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Research Article

Strengthening Pedestrian Safety: An Evaluation of Signals at Major Intersections in Lahore, Pakistan

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Abstract: Pedestrians' safe mobility at intersections is associated with the facilities provided at the crossings. Lahore is one of the most populous cities in Pakistan. Too many road accidents occur daily at various areas of Lahore in which pedestrian-vehicle collision has a major ratio. To reduce the pedestrian-vehicle collisions, pedestrian signals are installed at major intersections of Lahore city. This paper examines the relationship between pedestrian signals and Level of Service (LOS), with a focus on enhancing awareness of pedestrian signal operation and investigates the impact of pedestrian signals on the LOS of intersections in Lahore in terms of pedestrian movement. Research shows that the poor level of awareness about how pedestrian signals work contributes to the inadequate level of service of intersections in terms of pedestrian movement. The results also provide valuable insights for policymakers and practitioners in developing effective strategies to improve the pedestrian experience and reduce pedestrian-vehicle collisions at intersections.

Keywords: Pedestrian-Vehicle Collision, Pedestrian Signals, Pedestrians Awareness, Pedestrian Safety.

1. INTRODUCTION

Road safety with respect to pedestrian movement, is an important issue in cities around the world. Pedestrians are among the most vulnerable road users, and ensuring their safety is crucial for creating a comfortable and sustainable urban environment. Lahore, one of the most populous cities in Pakistan, is reportedly facing many road accidents on daily basis at various areas of the city. Among these, the pedestrian-vehicle collision has a major ratio. In view of high volume of traffic and increasing number of pedestrian-vehicle collisions at major intersections and saturated roads of Lahore, the Punjab Safe Cities Authority (PSCA) has installed pedestrian signals at major intersections of the city. PSCA is an autonomous government body that aims to improve road users' safety and traffic management in the province of Punjab, Pakistan. The main purpose of these signals was the safety and facilitation of pedestrians at crossings. Safe walking environments especially, along roadside encourage physical activities of people [1]. Occasionally, it is noticed that individuals feel greater ease when walking or crossing in areas equipped with suitable amenities. Govinda *et al.* [2] performed a comparative study of pedestrian crossing behaviour at uncontrolled intersection and midblock locations in medium size cities (Warangal and Thiruvananthapuram in India) under mixed traffic conditions and noted that the minimum crossing speed observed at the intersection is higher than the midblock. In low and middle income countries (LMICs) walking is still under consideration by majority of travellers. In LMICs, pedestrians' safety and security are an important public health objective with regard to injury control, as pedestrians suffer most of the road traffic fatalities and injuries. Compared to low and middle income countries (LMICs), high income countries (HIC) with crossing facilities have documented a decrease in pedestrian fatalities [3]. A Global burden of disease study states that there were half a million of pedestrian fatalities

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in the year 2010 [4]. Pedestrian fatalities usually occurred at the time of road crossing. Being a road user, pedestrians often get injured or even die during interaction with intersecting vehicles [5].

Some researchers have studied pedestrian non-compliance behavior at signalized intersections for the purpose of developing pedestrian speed flow relations [6] and also delay models [7]. Pedestrian crossing behaviors are important to know in order to examine the working of pedestrian signals. Factors affecting pedestrian crossing behaviors were identified for the improvement of pedestrian safety at signalized intersections [8]. Pedestrians exhibited increased confidence and ease when crossing in the presence of traffic signals. Conversely, at locations without a traffic signal, pedestrians had to exert nearly twice as much effort in determining appropriate gaps in traffic and making crossing attempts [9].

Pedestrians using crosswalk during pedestrian green phase were considered as compliance pedestrians while those who were using crosswalk during non-green phase were considered as non-compliance pedestrians. The percentage of pedestrian compliance was defined as the ratio between the number of pedestrians using the crosswalk during green phase and total number of pedestrians that arrived at crosswalks. Similarly, Marisamynathan and Perumal studied that during pedestrian non-green phases, pedestrians are prohibited to enter the intersection that is important for their safety [10]. Whereas, during pedestrian green phase, pedestrian-vehicle interactions might have occurred due to driver's negligence, that needs to be controlled for the safe movement of pedestrians on the crossings. Pedestrians' two stage crossing behavior is of great significance to enhance safety and efficiency for pedestrians at signalized intersections. A research shows that pedestrians in the two directions present different preferences in terms of route choice, waiting position, directional change and route type. Two-stage crossing is an effective measure to increase the pedestrian flow rate and the intersection capacity [11]. Pedestrians' walking speed is also an important parameter for designing traffic signals at signalized intersections [12]. Varsha and Bindhu have examined some factors affecting pedestrian crossing speed which are important for the improvement of pedestrian safety at intersections. Their field study shows that the crossing speed of pedestrians varies mostly from the expected constant value of 1.2 ms^{-1} [13]. Moreover, to predict vulnerable pedestrians' behavior there is a need for the highest level of development in the field of pedestrian safety. In this regard, Yang *et al.* [14], have introduced a groundbreaking neural network architecture that combines distinct spatio-temporal features in order to predict pedestrian crossing intentions.

In Pakistan, a large number of road accidents occur on daily basis at various sections/intersections of major roads in meteropolitan/most populus cities such as Lahore, Karachi etc in which pedestrian-vehicle collision has a major ratio. To reduce the pedestrian-vehicle collisions, the road authorities has installed pedestrian signals at major road intersections in these cities which has resulted in a fair decrease in the road traffic colloisons/crashes. As an example a prominent trend of decrease in road traffic crashes (RTC) in the city of Lahore has been observed during the year 2019 [15]. The data publicized by Punjab Emergency Service (PES) mentioned that in 2017, almost 443 people were killed in road accidents, whereas, in year 2019 the figure was reduced to 350 showing a clear decline in casualties. With the aim to provide safe and convenient crossing for pedestrians as well as vehicles PSCA has installed pedestrian signals at 65 intersections of Lahore. The main objective of present investigation is the evaluation of pedestrian signals at 4 major intersections of Lahore with respect to activation, working, effectiveness, awareness and users' satisfaction. Furthermore, evaluation of Level of Service (LOS) of intersections with respect to pedestrians' movement is also analyzed using SIDRA intersection tool. LOS is usually ranked by two parameters E (unstable flow) and F (forced traffic flow). The unstable flow (E) refers to the condition when the flow becomes irregular and speed varies rapidly because there are virtually no usable gaps to maneuver in the traffic stream and speeds rarely reach the posted limit. On the other hand, the forced traffic flow (F) refers to the condition when the amount of traffic approaching a point exceeds the amount that can be served. Accordingly, this type of LOS represents stop-and-go waves, increased accident exposure, low comfort and convenience, and poor travel times.

2. STUDY AREA

Lahore, the capital of the Punjab province Pakistan, has been selected for evaluation of signals at major road intersections in the city. The city of Lahore is a bustling metropolis with mixed traffic conditions that require careful consideration for pedestrian safety. There are a total of 6 towns in Lahore where pedestrian signals are installed, i.e., Model Town, Civil Lines, Saddar, Cantt, Iqbal Town and Walled city. The study area chosen for this research is Mall road in Civil Lines Town. Mall road is one of the major roads in Lahore. This historic road was built by the British on a route leading to governor house. Mall road is a wide, major traffic thoroughfare which has enough space to run along most sections of the road. Mall road Lahore is the one which is totally equipped with most of the technologies of Intelligent Transportation System under PSCA that is why this road is selected as study area. This road has 12 intersections in total among which only 4 four intersections namely, Faisal intersection, Regal intersection, GPO intersection and High Court intersection shown in Figure 1, on which pedestrian signals are fully operative have been selected for the analysis. These are the major intersections of Lahore having a minimum of 3 lanes road and a maximum of four lanes road with a greater volume of pedestrians.

3. RESEARCH METHODOLOGY

Current research has analyzed several pedestrian crossing behaviors at 4 selected signalized intersections on Mall road Lahore to provide insights for improving pedestrian safety. Figure 2 highlights the schematics/research methodology used in the present investigation.

The primary data about pedestrians crossing facility design, pedestrians' volume and signal control were obtained from field through pedestrians countdown survey. The pedestrian count surveys were conducted for peak hours in a single day. This data was used to evaluate the working of the pedestrian signals. Moreover, the data about awareness level, pedestrians' priority to cross the road, frequency of crossing, impact and effectiveness of pedestrian signals were also obtained from questionnaire survey. The questionnaire survey was divided into five sections i.e. socioeconomic factors, awareness level, usage/non-usage of signals, impact of signals on pedestrian accidents and effectiveness. The sample size comprised of 600 questionnaires. SPSS and SIDRA intersection tools were used for data analysis.

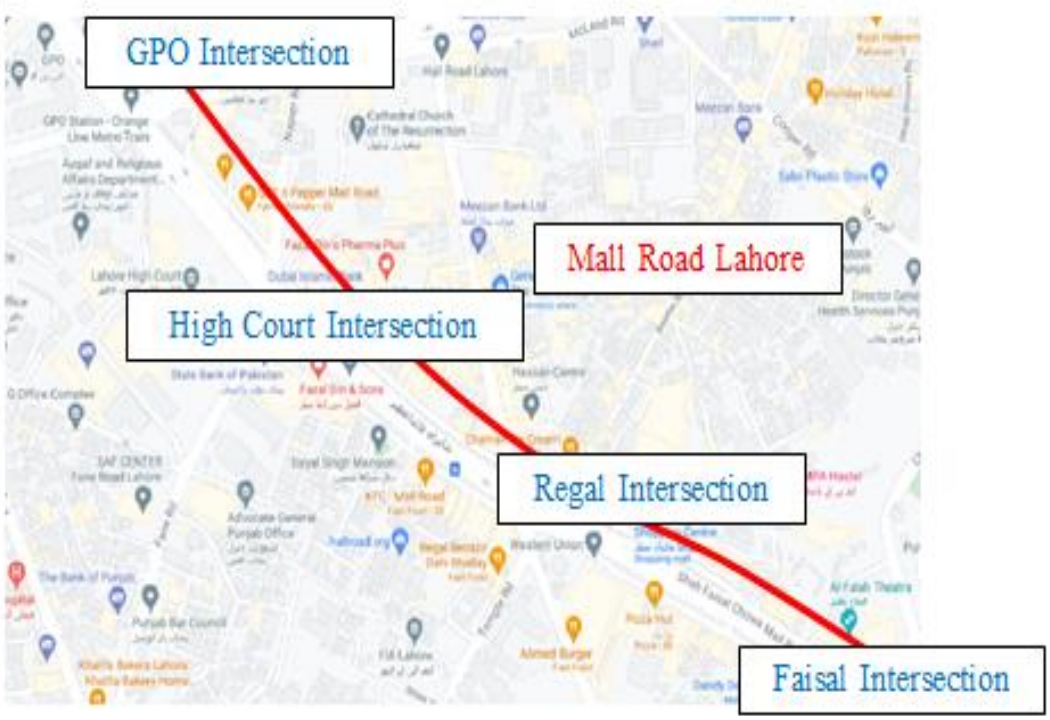

Fig.1. Map of study area/selected intersections on Mall road, Lahore

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis

Table 1 presents descriptive analysis with respect to various statistical parameters such as; (i) socioeconomic characteristics (age), (ii) awareness level of pedestrian signals, (iii) effectiveness of pedestrian signals (obeyance to follow pedestrian signals or otherwise, (iv) safety: reasons of pedestrian vehicles collisions, decrease in pedestrian vehicle collisions. The descriptive results shows that 30 % of respondents were females and 70 % were males. Maximum participants were of age between 20-35 years. Descriptive statistics show that 21 % of participants thought that pedestrians should cross the road whenever get a chance, while 41 % thought that pedestrians should cross the road when traffic light is red which is a safer option for the pedestrians. Moreover, 25 % of participants stated that they should watch the traffic flow before crossing the street while, 13 % suggested that pedestrians should not interrupt the flow of traffic if there is no urgency. Regarding the awareness of the pedestrian signals, only 44 % of pedestrians were aware of these signals but they were not fully aware about the working and usage of the signal. Furthermore, 34 % of participants said that they do not follow the signals. Some of the reasons were that they cannot wait much as it is time taking and sometimes crossing at intersection is not feasible as it is away from their destination. 51 % of users mentioned that awareness of pedestrian signals should be increased among people and 31 % stated that law enforcement should also be implemented to increase the effectiveness of these signals. Result shows that according to users' perspective 49 % of pedestrian vehicle collisions were due to the irresponsibility of drivers as well as pedestrians. Moreover, 55 % statistics shows that accidents take place due to the pedestrians who do no follow

Table 1. Descriptive statisctics

Variables	**Description**	**Distribution (%)**	**Frequency**
Socioeconomic characteristics			
Gender	Male	70	421
	Female	30	179
Age	<20	23	138
	20-35	63	375
	36-50	11	66
	51-65	2	17
	>65	1	4
Awareness level			
Awareness of pedestrian signals	Fully aware	21	126
	Aware	44	262
	Somewhat aware	29	176
	Not Know	6	36
Effectiveness of pedestrian signals (PS)			
Effectiveness of pedestrian signal	Very effective	17	103
Do you follow pedestrian signals?	Effective	57	344
	Neutral	21	124
	Not ffective	5	29
Reasons of not following the pedestrian signal	Always	39	234
	Sometimes	40	242
	Rarely	16	97
	Never	5	27
Reasons of pedestrian vehicle collisions	Time taking	34	206
	Away from destination	26	155
	Pedestrian Bridge is Provided	20	120
	Other	20	119
Safety			
	People donot follow signals	55	332
	High traffic volume	20	118
	High traffic speed	14	82
	Existing signals are not working	9	57
	Other	2	11
Decrease in pedestrian vehicle collisions	Increase in number of pedestrian crossing locations	12	73
	Raise awareness	51	306
	Law enforcement	31	183
	Increase speed bumps	6	38

the signals. According to users' perspective there was decrease in pedestrian-vehicle collision after the installation of pedestrian signals. Almost there was 51 % decrease is the accidents by raising the awareness about the installation and working of pedestrian signals which shows the effectiveness of pedestrian signals in reducing the pedestrian-vehicle collision. Moreover, 57 % of respondents mentioned that it is effective as per safety of the pedestrians if followed properly.

4.2 Intersection Analysis (SIDRA)

Faisal intersection, Regal intersection, GPO intersection and High Court intersection are located at mall road. All four intersections are four legged intersections with maximum of four lanes in each direction. Analysis was done using SIDRA intersection tool to check the level of service (LOS) and delays of these intersections with respect to pedestrians movement. The pedestrian volumes of Faisal intersection, Regal intersection, GPO intersection and High Court intersection were collected for peak hour of a day. Hourly average pedestrian volume at each intersection is given in Table 2.

A summary of the overall statistical analysis with regards to pedestrian characteristics (i.e., travel speed, travel distance, travel time, demand flow and control delay at intersections along with LOS of the intersection with respect to pedestrians' movement) for the four selected intersections on the Mall road (Table 3) is disscused in the following sections.

Table 2. Average pedestrian volume/hour

Cross walk location	Average pedestrians (volume/hour)
Faisal intersection	255
Regal intersection	268
GPO intersection	368
High Court intersection	208

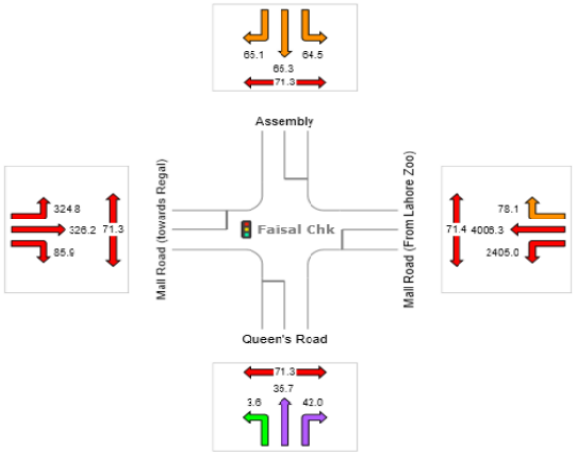

Fig. 3. LOS of Faisal Intersection Mall Road

4.2.1 Faisal Intersection

Table 3 shows that at Faisal intersection, the pedestrians were walking at an average speed of 1.9 km/h with total distance travelled of 17.6 pedestrian-km/hr. The delay time that the pedestrians were facing at this intersection was 7 1sec with a total hourly flow rate of 268 pedestrians/hour. Based on these values the overall pedestrian LOS at Faisal intersection (Figure 3) is ranked as "F" which means that all walking speeds were severly restricted and that there was frequent unavoidable contact with other pedestrians.

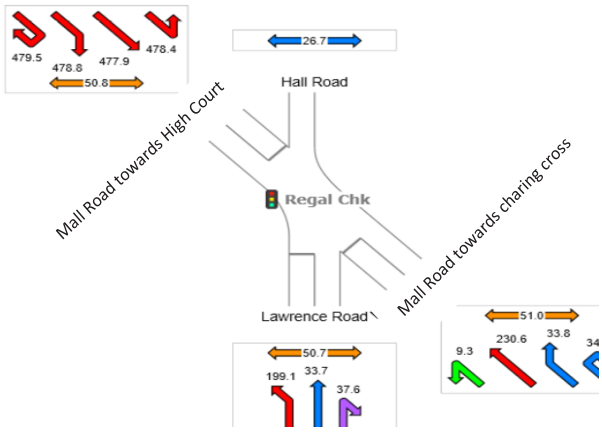

Fig. 4. LOS of Regal Intersection Mall road

Table 3. Intersection summary for pedestrians

Intersections	Travel speed (km/h)	Travel distance (Ped-km/h)	Travel time (Ped/h)	Demand flow (Ped/h)	Control delay (sec)	LOS
Faisal	1.9	17.6	9.1	268	71	F
Regal	1.8	11	6.1	272	50	E
GPO	1.4	16.6	12.3	387	81	F
High Court	2	8.6	4.4	219	42	E

4.2.2 Regal Intersection

Table 3 shows that at Regal intersection, the pedestrians were walking at an average speed of 1.8 km/h with a total distance travelled of 11 pedestrian-km/hr. The delay time that the pedestrians were facing at this intersection was 50 seconds with a total hourly flow rate of 272 pedestrians/hour. Based on these values the overall pedestrian LOS at Regal intersection (Figure 4) is classified as E which means that nearly all pedestrians restricted their normal walking speed and that space was not sufficient for passing slower pedestrians.

4.2.3 GPO Intersection

Table 3 shows that at GPO intersection, the pedestrians were walking at an average speed of 1.4 km/h with a total travelled distance of 16.6 pedestrians-km/hr. The delay time that the pedestrians were facing at this intersection was 81 sec with total hourly flow rate of 387 pedestrians/hr which results in pedestrian LOS F as shown in Figure 5.

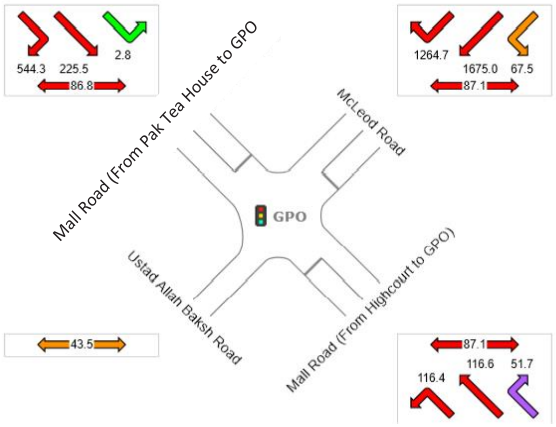

Fig. 5. LOS of GPO Intersection Mall Road

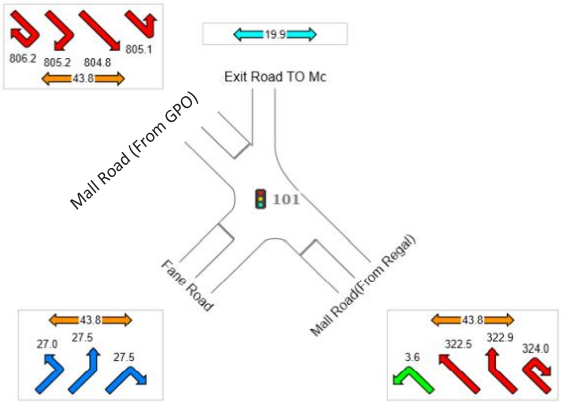

Fig. 6. LOS of High Court Intersection Mall Road

4.2.4 High Court Intersection

At High Court intersection in Table 3 shows the pedestrians were walking at an average speed of 2.0 km/h with the total distance travelled by pedestrian was 8.6 ped-km/hr. The delay time that the pedestrians were facing at the intersection was 42 sec with a total hourly flow rate of 219 ped/hour. Based on these values the overall pedestrian LOS at High Court intersection (Figure 6) is classified as E. The analysis shows that overall working of pedestrian signal at the intersection was not good enough in terms of delays and user satisfaction, which needs to be improved. This may be because of the lack of awareness about the usage and importance of the pedestrian signals which needs to be disseminated among masses travelling through this intersection. Figure 3 and figure 5 shows that pedestrians' LOS at Faisal intersection and GPO intersection was "F" which means that all walking speeds were severely restricted, and forward progress was made only by shuffling. There was frequent unavoidable contact with other pedestrians. Cross-and reverse-flow movements were virtually impossible which made the flow irregular and unstable. Space is a property of queued pedestrians than of moving pedestrians. On the other hand, figure 4 and figure 6 shows that pedestrians' LOS at Regal intersection and High Court intersection was E which means that nearly all pedestrians restricted their normal walking speed. Forward movement was possible only by shuffling. Space was not sufficient for passing slower pedestrians. Cross or reverse-flow movements were possible only with extreme difficulties. Design volumes approached the limit of walkway capacity which caused interruption of flow and difficulty in crossing.

5. CONCLUSION

The deployment and execution of the pedestrians' signals within the Lahore city has developed a great sense of responsibility among the road users. With this system, road users understand the value of road safety in true sense and meaning, which indeed guides them to follow the traffic rules. The present study has analysed the response of the pedestrians to the signals that are in use at various

road intersections within the Lahore city as a part of the transportation system. The pedestrian-vehicular interaction and the influencing factors on intersection LOS, providing an in-depth understanding of the factors that affect pedestrian safety has also been analyzed.

The study found that only 44 % of participants were aware of pedestrian signals at the intersection, while 34 % did not follow the signals due to inconvenience. To reduce pedestrian-vehicle collisions, 51 % suggested awareness campaigns, 31 % favored law enforcement and 57 % found pedestrian signals effective. The analysis of pedestrian signals reveals that working of pedestrian signals with respect to pedestrian movement was not perfect. At Faisal intersection the delay time that the pedestrians were facing was 71sec with a total hourly flow rate of 268 ped/hour. Based on these values the overall LOS of intersection was F. At Regal intersection the delay time was 50 seconds with a total hourly flow rate of 272 ped/hour. In addition, the overall LOS of intersection was E. Furthermore, analysis shows that at GPO intersection, the delay that the pedestrians were facing at this intersection was 81 seconds with total hourly flow rate of 387 ped/hour which results in overall intersection LOS as F. At High Court intersection, the delay time that the pedestrians were facing was 42 seconds with a total hourly flow rate of 219 ped/hour which results the LOS as E. The analysis shows that overall working of pedestrian signal at the intersection was not good enough in terms of delays and user satisfaction, which needs to be improved.

It is envisaged that the present studies will help to develop pedestrian delay models and pedestrian LOS (level of service) models at signalized intersections, which can be used by concerned authorities and policymakers to make informed decisions and who strive to make signalized intersections safer for all road users.

6. RECOMMENDATIONS

The following recommendations are made to improve pedestrian safety and to reduce pedestrian vehicle collisions:

- Conduct awareness campaigns to educate the public about pedestrian signals.
- Optimize pedestrian signal placement and timing to reduce delays and improve convenience.
- Coordinate pedestrian signals with traffic signals to improve safety.
- Increase law enforcement to ensure compliance with traffic rules.
- Regularly evaluate and improve pedestrian signals.

By implementing these recommendations, pedestrian safety can be improved, collisions reduced, and a better user experience may be provided for pedestrians.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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