Australasian Transport Research Forum 2013 Proceedings
2 - 4 October 2013, Brisbane, Australia
Publication website: http://www.patrec.org/atrf.aspx

A Study of Delay-Based Level of Service on Pedestrian Facility

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Abstract

Society has widely accepted that pedestrians or bikes should have right of way over vehicle traffic flow. However, little research on pedestrian flow improvement compared with vehicle traffic flow has been conducted. Previous studies have found that 31.6% of pregnant women and 47% of the handicapped population find pedestrian facilities such as over-paths difficult to use. Normal pedestrians also find them inconvenient to climb up. Although it does not seem to be considered as a good service for users, pedestrian level-of-service (LOS) can be high if pedestrian flow is low. Currently, pedestrian LOS is measured based on the pedestrian flow rate, density and speed. This allows the magnitude of interruption among pedestrians who share a same place and a same time to be determined. It has be found that even though the travel time and distance of a crossing increases, the LOS can accommodate these changes if pedestrian facilities are wide enough or the design matches pedestrian flow rate.

This paper presents a novel approach to determine the demand-oriented LOS on pedestrian facilities, which analysis an alternative to determine the LOS considering delay (travel time) by adopting the methodologies used in determining the road LOS. Over-paths were compared with walkways in terms of the new LOS in Cheonan, Korea. The results show that the current methodology indicates the LOS A whereas the alternative presents the LOS E on the same over-path.

1. Introduction

The transportation field has developed transport Policies addressing vehicle issues rather than pedestrian problems. This tendency has started moving to where a revision of policies and an improvement of facilities for pedestrians or bikes is demanded in some developed countries. However, not much research has been done with the aim to improve the quality of pedestrian and bike service.

The basic indicator identifying the condition of pedestrian facilities is pedestrian level of service (below, LOS). Pedestrian LOS can generally be derived from pedestrian traffic rate, pedestrian occupant space, pedestrian density, pedestrian mean speed, and pedestrian signal delay. These components are considered when pedestrians use facilities.

Pedestrian facilities consist of pedestrian roads, stairs, waiting areas, pedestrian crossings (signalized or non-signalized) and so on. Pedestrian flow rate is used for pedestrian roads or stairs while mean pedestrian delay caused by signal stages is used for signalized pedestrian crossings. Pedestrian occupant areas can be calculated for waiting areas.

These components are performed on the basis of the degree of interference between pedestrians that are normally derived from pedestrian density. This means they are the factors which determine how well pedestrians flow without hesitation or interruption.

However, in cases which LOS is calculated by pedestrian traffic rate and pedestrian occupant areas, pedestrian LOS can be high even though the total travel time increases due to a longer route. When the number of pedestrians compared to the size of areas is small, for example, it may be the case that the size of pedestrian facility is big or the number of pedestrians is small.

A significant number of pedestrians consider total travel time between departure and destination, and walking convenience using ramps or stairs as important factors to decide which facility they use. This idea can be observed in many cases where pedestrian crossings have been replaced with pedestrian overpasses.

It should be determined whether pedestrian facilities are comfortable and allow pedestrians to cross quickly by comparing several alternatives when a certain area is considered. Therefore, it becomes difficult to estimate the current LOS based on pedestrian flow rate and pedestrian occupancy rate.

There are many factors to be considered when pedestrian facilities are planned; street dimension, facilities, furniture, safety, security, comfort, convenience, continuity, system coherence, and attractiveness (Khisty 1994; Sarkar 1993). Several studies have introduced pedestrian LOS indexes for individual pedestrian links.

Hubbard et al. (2009) considered pedestrian safety by reflecting on the negative impact of right-turning traffic over pedestrians because the current pedestrian LOS at the signalized intersections considers factors such as space and delay.

LOS is a common method in traffic engineering to measure quality of service such as delay, queue, and speed (Das and Pandit 2013). LOS used in Korea was taken from the North American Highway LOS standards described by the letters from A to F. A is considered optimal, with the pedestrian traffic flowing freely while F is considered the worst with flow that is interrupted or forced.

Tanaboriboon and Guyano (1989) proposed an LOS measurement borrowed from Fruin’s LOS method for designing walkways in Bangkok based on the area occupancy per person. Fruin (1971) pioneered to develop a way of pedestrian LOS measurement using capacity and volume.

Like many Asian countries(Mateo-Babiano and Ieda 2007) , Korea has also adopted the US Highway Capacity Manual to fit the Korean environment.

Since different countries have different traffic environments, the perception of the quality of pedestrian facilities is also different. This matter has been criticized by researchers, with the main objection being that traditional LOS is too weak to explain what it means (Das and Pandit 2013).

Asadi-Shekari et al. (2012) have developed an analytical tool to estimate the disabled pedestrian LOS for various streets since Davidson (2006) acknowledged certain pedestrian facilities where the disabled find use uncomfortable needed to take care of the walking experience of disabled pedestrians.

Another research focusing on the LOS at signalized intersections was performed by Bian et al. (2009) in China. They investigated pedestrian perception of comfort and safety by taking care of traffic conflicts, right turning vehicle and bicycle traffic, permissive left-turning vehicles, crossing facilities and delay.

Delay is a widely used indicator for vehicle traffic to determine the LOS in normal cases. In this study, delay is defined as the actual travel time to cross against the ideal time to cross without any obstacle. This study adopted a delay calculated for a normal interchange in order to analyse the novel pedestrian LOS rather than the current density based way of determination.

2. Past study

2.1 Analysis in satisfaction of pedestrian overpasses

According to the study performed by Shin (2010), 30% of pregnant women answered 'unsatisfied' and 2.1% of them felt 'Very unsatisfied' when they used the pedestrian overpass. It also indicated that the handicapped showed more unsatisfied to pedestrian overpass in showing 27.2% of 'unsatisfied', and 14.0% of 'Very unsatisfied'.

Table 1 Pedestrian overpass satisfaction analysis

	The handicapped		Infant companion		The pregnant	
	Persons	Per cent	Persons	Per cent	Persons	Per cent
Very Satisfied	3	2.6	0	0	1	1.1
Satisfied	18	15.8	9	9.7	7	7.4
Undetermined	46	40.4	56	60.2	57	60.0
Unsatisfied	31	27.2	25	26.9	28	29.5
Very unsatisfied	16	14	3	3.2	2	2.1
Total	114	100	93	100	95	100

2.2 Current pedestrian LOS

KHCM (Korea highway capacity manual) pedestrian facilities consist of pedestrian roads, crossing roads with signals, stairs, and waiting areas (Ministry of land transportation and transport 2013). The LOS is estimated separately based on characteristics of facilities. The indicators for each facility are as follows;

- Pedestrian road : Pedestrian flow rate, pedestrian area, pedestrian density, pedestrian speed
- Stairs : Pedestrian flow rate
- Waiting area : pedestrian area
- crossing road with signal: pedestrian mean delay

KHCM discriminates the different levels of service by walking comfort that is defined by a size of space. The road crossing pedestrian facility such as pedestrian crossing or pedestrian overpass needs to be analysed in different ways.

Jinkyeong Lim (2004) suggested a new LOS on a basis of land use. Current density over speed was a good indicator for the LOS in an industrial area for the period of working. However, places such as commercial areas where shopping or entertainment is the main purpose, and alongside of rivers, parks where exercise or rest is the main purpose needs an alternative approach to estimate appropriate LOS. Therefore, it was concluded that alternatives were needed for identifying the LOS for various kinds of pedestrian facilities.

2.3 Vehicle oriented LOS

The definition of 'delay' is that to cause to be later or slower than expected or desired. In other words, the process is not performed in a timely fashion for some reason. In traffic flow, delay is a good indicator for the measurement of effects on urban interrupted roads; especially intersections.

There are several types of delay defined in traffic engineering. In general, stopped delay and approached delay are widely accepted. Sopped delay means the total time that vehicle(s) spend completely stopped due to signalized interchange. It is the time that a vehicle completely stops at a red signal and the time a vehicle starts accelerating again at a green signal. The approached delay is the time delay caused by vehicles slowing down plus the stopped delay. It is intuitive that the approach delay is more accurate than the stopped delay but it is not straightforward enough to determine accurately. Therefore, HCM recommends the approached delay is 1.3 times more than the stopped delay.

Table 2 Approached delay in the LOS.

Level of service	Delay per vehicle
A	≤ 15 sec
B	≤ 30 sec
C	≤ 50 sec
D	≤ 70 sec
E	≤ 100 sec
F	≤ 220 sec
FF	≤ 340 sec
FFF	> 340 sec

The source from Ministry of land transportation and transport (2013)

2.4 Findings

Current pedestrian LOS is determined by comfort that is calculated from the size of the area an individual pedestrian occupies. However, as there are a number of aspects that need to be considered in order to determine an appropriate measure of effects, alternatives such as pedestrian travel time or pedestrian comfort need to be taken into consideration.

Pedestrians feel annoyed when required to take a longer trip than is necessary to use the pedestrian facilities, so the delay that is widely used in vehicle LOS is considered as a measure of effects in this study.

3. Methodology

This study suggests a novel way of calculating LOS using delay in order to find the best alternative when pedestrian facilities where pedestrians cross over pedestrian crossing or pedestrian overpass are being planned for development.

The basic concept of this study is to compare the situation where pedestrians cross on the road and the situation where pedestrians need to use an overpass to cross by using both a current analysis method and the novel way (delay based).

Firstly, the LOS was calculated using the current method for pedestrian overpasses and pedestrian crossings. Second, it was recalculated using the delay based method. Lastly, three scenarios were analysed in terms of the LOS and recommendations and limitations are delivered.

3.1 Case study

3.1.1 Area selection and characteristics

The case study area was selected in which the pedestrian over pass that makes pedestrians uncomfortable can be replaced with a pedestrian crossing.

Figure 1 Study area satellite photo (Note: the satellite photo in this area has a low resolution)

Engineering Street in Cheonan, South Korea where a pedestrian overpass exists but no pedestrian crossing currently exists was selected. One elementary school, one middle school, two high schools and one university are located within 1 km of this area. This area is well known for frequent illegal crossings by students and for being difficult for the elderly to use facility.

As a result of survey, traffic is the highest between 07:00 am and 08:00am at which a great number of students go to school. 15 minutes peak pedestrian flow is 134 persons at 07:45am to 08:00 am. 90% of total pedestrian traffic (120 people) is comprised of teens.

Table 3 Pedestrian facility attributes

Pedestrian path		Stairs
Facility 1	Width* = 3.0m	Left side
Overpass	Length = 26m	Width = 2m
		Length = 6.6m/5.7m
		Right side
		Width = 2m
		Length = 6.0m/6.0m
Facility 2	Width* = 3.0m	
Pedestrian crossing	Length = 26m	

Note ,*: Effective road width

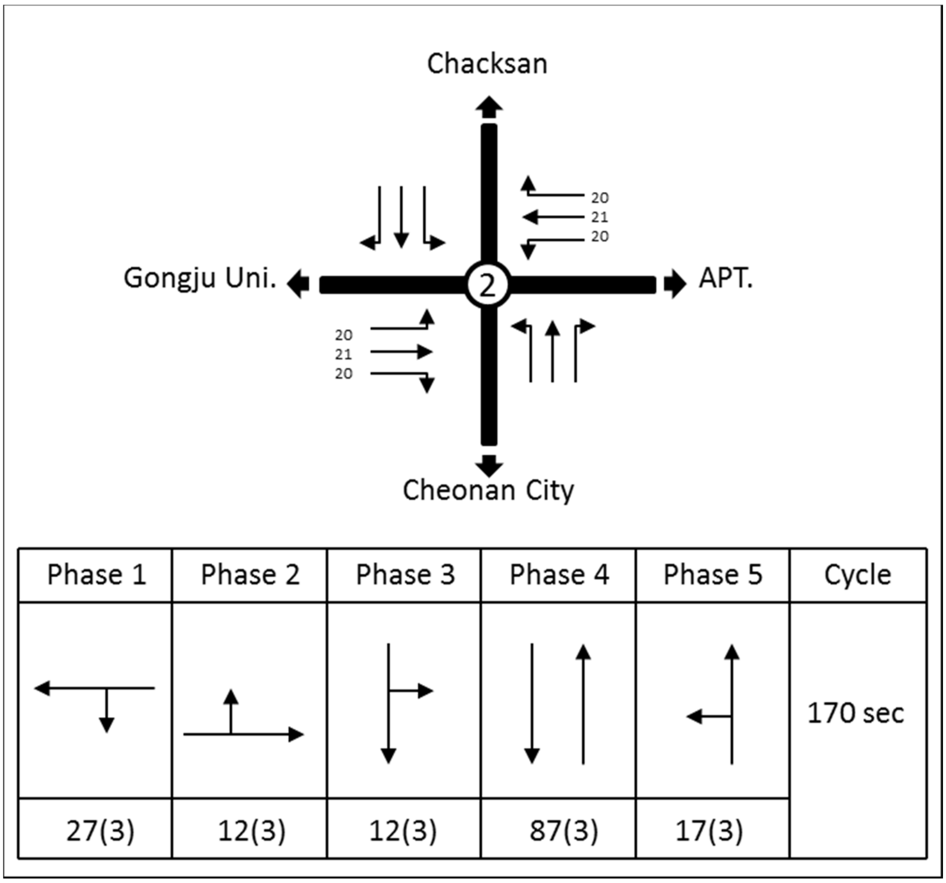

Figure 2 a signal plan at the study area

3.1.2 Design of alternatives

Alternative 1 is designed to analyse the LOS on the pedestrian overpass using the current method. Alternative 2 is the same as alternative 1 but uses a delay based calculation. The last alternative is to consider the pedestrian crossing with signals using a delay based calculation.

Table 4 selection of alternatives

	Alternative	The method
1	Overpass (current method)	Pedestrian flow rate
2	Overpass (delay based method)	Delay
3	Crossing (delay based method)	Signalized delay

4. Results

4.1 The overpass LOS analysis using a current method: Alternative 1

The overpass consists of pedestrian road and staircases so these two components were calculated separately. In this study, the worse LOS was chosen as a final measure.

- LOS on overpass concourse
  On the basis of 15 min. pedestrian flow, pedestrian flow rate can be calculated from Equation 1.

$$V_p = \frac{V_{15}}{15W_E} \qquad \text{Equation 1}$$

Here, V_p = Pedestrian flow rate (per/min/m)
V_{15} = pedestrian flow for 15min.
W_E = effective lane width

According to the equation, $V_p = \frac{134}{15\times3}$ = 2.98.

From Table 5, the LOS is A.

Table 5 Pedestrian LOS

LOS	Pedestrian flow rate (per/min/m)	Pedestrian area (m^2/per)	Pedestrian density (per /m^2)	Pedestrian speed (m/min)
A	≤ 20	≥ 3.3	≤ 0.3	≥ 75
B	≤ 32	≥ 2.0	≤ 0.5	≥ 72
C	≤ 46	≥ 1.4	≤ 0.7	≥ 69
D	≤ 70	≥ 0.9	≤ 1.1	≥ 62
E	≤ 106	≥ 0.38	≤ 2.6	≥ 40
F	-	〈 0.38	〉 2.6	〈 40

The source from Ministry of land transportation and transport (2013)

- LOS on stairs of overpass

  There are five processes to analyse it.
  1) Measuring geometry of study area.
  2) Observing peak 15minitues pedestrian flow
  3) Observing pedestrian flow platoon on stairs
  4) Dividing observed pedestrian flow by effective lane width to become pedestrian flow rate (flow rate) (per/min/m)
  5) Based on an existence of pedestrian platoon, the LOS is determined in Table 6.

From this procedure, V_p (per/min/m) is 4.47 on stairs which leads to the LOS of A.

Table 6 pedestrian LOS on stairs

Level of Service	Pedestrian flow rate (per/min/m)
A	≤ 18
B	≤ 20
C	≤ 25
D	≤ 32
E	≤ 52
F	-

The source from Ministry of land transportation and transport (2013)

- LOS on overpass

As presented above, the LOS on pedestrian overpass is A by considering the current method.

4.2 The overpass LOS analyses using delay: Alternative 2

The delay is defined by comparing the time that pedestrians use the overpass to the time that pedestrians use the pedestrian crossing. The LOS is then determined by the difference between them.

- Travel time on crossing.

If there is no delay, the travel time to cross at a normal pedestrian speed (1.2m/s) is

$$\text{Crossing time} = \frac{23m}{1.2m/s} = 19.17 \text{ seconds.}$$

- Travel time on overpass

Park (2011) stated the pedestrian speed is 0.58m/s when platoon density is 1per/m^2. In this study, the overpass consists of a pedestrian corridor of 26m and stairs of 11.7m.

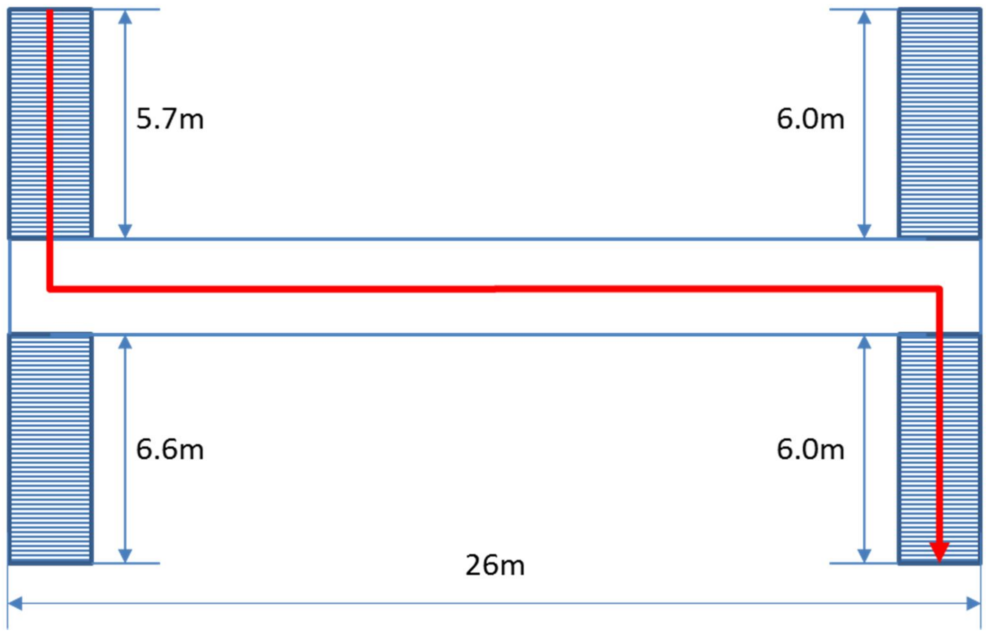

Figure 3 A sketch of pedestrian over pass

The total travel time is crossing time plus stair time.

The total travel time = $\frac{26m}{1.2m/s} + \frac{12.8m}{0.58m/s} = 43.23 \text{ secs}$

- Delay caused by overpass

The delay is the difference between the total travel time and the crossing time; 43.23-19.17 = 24.06 seconds.

- The LOS on overpass

Since little research on pedestrian LOS has been conducted, the LOS in the signalised pedestrian crossing was adopted for pedestrian facilities.

The LOS is in fact to indicate how pedestrians or drivers feel about the situation where they find themselves. According to Table 7, the LOS is B as delay in overpass is 24.06.

4.3 The signalized pedestrian LOS analyses using delay: Alternative 3

There are two types of methods to calculate delay in signalized pedestrian crossings; pedestrian mean delay and pedestrian crossing occupancy area. In this study, in order to compare delay for the LOS, pedestrian mean delay was used.

There are 3 steps to analyse the LOS by using pedestrian mean delay in signalized crossings.

1) Measuring an effective green time and cycle at crossing with signal.
2) From the Equation 2, pedestrian mean delay can be derived.

$$d_p = \frac{(C-g)^2}{2C}$$ Equation 2

Here, d_p = pedestrian mean delay (secs)

g = effective green time (sec)

C = Cycle (sec)

There are two ways to calculate effective green time;

1) Green time – Start-up lost time + clearance lost time
2) Green time + Amber time – Start delay time

In this study, the second calculation was used and start delay time was assumed to be 2 seconds.

3) From Table 7, the LOS is determined.

From the observation, the effective green time for pedestrians is 18 seconds and pedestrian mean delay d_p showed 67.95. Therefore, the LOS is E according to the Table 7.

Table 7 Pedestrian LOS at the crossing with signals

Level of Service	Pedestrian mean delay (sec/per)
A	< 15
B	≤ 30
C	≤ 45
D	≤ 60
E	≤ 90
F	> 90

The source from Ministry of land transportation and transport (2013)

5. Discussion and future research

Although 31.6% of pregnant women and 47% of handicapped people find the pedestrian overpass uncomfortable (Shin 2010), the LOS can still be high based on the current method of calculation. The results of this study are shown in Table 8.

The LOS at the study area is A on the basis of the current method. However, if the delay based method is used it drops to B. At signalized pedestrian crossings, the LOS is E when current signal plan is operating. This can be improved by considering pedestrians crossing. In analysis, the travel time through the overpass is 24.06 sec which is approximately three times shorter than the travel time through signalized crossing (67.95 sec). By adopting signal optimization this gap can be minimized.

Table 8 The results of alternatives

Scenario	Level of Service
Alternative 1	A
Alternative 2	B
Alternative 3	E

A demand for pedestrian facilities has increased where vehicle oriented facilities used to be favoured. For this reason, a substantial number of policies have been approved but pedestrian facilities follow at a slow pace.

If the pedestrian LOS is estimated based on delay as described in this study, pedestrian comfort can be better addressed.

As this study covers an initial stage of pedestrian facility measure of effects, the LOS was found based on pedestrian delay and signal timing only. This paper does not cover the effect of optimizing signal controls on the LOS.

In future research, relevant survey and pedestrian simulation models need to be performed and developed to evaluate the LOS on pedestrian facilities in more detail. Also, signal optimization can be applied in pedestrian simulations in order to analyse situations between overpasses and crossings with signals. Additionally, not only normal pedestrians but also bike users, trolley users and the elderly need to be included to recreate real life scenarios.

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