

Nagraj, R., & Vedagiri, P. (2013). Modeling Pedestrian Delay and Level of Service at Signalized Intersection Crosswalks under Mixed Traffic Conditions. *Transportation Research Record: Journal of the Transportation Research Board*, *2394*(1), 70–76. https://doi.org/10.3141/2394-09

Paudel, A. (2014). Analysis of pedestrian crossing speed and estimation of level of service for crosswalks at signalized intersections: A case study of Tinkure-Suryabinayak Road (Master's thesis). Pulchowk Campus, Institute of Engineering, Tribhuvan University.

Petritsch, T. A., Landis, B. W., McLeod, P. S., Huang, H. F., Challa, S., & Guttenplan, M. (2005). Level-of-Service Model for Pedestrians at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, *1939*(1), 54–62. https://doi.org/10.1177/0361198105193900107

Raad, N., & Burke, M. I. (2018). What Are the Most Important Factors for Pedestrian Level-of-Service Estimation? A Systematic Review of the Literature. *Transportation*

Research Record: Journal of the Transportation Research Board, *2672*(35), 101–117. https://doi.org/10.1177/0361198118790623

Sarkar, S. (1993). Determination of Service Levels for Pedestrians, with European Examples. *TRANSPORTATION RESEARCH RECORD*.

Virkler, M. R. (1998). Pedestrian Compliance Effects on Signal Delay. *Transportation Research Record: Journal of the Transportation Research Board*, *1636*(1), 88–91. https://doi.org/10.3141/1636-14

Ye, X., Chen, J., Jiang, G., & Yan, X. (2015). Modeling Pedestrian Level of Service at Signalized Intersection Crosswalks under Mixed Traffic Conditions. *Transportation Research Record: Journal of the Transportation Research Board*, *2512*(1), 46–55. https://doi.org/10.3141/2512-06

APPENDIX A: Sample Questionnaire

Dear Informant,

I am conducting a study for my thesis project "Modeling Pedestrian Level of Service for Crosswalks at Signalized Intersection in Kathmandu Valley". Your personal experiences and insights will significantly contribute to the understanding and enhancement of pedestrian safety and accessibility.

The following questionnaire will remain confidential and is aimed solely at enhancing pedestrian infrastructure in our city. I sincerely appreciate your contribution to this important study.

Please proceed with the questionnaire.

Site: __________

Name: ____

Gender: _____ *(1-Male, 2-Female)*

Age: _____ *(1:<25years, 2:26-59 years, 3: >60 years)*

How often do you use the signalized crosswalk at this intersection?

[ ] Daily

[ ] Several times a week

[ ] Once a week

[ ] Rarely

[ ] This is my first time

At what time of day do you typically use this crosswalk?

[ ] Morning (6 am - 10 am)

[ ] Mid-day (10 am - 2 pm)

[ ] Afternoon (2 pm - 6 pm)

[ ] Evening (6 pm - 10 pm)

[ ] Night (10 pm - 6 am)

1) **How would you rate the pedestrian flow at this crosswalk during peak hours?**

[ ] Very Low — *<1 pedestrians/minute*

[ ] Low — *1-10 pedestrians/minute*

[ ] Moderate — *10-20 pedestrians/minute*

[ ] Congested — *20-40 pedestrians/minute*

[ ] Very Congested — *>40 pedestrians/minute*

2) **How would you rate the adequacy of the signal timing for crossing the intersection?**

[ ] More than adequate: *Ample crossing time, extra time to spare even for people with mobility limitations*

[ ] Adequate: *Enough crossing time under normal walking condition*

[ ] Satisfactory: *Moderately sufficient crossing time for most of the pedestrians*

[ ] Insufficient: *People may feel rushed when crossing, and some might struggle to reach the other end before signal changes*

[ ] Highly insufficient: *Signal time too short to cross the road*

3) **On average, how long do you have to wait at the crosswalk signal before it changes?**

[ ] < 10 seconds

[ ] 11 seconds - 25 seconds

[ ] 26 seconds - 45 seconds

[ ] 46-seconds - 80 seconds

[ ] > 80 seconds

4) **How would you rate the length of the road crossing at the crosswalk?**

[ ] Very short: *1 lane*

[ ] Short : *2 lanes*

[ ] Neutral: *3 to 4 lanes*

[ ] Long *5 to 6 lanes*

[ ] Very long: *>6lanes*

5) **How would you rate the overall safety of the crosswalk?**

[ ] Very Safe: *Well illuminated, presence of street light, Good visibility, CCTV, constant monitoring by traffic police*

[ ] Somewhat Safe: *Any three parameters*

[ ] Neutral: *Any two parameters*

[ ] Somewhat Unsafe: *Any one parameter*

[ ] Very Unsafe: *None*

6) How often is the crosswalk blocked by vehicles, making it difficult for pedestrians to cross?

[ ] Never

[ ] Rarely

[ ] Sometimes

[ ] Often

[ ] Always

7) Is the crosswalk clearly marked and easily visible to both pedestrians and motorists?

[ ] Very visible *Crosswalk marking highly visible from a distance greater than 50m,with proper signage*

[ ] Somewhat visible *Crosswalk marking is clear and visible from a distance between 30-50m with proper signage*

[ ] Neutral: *Crosswalk marking is sometimes clearly marked and visible upto a distance of 10m, without proper signage*

[ ] Somewhat invisible: *Crosswalk marking somewhat faded but still distinguishable and without proper signage*

[ ] Very invisible: *No presence of crosswalk/ completely faded*

8) How often do vehicles yield to pedestrians at the crosswalk?

[ ] Always

[ ] Often

[ ] Sometimes

[ ] Rarely

[ ] Never

9) How effective are the traffic control measures in improving pedestrian safety at the crosswalk?

[ ] Very effective *Complete compliance of the signal*

[ ] Somewhat effective *Generally the rules and signals are followed by the road users*

[ ] Neutral *Often followed when presence of a authorization personnel*

[ ] Somewhat ineffective *Only few people comply with the signal*

[ ] Very ineffective *Generally none of the road user comply with the signal*

10) How would you rate the presence and, if applicable, the size of the refuge island?

[ ] Excellent	*Available and accommodate more than 15 pedestrians*
[ ] Good	*Available and accommodate 10-15 pedestrians*
[ ] Adequate	*Available and accommodate 5-10 pedestrians*
[ ] Poor	*Presence in the form of space in front of medians upto 5 people*
[ ] Non-presence	*No availability of refuge island*

11) How would you rate the accessibility of the crosswalk for individuals with disabilities?

[ ] Very accessible:	*Curb ramps, Accessible pedestrian signals, Tactile Walking Surface Indicators, Pedestrian Push Buttons, Extended signal timing*
[ ] Somewhat accessible:	*Any three parameters*
[ ] Neutral:	*Any two parameters*
[ ] Somewhat inaccessible	*Any one parameter*
[ ] Very inaccessible:	*None of the above*

12) How would you rate the continuity of the sidewalk leading to and from the crosswalk?

[ ] Complete continuity	*Sidewalk is continuous at both ends, extends more than 200m without any interruption or obstructions*
[ ] Substantial continuity	*Continuous at both ends, extends between 100-200m*
[ ] Partial continuity	*Continuous at one or both ends, extends between 50-100m*
[ ] Minimal continuity	*Sidewalk is barely continuous. It exists at one or both ends but extends less than 50m.*
[ ] No continuity	*Sidewalk doesn’t continue at either end*

13) How would you rate the footpath connecting to the crosswalk in terms of its protection and elevation?

[ ] Excellent Protection and Elevation	*Raised footpath, Continuous guard rails along at least a length upto or more than 100m.*
[ ] Good Protection and Elevation	*Raised footpath, continuous guard rails in some sections, length of section being less than 100m*
[ ] Adequate Protection and Elevation	*Raised footpath, discontinuous guard rails*
[ ] Poor Protection and Elevation	*Unraised footpath, discontinuous guard rails*
[ ] No Protection and Elevation	*Footpath is neither protected nor raised.*

APPENDIX B: Sample of Pedestrian Delay Data

SN	Direction	SITE ID	Gender	Phase	Status	Delay
1	a	S-1	M	G	C	1
2	a	S-1	F	G	C	3
3	a	S-1	M	G	C	3
4	a	S-1	M	G	C	2
5	a	S-1	M	G	C	2
6	a	S-1	F	NG	NC	63
7	a	S-1	F	NG	NC	33
8	a	S-1	F	NG	NC	0
9	a	S-1	F	NG	NC	0
10	a	S-1	M	NG	NC	-2
11	a	S-1	M	NG	NC	-5
12	a	S-1	M	NG	NC	3
13	a	S-1	F	NG	NC	4
14	a	S-1	M	G	C	1
15	a	S-1	F	G	C	3
16	a	S-1	M	G	C	3
17	b	S-1	F	NG	NC	32
18	b	S-1	F	NG	NC	4
19	b	S-1	F	NG	NC	75
20	b	S-1	M	NG	NC	58
21	b	S-1	M	NG	NC	39
22	b	S-1	M	NG	NC	34
23	b	S-1	M	NG	NC	-5
24	b	S-1	F	NG	NC	118
25	b	S-1	M	NG	NC	17
26	b	S-1	M	G	C	1
27	b	S-1	M	NG	NC	8
28	b	S-1	M	NG	NC	1
29	a	S-2	M	G	C	27
30	a	S-2	M	NG	C	64
31	a	S-2	M	NG	C	5
32	a	S-2	M	NG	NC	41
33	a	S-2	F	NG	C	20
34	a	S-2	M	NG	NC	-11
35	a	S-2	M	NG	C	33
36	a	S-2	F	NG	C	45
37	a	S-2	F	NG	NC	-11
38	a	S-2	M	G	C	-9

SN	Direction	SITE ID	Gender	Phase	Status	Delay
39	b	S-2	F	NG	NC	34
40	b	S-2	M	NG	NC	28
41	b	S-2	M	NG	NC	21
42	b	S-2	M	NG	NC	21
43	A	S-3	M	G	C	-4
44	A	S-3	F	NG	NC	1
45	A	S-3	M	NG	C	37
46	A	S-3	F	NG	C	77
47	A	S-3	F	NG	C	77
48	A	S-3	M	NG	C	60
49	A	S-3	M	NG	NC	1
50	A	S-3	F	NG	NC	1
51	B	S-3	F	G	C	9
52	B	S-3	F	G	C	9
53	B	S-3	M	G	C	-3
54	B	S-3	M	NG	C	106
55	B	S-3	F	NG	C	90
56	B	S-3	F	NG	C	82
57	B	S-3	M	NG	C	59
58	A	S-4	F	G	C	2
59	A	S-4	F	G	C	4
60	A	S-4	F	G	C	1
61	A	S-4	M	G	C	-1
62	A	S-4	M	NG	NC	-1
63	A	S-4	M	NG	C	32
64	A	S-4	M	NG	C	32
65	A	S-4	M	NG	NC	-4
66	A	S-4	M	NG	C	58
67	B	S-4	F	NG	NC	21
68	B	S-4	F	NG	NC	19
69	B	S-4	F	NG	NC	12
70	B	S-4	M	NG	NC	3
71	B	S-4	M	NG	NC	3
72	B	S-4	M	NG	NC	11
73	B	S-4	M	NG	NC	7
74	B	S-4	M	NG	NC	12
75	B	S-4	M	NG	NC	52
76	B	S-4	F	G	C	1
77	B	S-4	F	G	C	-3

SN	Direction	SITE ID	Gender	Phase	Status	Delay
78	B	S-4	F	G	C	1
79	B	S-4	M	G	C	-2
80	A	S-5	M	G	C	2
81	A	S-5	F	G	C	-1
82	A	S-5	F	G	C	-1
83	A	S-5	F	G	C	1
84	A	S-5	M	G	C	5
85	A	S-5	M	G	C	2
86	A	S-5	M	NG	NC	2
87	A	S-5	F	NG	NC	21
88	A	S-5	F	NG	NC	22
89	A	S-5	F	NG	NC	6
90	A	S-5	F	NG	NC	19
91	A	S-5	F	NG	NC	20
92	A	S-5	F	NG	NC	19
93	B	S-5	F	NG	C	61
94	B	S-5	M	NG	NC	5
95	B	S-5	F	NG	NC	8
96	B	S-5	M	NG	NC	11
97	B	S-5	M	NG	NC	13
98	B	S-5	M	G	C	6
99	B	S-5	M	G	C	1
100	B	S-5	F	NG	NC	4

Where,

a = direction of pedestrians from left end of the cross walk to the right end taken in the direction of entry of vehicles in the intersection

b = direction of pedestrians from right end of the crosswalk to the right end taken in the direction of entry of vehicles in the intersection

M = Male

F= Female

G= Green Phase

NG = Non-green Phase

C= Compliance to signal

NC = Non- compliance to signal

APPENDIX C: Sample of Questionnaire Score

ID	Time (min)	Gender *	Age **	Flow of pedestrian	Average waiting time	Overall safety	Vehicle blocking crosswalk	Crosswalk marking	Vehicle yield	Effective traffic control	Accessibility for disabled	Sidewalk continuity	Footpath condition	Overall rating
S-1	0-15	2	1	2	4	3	2	4	2	2	5	3	3	30
S-1	0-15	2	3	2	4	4	2	3	2	4	5	3	2	31
S-1	0-15	2	2	3	3	3	2	3	2	3	4	3	2	28
S-1	15-30	2	3	3	4	4	1	3	2	2	5	3	3	30
S-1	15-30	2	2	3	3	4	1	3	3	2	5	3	3	30
S-1	15-30	1	1	2	3	4	1	3	3	2	4	2	3	27
S-1	30-45	2	1	3	3	4	1	3	2	3	5	3	2	29
S-1	30-45	2	2	2	4	3	1	3	2	3	4	3	3	28
S-1	30-45	2	3	2	4	3	2	2	3	4	4	3	3	30
S-1	45-60	1	1	2	3	4	1	3	3	3	4	2	3	28
S-1	45-60	1	1	2	4	3	2	3	3	3	5	2	2	29
S-1	45-60	2	2	3	4	4	2	4	2	3	5	2	3	32
S-2	0-15	2	1	2	3	3	2	2	2	3	5	3	2	27
S-2	0-15	2	2	1	3	3	1	2	2	3	5	2	2	24
S-2	15-30	2	2	2	2	2	2	2	2	3	5	2	2	24
S-2	15-30	2	2	1	3	3	1	3	2	3	5	3	2	26
S-2	15-30	2	2	2	3	2	2	3	2	2	5	2	3	26
S-2	30-45	1	3	2	4	3	2	2	3	2	5	2	2	27
S-2	30-45	1	1	2	2	4	1	3	2	3	5	2	3	27
S-2	45-60	1	3	2	3	4	1	2	2	3	5	2	2	26
S-2	45-60	2	2	2	3	3	2	2	2	3	5	3	2	27
S-3	0-15	1	1	3	4	2	2	3	2	2	5	4	3	30
S-3	0-15	1	2	5	5	3	2	3	3	2	5	3	2	33
S-3	15-30	2	1	3	4	2	2	3	3	2	5	3	2	29
S-3	15-30	2	1	4	5	2	4	2	3	2	5	4	2	33

ID	Time (min)	Gender *	Age **	Flow of pedestrian	Average waiting time	Overall safety	Vehicle blocking crosswalk	Crosswalk marking	Vehicle yield	Effective traffic control	Accessibility for disabled	Sidewalk continuity	Footpath condition	Overall rating
S-3	30-45	2	1	4	4	3	3	3	3	3	5	3	2	33
S-3	30-45	1	3	4	3	2	2	3	2	2	4	4	2	28
S-3	45-60	1	2	4	4	2	2	3	3	3	5	4	2	32
S-3	45-60	2	2	3	4	4	4	4	3	2	5	4	3	36
S-3	45-60	1	2	3	5	2	3	2	3	3	5	3	3	32
S-4	0-15	2	2	3	3	4	3	5	2	3	5	2	2	32
S-4	0-15	2	2	3	3	3	2	5	2	2	5	3	3	31
S-4	15-30	2	3	3	3	3	2	5	3	3	5	3	2	32
S-4	15-30	1	1	3	3	3	2	5	3	3	4	3	2	31
S-4	30-45	2	2	2	3	4	3	5	2	3	5	3	2	32
S-4	30-45	2	2	2	3	4	2	5	2	3	5	3	2	31
S-4	45-60	2	2	2	3	4	2	5	2	3	4	2	3	30
S-4	45-60	1	2	3	4	4	2	5	2	4	5	3	2	34
S-5	0-15	1	2	3	2	5	4	5	5	5	5	4	3	41
S-5	0-15	2	3	2	3	5	5	5	5	5	5	4	3	42
S-5	0-15	2	3	4	2	5	5	5	5	5	5	4	3	43
S-5	15-30	1	1	3	3	5	5	5	4	5	5	4	3	42
S-5	15-30	1	1	2	3	5	5	5	5	5	5	4	3	42
S-5	30-45	1	1	3	3	5	5	5	4	5	5	4	3	42
S-5	30-45	1	2	4	2	4	5	5	5	5	5	4	3	42
S-5	30-45	2	1	2	2	5	5	5	4	5	5	4	3	40
S-5	45-60	2	3	3	2	5	4	5	5	5	5	5	3	42
S-5	45-60	1	3	3	2	4	5	5	4	5	5	4	3	40
S-5	45-60	1	3	2	3	5	4	5	5	5	5	3	3	40

* gender: 1- Male, 2-Female; **Age: 1- <25 years, 2: 26-59 years, 3: >=60 years