

# IDENTIFICATION OF FACTORS AFFECTING PEDESTRIAN LEVEL OF SERVICE OF CROSSWALKS AT ROUNDABOUTS

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**Abstract** - Walking is the most basic mode of commute and is an essential part of transportation. Every trip essentially starts or ends with a walk trip. Over the years, it has been realized that in order to encourage walking and non-motorized transport and reduce the use of personal vehicles, pedestrian facilities need to be provided keeping in mind the requirements of the users and also improving the serviceability of the facilities. Roundabouts form an integral part of the road network and offer many advantages over conventional signalized and unsignalized intersections. Crosswalks are a critical element of pedestrian infrastructure at roundabouts. For improving the level of service of crosswalk facilities and enhancing the level of safety and comfort perceived by the users, identification of factors which significantly affect pedestrian level of service at crosswalks is very important. Only after the identification of these factors, measures can be taken to improve the facility. In this paper, review of existing literature on pedestrian level of service of crosswalks has been done and significant factors are identified.

**Key Words:** Crosswalks, Roundabouts, Pedestrian facilities, Level of service, Signalized intersection, Midblock crossings

## 1. INTRODUCTION

Walking is the most basic mode of transport. To enable and encourage walking for different purposes a sound pedestrian infrastructure needs to be provided to support the physiological, psychological and social needs of pedestrians and ensure them against overexertion, interference by other pedestrians and accidents [1]. The term 'Pedestrian' includes people who walk, sit, and stand in public spaces, or use a mobility aid like a walking stick, crutches or wheelchair, be they children, teenagers, adults, elderly persons, persons with disabilities, workers, residents or shoppers [2]. Developing a pedestrian environment means more than constructing a footpath or installing a signal. The most important aspect of a pedestrian friendly design is keeping in mind the perception of pedestrians regarding safety, comfort, convenience, economy etc. and all the factors which affect their perception. Since the pedestrian environment is multi-dimensional, the pedestrian in the roadside

environment is subjected to a set of several factors significantly affecting his or her perception of safety, comfort, and convenience. Measurement of these factors is necessary to evaluate the pedestrian facilities and evaluation methods are needed to understand how well a particular street accommodates pedestrian travel. Many transport planners and designers are now considering roundabouts to improve vehicle safety, increase roadway capacity and efficiency, and to reduce vehicular delay and emissions. Pedestrian crosswalks at roundabouts are provided to increase pedestrian safety and convenience without incurring excessive delays to traffic. These objectives will only be achieved if crosswalks are sited to attract the maximum number of pedestrians who would otherwise cross the street at random and also to give drivers adequate opportunity to recognize them in time to stop safely [3]. The main aim of this paper is the identification of factors affecting pedestrian level of service (PLOS) of crosswalks at roundabouts through review of existing literature.

## 2. PLOS OF CROSSWALKS

The quality of the pedestrian environment has been measured for many years using the Level of Service (LOS) approach. Commonly, six levels of service are recognized which are designated from A to F, with LOS A representing the best operating condition and Level of Service F representing the worst operating condition [4]. The LOS for pedestrian facilities is influenced by a lot of factors and different pedestrians have different perception on the LOS. Pedestrian level of service gives an indication regarding the environmental qualities of a pedestrian space and serves as a guide for development of standards for pedestrian facilities. Environmental factors that contribute to the walking experience and therefore to the perceived level of service, such as comfort, convenience, safety, security and attractiveness, should be given their due importance. Pedestrian spaces should be designed in consideration of human convenience and have to be qualitatively suitable to the needs of the users. Since the pedestrian environment is multi-dimensional, the pedestrian in the roadside environment is subjected to a set of several factors significantly affecting his or her perception of safety,

comfort, and convenience. Measurement of these factors is necessary to evaluate the pedestrian facilities and evaluation methods are needed to understand how well a particular street accommodates pedestrian travel.

Crosswalks are a critical element of transport system since there is a direct conflict between various users. The most vulnerable users at the crosswalks are the pedestrians. As soon as they start to cross a road, they are put to a great risk of getting hit by a vehicle. Also, other than the safety aspect of pedestrian crossings, comfort is another factor which plays an important part in determining the LOS of a crosswalk. It depends on a number of factors like the width of carriageway, presence of pedestrian refuge, condition of the crosswalk surface etc. The pedestrian movement through an intersection can be described by the conflicts, exposure and delay experienced by the pedestrian. As the pedestrians walk along the primary facility and travel through an intersection, they experience conflicts with various motor vehicle turning movements, volume and speed of which are believed to affect the pedestrian perception of safety and comfort. Likewise, exposure of pedestrians to conflicts with vehicular traffic is believed to affect their perceived level of service [5].

### 3. LITERATURE REVIEW

This section presents the review of literature including research papers, reports and codes for identification of factors affecting PLOS of crosswalks. It has been found that there exists a gap in literature regarding PLOS studies of crosswalks at roundabouts. In such a scenario, the available literature which deals with LOS of pedestrians facilities like signalized intersection crosswalks and midblock crossings has been reviewed in order to identify factors affecting PLOS of crosswalks at roundabouts.

#### 3.1 PLOS of Signalized Intersection Crosswalks

Kadali and Vedagiri (2016) conducted a study to analyze issues related to PLOS of crosswalks namely, signalized, unsignalized, and midblock locations. It was asserted that the focus for evaluation of PLOS has shifted from quantitative approach to qualitative methods and factors considered for the assessment of these facilities have been changing. Usually, a measure of effectiveness is used for evaluation of pedestrian facilities and the measure of effectiveness varies for each type of facility. For signalized intersections, pedestrian delay and space at the corner are considered as measures of effectiveness. However, at unprotected midblock crosswalks, the measures of effectiveness might depend on pedestrian delay, available vehicle gaps (crossing difficulty), safety and behavior of vehicle drivers as well as that of pedestrians [6]. Nagraj and

Vedagiri (2013) undertook a study to identify the factors which affect PLOS of signalized intersection crosswalks under heterogeneous traffic conditions and to propose a method for estimating pedestrian LOS. The study attempted to develop a PLOS model for crosswalks of signalized intersection in Mumbai, India, by using pedestrians' perceptions of various influencing factors. The important factors considered to develop the model were number of pedestrians, turning traffic, through traffic and pedestrian delay. On the basis of previous research, the main factors affecting PLOS at a signalized intersection are crossing facilities (including crossing distance, space at the corner of an intersection, the type of crossing markings, etc.), traffic conflicts (through traffic, turning traffic, and number of pedestrians), and delay. The study concludes that turning vehicles, through vehicles, and pedestrian delay are the main factors affecting LOS of crosswalks at signalized intersection [7].

Ling et al. (2014) proposed a method to estimate PLOS based on traffic environments and pedestrians' perceptions in Shanghai, China. The researchers found that of the factors which influence PLOS; turning traffic, mixed two-wheeler volume, and pedestrian delay have negative impact to PLOS. On the other hand, factors such as pedestrian volume and the presence of a refuge island which enables a two-step crossing improve the PLOS of signalized crosswalks. The identified relevant factors were: leaving left-turning non-motorized vehicles, entering right-turning motorized vehicles, mixed cyclists volume, pedestrian volume at the beginning of green time, pedestrian delay, presence of refuge islands and presence of two-step crossing [8]. Muraleetharan et al. (2005) aimed to identify the factors that affect PLOS of crosswalks at signalized intersections and to propose a method for the estimation of PLOS at signalized crosswalks. A stepwise multi-variable regression analysis was performed in the city of Sapporo, Japan using the collected data of various types of intersections. Factors like turning vehicles, space at corner, crossing facilities, pedestrian-bicycle interaction and delay at signals were found to significantly affect PLOS of crosswalks at intersections. The results of the study revealed that turning vehicle volume has greater influence on PLOS than other factors. The results showed a corresponding decrease in the perceived safety to the pedestrians when the number of turning vehicles increased. It was also observed that, regarding crossing facilities, pedestrians prefer design improvements like separate path for bicycles, high visibility zebra crosswalk markings, and well-designed curb ramps. Also, it was found that as the pedestrians do not accept long delays at signalized intersections, they prefer pedestrian crosswalks where pedestrians are given priority [9].

Florez et al. (2014) carried out a study to identify the attributes which define the pedestrians quality of service

based on interviews conducted with spectators at the three matches of the FIFA Confederations Cup which were played in June 2013 in Rio de Janeiro. The authors found that factors such as pavement and width of the sidewalk, absence/presence of obstacles, topography, noise and pollution, cleanliness, ease of crossing etc. influences pedestrians' perception of comfort while volume and speed of traffic, safety of intersections and separation between pedestrians and vehicles influences pedestrians' perception of comfort [10]. Archana and Reshma (2013) studied the effect of factors which affect pedestrian level of service at signalized intersections and aimed to develop a pedestrian level of service model which takes into account pedestrians' perception of safety and comfort using multiple regression analysis. The researchers concluded that PLOS of a crosswalk at a signalized intersection is greatly influenced by pedestrian volume, crosswalk surface condition and crosswalk marking visibility [5]. Petritsch et al. (2005) performed a study to develop a PLOS model which can represent perceptions of pedestrians' at crossings of signalized intersections. Motor vehicle volume and right turn on red volumes on the street being crossed, permissive left turns from the street parallel to the crosswalk, number of lanes being crossed, midblock 85th percentile speed of the vehicles on the street being crossed, presence or absence of right-turn channelization islands and pedestrian's delay were considered as the primary factors in the PLOS model for crosswalks of signalized intersections [11].

Bullock et al. (2006) claimed that the PLOS for signalized intersections in HCM which is based on pedestrian delay does not consider other significant factors such as likelihood of a pedestrian crossing a road within a reasonable time successfully and safely. The researchers found that factors such as the presence of geometric characteristics, pedestrian signal phasing characteristics and conflicting vehicle volumes increase the difficulty a pedestrian encounters while crossing any road. It was also found that PLOS at crosswalks of signalized intersections can be modeled considering factors such as geometry of the intersection, traffic volume and signal timing [12]. Jensen (2013) aimed to develop methods for quantifying pedestrian and cyclist stated satisfaction objectively with roundabouts, signalized and non-signalized intersections, mid-block crossings, and pedestrian bridges and tunnels in Denmark. The researcher found that variables such as type, width and height of pedestrian and bicycle facility, length of crossing, size of roundabout, width of roadway, traffic volume, waiting time and speed limit significantly influence the level of satisfaction [13].

### 3.2 PLOS of Midblock Crosswalks

Zhao et al. (2014) aimed to develop a pedestrian level of service (LOS) model for unsignalized midblock crossings from the pedestrian's perception of safety and convenience perspective in China. The potential factors influencing pedestrian LOS at unsignalized midblock crosswalks were summarized from four respects: traffic conflicts, the distance between crosswalks, crossing facilities, and delay. The results revealed that the factors significantly influencing pedestrian LOS of the overall unsignalized midblock crossings of road segments included volume of two-way motor vehicle, the distance between marked midblock crosswalks, and the distance between unmarked crosswalks. Motor vehicle traffic volume was found to have negative effect on pedestrian LOS, and the distance between marked midblock crosswalks and the distance between unmarked midblock crosswalks have differently positive effect on pedestrian LOS [14].

Kadali and Vedagiri (2015) aimed to evaluate the LOS of midblock crossing facilities with respect to different land-use type under mixed traffic conditions. An ordered probit (OP) model was developed by using NLOGIT software package, considering road crossing difficulty as well as safety, number of vehicles encountered, pedestrian individual factors, and roadway geometry and land-use type. The researchers found that perceived safety, crossing difficulty, number of vehicles encountered, land-use condition, number of lanes and median width have significant effect on pedestrian perceived LOS. Increase in vehicle volume results in decrease in pedestrian perceived LOS. The pedestrian safety can be improved by improving crossing facilities such as proper markings, adequate barrier width, lighting and controlling vehicular movement [15]. Chu and Baltes (2001) developed a methodology for assessment of PLOS of midblock crosswalks. The difficulty in crossing was defined on the basis of a number of factors such as the amount of time to wait for a suitable gap in traffic, risk of being hit by a vehicle, presence of a pedestrian refuge or a median, lack of an acceptable traffic gap, parked cars, or anything else that may have an effect on the crossing difficulty. The results of this study revealed that the crossing difficulty tended to increase with signal spacing, width of painted median, and turning movements while the presence of pedestrian signals the perception of difficulty in crossing [16].

### 4. FACTORS AFFECTING PLOS OF CROSSWALKS AT ROUNDABOUTS

From the review of literature, the following factors have been identified which may affect PLOS of crosswalks at roundabouts based on practical and logical reasoning:

**i. Vehicle Volume:** Since, at roundabouts the movement of traffic is continuous, there is always conflict between vehicular and pedestrian movement. This conflict highly affects pedestrians' perception of safety and comfort while crossing roads at roundabouts. It has been found that PLOS decreases significantly with increase in vehicle volume.

**ii. Vehicle Speed:** At unsignalized intersections, pedestrians need to find a gap in vehicular movement in order to cross a road. However, as the speed of vehicles increases at crosswalks, pedestrians are put to a greater risk of accidents. Hence, increase in vehicle speed at crosswalks has a negative effect on PLOS.

**iii. Carriageway Width:** As the carriageway width increases, the pedestrians need to cover longer distance to cross the road. This also means that a pedestrian will encounter more number of vehicles and will be in the vulnerable zone for a longer duration. Hence, it negatively affects PLOS of crosswalks at roundabouts.

**iv. Pedestrian Refuge:** A pedestrian refuge positively affects PLOS and also acts as a median. It not only provides a safe haven to crossing pedestrians in the middle of the road but also facilitates a comfortable two-step crossing. The pedestrians only need to look for vehicle in one direction at a time. This greatly increases the comfort and safety level while making the crossing.

**v. Crosswalk Marking Condition:** As soon as a pedestrian steps on a zebra crossing, he/she gains a right of way over vehicular traffic. Also, a well-marked crosswalks attracts pedestrians for crossing who otherwise would cross the street at random locations endangering their life as well as of others. But the drivers need to yield to pedestrians in order to give them right of way. Sometimes, the crosswalks marking fade or are not properly visible to motorists and hence they do not yield to pedestrians. A crosswalk marking of high visibility preferably of retro-reflective type helps in increasing PLOS of crosswalks.

**vi. Crosswalk Surface Condition:** A smooth, levelled and slip resistant surface is preferred by pedestrians for walking as it is more comfortable and safe than a deteriorated one. Thus, a crosswalk with good surface condition will have better LOS than a crosswalk with poor surface condition.

**vii. Lighting Condition at Crosswalk:** A well-lit crosswalk area provides motorists to have proper visibility of crossing pedestrians during night hours. Hence, good lighting at crosswalks enhances pedestrian safety and hence PLOS. The above are the most important factors which affect PLOS of crosswalks at roundabouts. Other than the above factors, many factors affect PLOS of crosswalks at roundabouts but

not significantly. Factors such as delay, presence of other pedestrians, pedestrian volume, pedestrian holding area, density, width of crosswalks affect PLOS of signalized intersection crosswalks but not of crosswalks at roundabouts as the vehicular and pedestrian traffic is comparatively lower at roundabouts than at signalized intersections and hence delay is not significant and accumulation of pedestrians also does not take place as the movement is uninterrupted.

## 5. CONCLUSION

From the above discussion, it has been tried to convey the importance of pedestrians in an urban environment. It is the need of the hour to reduce vehicles on the roads and encourage non-motorized transport. Walking is the most basic form of commuting and is accompanied by a number of social, economic and environmental benefits. In order to encourage walking as a sustainable mode of transport, pedestrian facilities need to be provided keeping in mind the perception of pedestrians in terms of safety, comfort, convenience etc. There is a need to evaluate PLOS of various pedestrian facilities including crosswalks which form an integral part of a pedestrian friendly urban environment. Roundabouts come with a number of advantages over conventional signalized and unsignalized intersections such as uninterrupted flow, saving in fuel and time etc. In order to improve PLOS of crosswalks, the factors affecting it need to be identified and required measures need to be taken. From the review of existing literature and keeping in mind practical and logical considerations, factors which significantly affect PLOS of crosswalks at roundabouts are vehicle volume, vehicle speed, carriageway width, pedestrian refuge, crosswalk marking condition, crosswalk surface condition and lighting at crossing area. Factors like delay, pedestrian volume, crosswalk width, pedestrian holding area and space per pedestrian do not have significant effect on PLOS as the flow is continuous and hence no accumulation of pedestrians takes place on either side of the crosswalk. Further studies may be conducted in the area of PLOS taking into consideration the opinion of experts and pedestrians making real time crossings at roundabout crosswalks in order to find the relative importance of the various factors.

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