KSCE Journal of Civil Engineering (2011) 15(5):883-889
DOI 10.1007/s12205-011-1173-1

Transportation Engineering

www.springer.com/12205

Determining the Sidewalk Pavement Width by Using Pedestrian Discomfort Levels and Movement Characteristics

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Received March 25, 2010/Accepted October 12, 2010

Abstract

This paper presents a sidewalk pavement width design method for making more pedestrian friendly and walk-inspiring sidewalk pavements in the urban area. Instead of using the current sidewalk pavement width design standard that usually leads to having minimum values, this research investigated pedestrians' preferences on the levels of service, surveyed actual foot path trajectories in the sidewalk pavements, and observed pedestrian movement characteristics in the streets. Further, these investigation results were summarized to propose a new urban sidewalk pavement width determination procedure. The proposed procedure was applied in a case study site in Seoul, and its application resulted in a much higher pedestrian level of service. It is anticipated that the proposed method should be of service in both planning and retrofitting urban streets to make more pedestrian sensitive street designs.

Keywords: *sidewalk pavement width, state preference, pedestrian level of service, foot path trajectory, urban street cross section*

1. Introduction

1.1 Background

Everybody travels, whether it is for work, school, or simply pleasure. Lately the government agencies have pushed enthusiastically for sustainable and low-carbon emission transportation development, and people are advised to walk when possible. Inarguably, walking is most desirable method of transportation for sustainable development, and engineers can inspire people to walk more by designing pedestrian-friendly urban streets. However, to promote walking in a city and increase its patronage to a desirable level, engineers and policy makers must make pedestrians feel more comfortable walking than driving in urban streets. In order to lead pedestrians into thinking that their sidewalk pavements are really walker-friendly, engineers should focus on providing pedestrians with very attractive sidewalk pavements that are significantly wider than the minimum value specified in the highway design standard. A recent study on pedestrian behaviour indicates that, of the various reasons that people give up walking in favour of car use for their travel, a sidewalk pavement with a too-narrow width is the main reason for their car use (Kockelman, 1997).

The decision to build a narrow sidewalk pavement can be attributed to several factors, including current highway design standards and the engineers assigned to the project. Current highway design standards suggest that engineers choose from typical street cross-sections composed of vehicle lanes and sidewalk pavement (KMOCT, 1999; KMOCT, 2001), where these cross-sections only indicate the minimum values. However, when the final right-of-way acquisition for an urban street is determined, it is often greater than the minimum value. As a result of this, engineers must decide how to assign the extra value. Deciding which mode of transportation is going to have a wider design value than the suggested minimum is a matter of engineer discretion, and engineers traditionally choose car user interests over the pedestrians, thus leaving the sidewalk pavement width at the minimum.

The goal of the research presented in this paper is to examine the effect of the sidewalk pavement width on pedestrian levels of comfort. This paper provides a balanced urban cross section design methodology with which one can fix the problem of the inappropriate distribution of urban street width. The essence of this methodology is to determine the sidewalk pavement width based on pedestrian levels of service rather than the minimum width criterion set forth by highway design standards. The Korean Highway Capacity Manual includes the pedestrian level of service determination procedure (KMOCT, 2001), but this procedure was designed to perform operational analyses of pedestrian flow for existing sidewalk pavements and basically imitated vehicle flow analysis theory which is different from pedestrian flow theory. Realizing this weakness, researchers indicate that the current procedure cannot be used for the case

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where pedestrian comfort levels are to be included in the analysis (Sisiopiku *et al*., 2007).

1.2 Research Approach

In this research, in order for engineers to determine the balanced weights in terms of widths for the sidewalk pavements and the vehicle lanes, several pre-selected people were interviewed about their pedestrian preferences. The subjects were asked to state their preferences for the following questions: "Is providing better levels of service to vehicles preferred to providing better ones to pedestrians?" In addition to interview, the researchers also performed a pedestrian behavioural test in an experimental field site to gather background information for determining proper sidewalk pavement widths for each level of increased pedestrian volume. Another field survey was carried out separately on major arterial routes in Seoul to collect pedestrian movement characteristics on the sidewalk pavements. Finally a comparative analysis to check the difference made by using the proposed sidewalk pavement design method was carried out for a residential area case in Seoul.

2. Balanced Width of the Urban Street Cross Section

What is the *balanced width* in the urban street cross section? To answer this important question, a clear understanding is required that the urban street cross section should include both vehicle lanes and sidewalk pavements. Obviously, the sidewalk pavement is the space allotted for pedestrians and its main function is to allow for comfortable pedestrian movement. The pedestrians in this sense should be treated as importantly as car drivers in urban street designs because, although pedestrians and drivers take different form of transportations, they are all human beings. Therefore, for one urban street section, it is desirable for the levels of service for pedestrians and car drivers to be the same.

This paper presents a procedure with which the balanced width in the urban street can be acquired.

2.1 Preference Survey for Pedestrian Levels of Service

A total of fifty five volunteers who were mostly male and working with one of the authors for a government research institute participated in the state preference survey. All responses from the fifty five people were put into a further analysis. In the survey, the participants were asked to score their preferences for the pedestrian level of service versus the vehicle level of service in the range of 1-100. For example, 60:40 means that the pedestrian level of service has 60 marks and vehicle level of service of 40, that is, in favour of the pedestrian level of service in width design. In addition, the age distribution of the respondents showed 12 people in their twenties, 28 in their thirties, and 15 in their forties. Also, their driving experiences indicated five people with less than one year's experience, 35 with less than 5 year's, and 15 with more than 6 year's. It should be noted for the better understanding of their attitude toward walking and driving that since the government research institute was located in a small satellite city of Seoul, the respondents would drive, walk or use bicycles to commute, and this will leave their preferences to each transportation mode fairly unbiased. Also, in this survey, three types of land use patterns were used, a Central Business District (CBD), a residential area, and a commercial area, to account for the effects of land use patterns on each level of service.

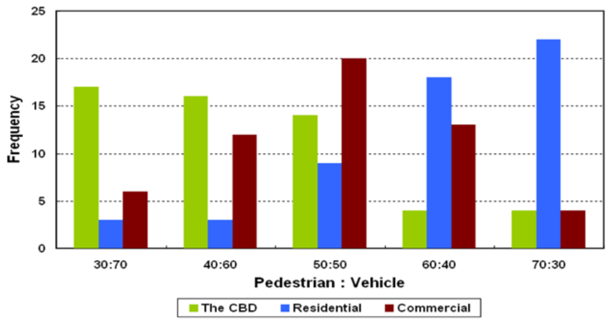

Fig. 1. Stated Preference for Pedestrian Levels of Service by Land Use

Table 1. State Preference Result for Pedestrian Level of Service

Land Use Pattern	Weighting Factors (Pedestrians : Vehicles)
The CBD	0.44 : 0.56
Residential area	0.60 : 0.40
Commercial area	0.48 : 0.52

Figure 1 is the survey result, and Table 1 shows their mean values. It was found that people generally gave high scores to the vehicle level of service within the CBD and commercial areas, but they showed the opposite response for residential areas. Interestingly, a similar survey result was reported in another paper (Muraleethanran & Hagiwara, 2007), and these results illustrate the difficulty in having wide sidewalk pavements in high-price land areas.

2.2 Width based on Pedestrian Movement Characteristics

2.2.1 The Concept

The urban street comprises travel lanes, sidewalk pavements, and other cross section elements. Engineers apply the Korean Highway Capacity Manual (KMOCT, 2001) to determine their levels of service. The problem is that pedestrians on the sidewalk pavement and drivers in the vehicle lane are entirely different traffic participants in the street. Being asked if they were satisfied with the level of service on the sidewalk pavement or in the vehicle lane, they would apply different service evaluation criteria that could account for their feelings towards the quality of movement, engineering exceptions, and even their tolerance levels to discomfort. For example, while the level of service on the vehicle lane does not change greatly with reduced vehicle gaps in the flow, the one on the sidewalk pavement does change significantly even with the presence of one pedestrian approaching in the opposite direction. This recognizes the fact that, in determining the pedestrian level of service on the sidewalk pavement, the degree of lateral clearance instead of the longitudinal gap becomes far more significant. Furthermore the authors are of the opinion that this was ascertained in one research paper. This paper states (Muraleethanran & Hagiwara, 2007) that pedestrians experience extensive discomfort at obstacles in their moving paths and these include trees, lamp posts, and even other pedestrians. Obviously, this particular result must have been acquired in urban street cases, and there is the possibility of a quite different result in a suburban or a rural setting, because pedestrian discomfort is a human characteristic that varies depending upon the walking environment such as density of pedestrians, attractiveness of the neighbourhood, and the purpose of travel.

Putting all these views into one perspective, this research attempts to provide a procedure that determines the sidewalk pavement width based on a pedestrian level of service that is totally different from the one in the existing KHCM. The new procedure assumes that there are two directional pedestrian flows in the sidewalk pavement, and pedestrians would leave foot trajectories that should reflect their feelings to the opposing pedestrians. In other words, their foot trajectories can be related to the pedestrian level of service in such a way that the level of service is poor when the trajectory involves large lateral variations. Then the question becomes how would the levels of service deteriorate if these variations vary from zero to an extensive value? To answer this, the authors decided to do a foot trajectory test and make use of the test result to set the pedestrian level of service table. Six pedestrian levels of service were categorized as follows. Six pedestrian levels of service were categorized A-E as follows. If scores are necessary instead of an alphabetical expression for each level of service, 6 corresponds to level A, 5 to B etc.

- Level of service A: the opposing stream of pedestrians makes a negligible influence on the subject’s foot path
- Level of service B: the opposing stream of pedestrians starts to make a slight influence on the subject’s foot path
- Level of service C: the opposing stream of pedestrians makes a noticeable influence on the subject’s foot path, so that some lateral variations in foot path are observed
- Level of service D: the opposing stream of pedestrians makes a moderate influence on the subject’s foot path, so that two pedestrian streams start to merge
- Level of service E: the opposing stream of pedestrians makes a heavy influence on the subject’s foot path, so that pedestrian streams completely merge
- Level of service F: the pedestrian stream breaks down, so that it shows the stop and go pattern

Now, how do desirable sidewalk pavement widths vary depending on the above pedestrian levels of service? To develop their relationships empirically in the real world, this research first subdivided the sidewalk pavement width and pedestrian volume into several levels, matched them in a tabular form, and asked people to state their presumed pedestrian level of service for each cell. At this stage, the authors realized that the pedestrian volume as expressed in the form of vehicular volume –persons/hour– was unable to explain pedestrian comfort levels on the sidewalk pavement because pedestrian streams would not be as continuous as vehicle streams. Recognizing this, the authors looked for a substitute so that they could explain pedestrian comfort changes occurring as opposing pedestrians approached. Intuitively, the authors understood that the comfort changes could be observed in the real world by checking the lateral variation of pedestrian foot paths on the sidewalk pavement.

One final question relative to investigating pedestrian movements on the sidewalk pavement is the pedestrian group size, that is, the number of pedestrians walking in parallel. This number can vary, and its pattern must be understood so that its impacts can be reflected in the changes in pedestrian service levels. In this research the pedestrian group size is expressed based on the moving direction and group size. For example, 2:3 indicates that the subjective and the opposing directions have 2 and 3 pedestrian group sizes, respectively.

The sidewalk pavement width has 1.2-4.5 metre range in this research.

2.2.2 Test Method

This research uses two tests for investigating pedestrian moving behaviours. One is to create a table with different levels of sidewalk pavement width and different pedestrian group sizes and to ask test subjects to write down their perceived levels of service for each cell. Another is to do a pedestrian foot path trajectory test to capture how they move around each other in a lateral direction when encountering opposing pedestrians. The authors note that this pedestrian simulation approach may involve site-specific effects, and the pedestrian sample size must be re-evaluated in future general applications. Fig. 2 denotes the envisioned diagram of 1:1 pedestrian movements on the experimental sidewalk pavement. The subjects were equipped with the GPS (Global Positioning System) receivers by wearing over their jackets. Whenever the subjects move, the GPS receivers sense them and record the coordinates at every one second interval. The GPS data were later retrieved by indoor personal computers. The GPS equipments apply the 12 channel mode to detect the lateral movements of the subjects accurately with the error range of less than 1 cm at stationary conditions.

2.2.3 Survey Results on Perceived Pedestrian Levels of Service

Table 2 is the summary of the survey results on how the subjects perceived levels of services for various pedestrian

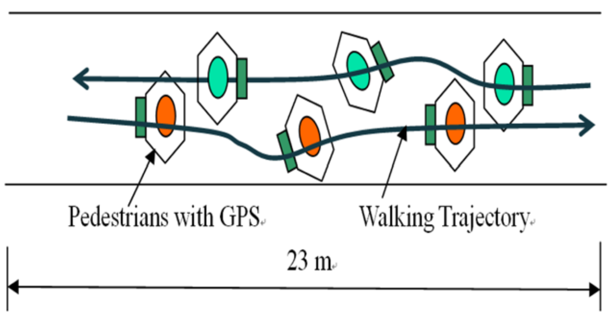

Fig. 2. Pedestrian Foot Path Diagram

Table 2. Perceived Pedestrian Levels of Service by Sidewalk Pavement Width

Sidewalk pavement Width (m)	Perceived Pedestrian Levels of Service with Different Group Sizes					
	1:1	1:2	1:3	2:2	2:3	3:3
1.2	B	C	E	E	F	F
1.5	A	B	D	E	F	F
2.0	A	A	D	C	E	E
2.5	A	A	A	B	C	D
3.0	A	A	A	A	B	C
3.5	A	A	A	A	A	B
4.0	A	A	A	A	A	A
4.5	A	A	A	A	A	A

walking situations. In Table 2, it is found that pedestrian levels of service deteriorate when sidewalk pavement widths are reduced. Also, within the same level of sidewalk pavement width, if the pedestrian group size grows, the corresponding levels of pedestrian service are reduced. This survey result provides informative evidence of the changing pattern of pedestrian levels of service for reduced sidewalk pavement widths.

2.2.4 Foot Path Test Result on Pedestrian Levels of Service

Although helpful in understanding pedestrian behaviour, Table 2 provides limited information on pedestrians, because this result only shows their stated preferences, but is not based on actual data for pedestrian movement on the sidewalk pavement. To eliminate this limitation, this research carried out a pedestrian foot path trajectory test on an experimental sidewalk pavement. The experimental site was located in an open space near the government research institute described in the previous section and there is neither car nor pedestrian movements in the vicinity of the site. Also, to simulate the confined paths of pedestrians on the sidewalk pavements, the research team created a general walking boundary by delineating with line tapes. The sidewalk pavement width was 1.2 metres. And the pedestrian group sizes were 3:3 and 2:2.

It is to be noted that this research concerns; 1) the lateral variation in pedestrian foot paths when the sidewalk pavement width is relatively narrow and the pedestrian group sizes are big; 2) whether the changing patterns of the pedestrian levels of service be predictable. The authors assume that, to obtain the answers, the test environment for the experiment should comprise relatively narrow sidewalk pavement widths and fairly large pedestrian group sizes. Hence the reason this research confines the sidewalk pavement width.

Figure 3 shows the test result. These two graphs are both for 1.2 m sidewalk pavement widths, and revealed that with a 3:3 group size there was a significant amount of lateral variation in foot paths, even approaching 1.5 m in an extreme case. However, in the case of 1:1, a completely different pattern showing little variations in foot paths was observed. These results confirm the assumptions made by the authors in the initial stage that pedestrian foot trajectories can be related to the pedestrian level of service in such a way that the level of service is poor when the trajectory involves large lateral variations. Also, the question "how would the levels of service deteriorate if these variations vary from zero to an extensive value?" can now be answered by investigating the variations at each levels of service. Based on the findings, the authors are of the opinion that the changes in the pedestrian foot paths at each sidewalk pavement widths and pedestrian group sizes must be considered in determining the balanced sidewalk pavement width in urban streets.

Also, although other flow variables associated with pedestrian movements, including walking speed, density, and the area type, could result in different pedestrian levels of service, this research did not address them and instead concentrated on the issue of the balanced width between vehicle lanes and sidewalk pavements in urban streets.

2.2.5 Field Study of the Pedestrian Group Sizes

To apply Table 2 and look up an appropriate sidewalk pavement width for an urban street, engineers are required to specify a pedestrian group size. In fact, the group sizes in Table 2 are hypothetical values, meaning they are not taken from actual field survey data, so validations are required in this research. An actual pedestrian stream data survey was made in this research, and the following summarizes the survey method.

- One field survey site was assigned for the CBD, the residential area, and the commercial area
- Data was collected between 07:00 ~ 19:00 on Thursday. One extra survey was undertaken on Sunday for the CBD
- Survey items were directional volumes of pedestrians on the sidewalk pavement and the pedestrian group sizes. The group sizes ranged from 1 to 4, and their associated frequencies were checked.

Table 3 and Table 4 are the field survey results. In Table 3, it was found that the pedestrian volume levels in Seoul were 40,000-3,600 pedestrians/day (ped/day), and the CBD volume level was the highest, followed by the residential area and the commercial area. It was also found that directional distributions were noticed only in the residential area.

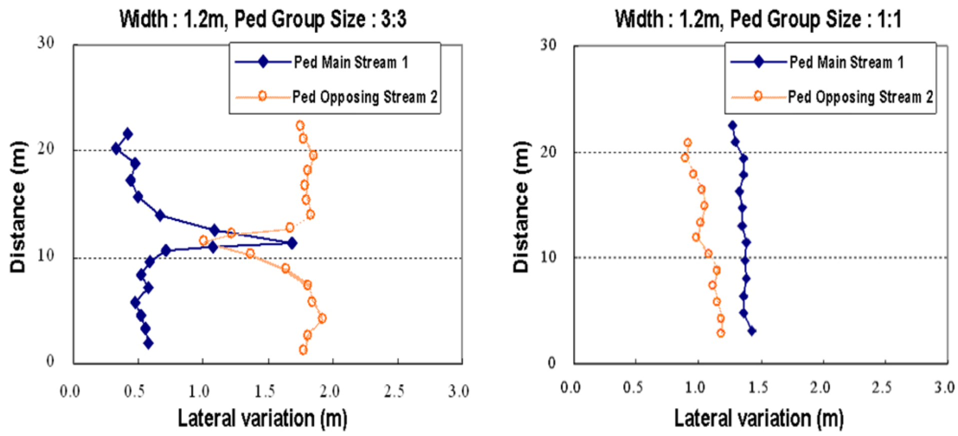

Fig. 3. Pedestrian Foot Path Trajectories in the Experiment Site

Table 3. Pedestrian Volume Levels and Directional Distributions in Seoul

Land Uses		Volume (ped/day)	Direction A		Direction B	
			Volume (ped/day)	Percentage	Volume (ped/day)	Percentage
The CBD	Weekday	39,577	20,882	53	18,695	47
	Weekend	28,577	14,667	51	13,890	49
Residential area		11,862	3,642	8,597	72	3,265
Commercial area		3,642	1,891	1,891	52	1,751

Table 4. Pedestrian Group Sizes in Seoul

Land Uses		Pedestrian Group Sizes and their Directional Distributions (%)							
		Direction A				Direction B			
		Single	Two	Three	Four	Single	Two	Three	Four
The CBD	Weekday	60.2	36.5	3.1	0.3	66.9	30.7	2.2	0.3
	Weekend	86.4	12.7	0.9	0.1	88.0	11.3	0.6	0.1
Residential area		85.4	85.4	12.3	2.0	0.3	91.2	7.7	0.8
Commercial area		83.7	83.7	13.4	2.2	0.7	79.3	17.1	3.3

Table 4 is the field survey result for the pedestrian group sizes. It is understood that generally pedestrians move singly and they seldom walk in groups of 3 and 4.

Based on these pedestrian stream patterns in Seoul, this research produced the following conclusions.

- In the CBD, the pedestrian group size is 3:3. This is based on two observations in Seoul. First, in Table 4, although a little different by direction, the CBD reports single pedestrian groups of 60-67% on the weekday, with the two pedestrian groups exceeding 30%. Second, it is likely that single groups share their lateral spaces with two groups, because normally sidewalk pavements in the CBD are full of pedestrians.
- In the commercial area, the pedestrian group size is 2:2. Similarly to the CBD case, in Table 4, the single group accounts for approximately 80%, also leading to sharing their lateral spaces with other single groups.
- In the residential area, the pedestrian group size is 3:3. Initially, in Table 4, the pedestrian group size is the same as in the commercial area. However, the directional distribution of pedestrian volume shown in Table 3 indicates that its conspicuous directional pattern in the residential area is much different to the one found in the commercial area. To reflect this finding, this research concludes by applying the 3:3 pattern for the residential area.

Conclusively, this research proposes Table 5 to be applied when engineers want to decide the sidewalk pavement width in an urban street. In contrast to the current design standards (KMOCT, 1999; KMOCT, 2001), engineers can consider with Table 5 how the pedestrian level of service influences the sidewalk pavement width for each land use case in surrounding areas.

3. Case Study

This research carries out a sidewalk pavement design case

Table 5. Proposed Sidewalk Pavement Widths by the Pedestrian Levels of Service (LOS) (Unit: m)

Land Uses	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
The CBD	4.5	4.0	3.5	3.0	2.5	2.0
Residential	4.5	4.0	3.5	3.0	2.5	2.0
Commercial	3.5	3.0	2.5	2.0	1.5	<1.5

†) Extra width of 0.5m is added to take into account the curb width.

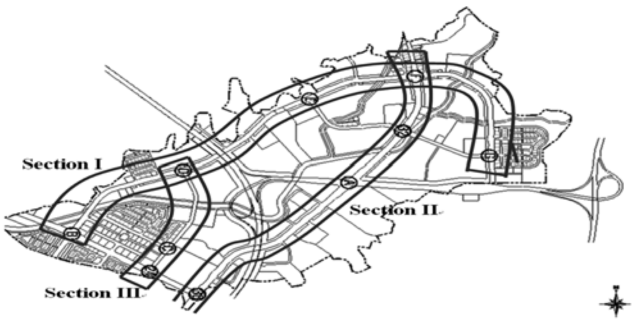

Fig. 4. Case Study Site

Table 6. Existing Street Characteristics in the Case Study Site

	Street Function	Total Street Width (m)	Number of Lanes	Traffic Lane Width (m)	Sidewalk pavement Width (m)
Section I	Arterial	29	4	3.25	3.00
Section II	Arterial	35	6	3.25	3.00
Section III	Collector	21	4	3.25	2.25

study to investigate how the proposed design standard is able to contribute to making more pedestrian-friendly urban streets. The essence of the case study is to compare two kinds of urban street cross sections including the existing design and the new proposed design. The case study site is located in a residential area within Seoul, and three urban arterial routes in the site are subject to the analysis. Fig. 4 shows the case study site.

Existing street characteristics are summarized in Table 6. According to the current sidewalk pavement design standard for the residential area (KMOCT, 1999), the minimum widths for urban arterial and collector routes are 3.0 and 2.25 metres, respectively. It is therefore worrisome that the existing streets are designed only at the minimum width levels, leaving pedestrian levels of service precluded from their width design. It is also noteworthy that this particular design is not exceptional in Seoul, thus obviously frequent pedestrian discomfort prevails in Seoul streets.

The pedestrian levels of service for the existing streets were calculated by using the proposed method, and are summarized in Table 7.

It is to be remembered that this research concerns how engineers can improve the walking environment of the urban street by reflecting the pedestrian levels of service in the sidewalk pavement width. The authors looked into Table 7, selected Section III for further analysis because of its lower

Table 7. Existing Levels of Service on the Sidewalk Pavements and the Vehicle Lanes

	Pedestrian LOS (Score)	Vehicle LOS (Score)	Evaluation Score†
Section I	B (5)	D (3)	0.60*5+0.40*3=4.2
Section II	B (5)	B (5)	0.60*5+0.40*5=5.0
Section III	D (3)	C (4)	0.60*3+0.40*4=3.4

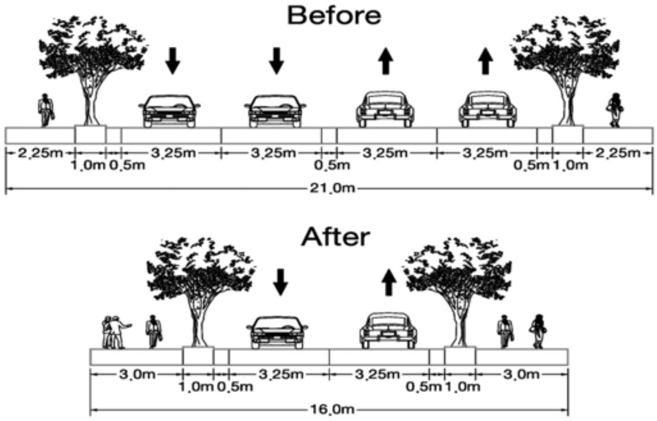

Fig. 5. Proposed Street Cross Section and the Existing Cross Section

pedestrian service level, and provided a better sidewalk pavement width design as shown at the bottom of Fig. 5. In this new design, the sidewalk pavement width and the vehicle lane width were subject to change, but the dimensions for the median strip and other cross section design elements remained unchanged, because this research tries to stress the impacts of the *balanced width* design for the sidewalk pavement width and the vehicle lane width. Despite that there are three possible design alternatives for the cross-section design of this route, which will include four lanes, three lanes with the middle lane reversed, and two lanes designs, the authors decided to apply only the two lanes design, which seems rather narrow for current design standards, and demonstrate that this design is still comparable to the four lanes design. Hence, while the existing sidewalk pavement width of 2.25 m was widened to 3.0 m, the existing number of vehicle lanes was reduced from 4 to 2 lanes. This change resulted in a total street width change from 21.0 m to 16.0 m in Section III. In spite of the reduced number of vehicle lanes and total street width, the proposed street design is anticipated by the authors to provide not only a better walking environment but also a more balanced street width compared to the existing street design.

Will the authors' anticipation come true? To see this, service levels for both pedestrians and vehicles were calculated, and summarized in Table 8. In fact, it is found that the proposed cross section design leads to a much higher pedestrian level of service in spite of its significant width reduction in total street width and vehicle lanes. However, to compensate for the improved pedestrian service level, the vehicles in Section III need to pay their share of the cost, that is, a one step lowered service level

Table 8. Levels of Service Comparison for Proposed and Existing Cross Sections

	Pedestrian LOS (Score)	Vehicle LOS (Score)	Evaluation Scores
Current Design	Poor (3)	C (4)	0.60*3+0.40*4=3.4
Alternative	Fair (5)	D (3)	0.60*5+0.40*3=4.2

compared to the existing design. Table 8 summarizes these changes.

4. Conclusions

The urban street is a place for people to travel in vehicles as well as to walk. Based on the stated preferences of people surveyed in this research, the authors found that the current urban cross section design method should be improved to be used in balance for both vehicles and pedestrians, and this could be done by reflecting the change of pedestrian comfort levels in a proposed sidewalk pavement width design method. The research also found that pedestrian foot path trajectories would be a good source in understanding how pedestrians experience discomfort on the sidewalk pavement, and that the comfort levels also varied by how many pedestrians group together in their lateral spaces. Finally, when the proposed sidewalk pavement design method was applied to a case study site, a more pedestrian friendly urban cross section was made possible. Although theoretically sound, the proposed sidewalk pavement width design still requires a larger sample size to be generally applicable in other cities.

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