Evaluation of service quality for pedestrian crossing flow at signalized intersection

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ABSTRACT: Pedestrians can be considered as a basic element of transportation. Every transport related ot travel and journeys must begin and end in walking. Pedestrian crosswalk significantly affects the performance of signalized intersections in terms of mobility and safety.

The objective of this research is to evaluate the service quality for pedestrian crossing at signalized intersections. Multi stages and bi-directional crosswalk at signalized intersection located in Dubai CBD area named Union intersection was selected for this purpose.

Crossing time, pedestrian flow, walking speed, signal timing for pedestrians and motorists, delay, and the adequacy of the geometric of the selected crosswalk were observed using video recording technique. Collected data were analyzed, processed and computed using EVENT program and illustrated graphically by using Microsoft Excel. The effect of these parameters was examined on the pedestrian behavior and their regarding to the traffic rules.

The study indicated that 37.4% of the crossed pedestrians are non-compliance. This is mainly attributed to the wrong design of the signal timings, and secondly to the pedestrians disregard for signal indication. The average crossing speed was found to be (4.07) f/s. It was concluded that the crosswalk width is slightly affects the crossing speed or the density because the pedestrian has the tendency to cross outside the crosswalk. In addition, the study confirmed the previous researches, which indicated that the average delay of pedestrians at signalized intersection crossings is not constrained by capacity.

Keywords: crossing time, crossing speed, pedestrian flow, signal timing, crosswalk

Introduction

Pedestrians can be considered as a basic element of transportation. All transport related travel and journeys must begin and end in walking. The presence of crosswalks is considered a calming effect to the vehicular traffic and will cause delay and then congestion if not handled correctly. Crosswalks are portions of roadway designated for the use of pedestrians to cross the street whenever they have the right of way. They affect the performance of signalized intersections significantly in terms of mobility and safety.

The need to provide a safe, secure and convenient way of traveling is the main objective of a transport planner. This is of particular concern in urban areas where traffic flow is high and traffic movements are often unpredictable. Any good traffic management scheme recognizes pedestrians as a class of traffic requiring equal treatment with vehicles.

In addition to pedestrian needs and safety there is the operational efficiency of the intersection to consider. At intersections where it is difficult particularly during peak periods to provide adequate vehicle capacity, the inclusion of an all red period necessary for separate pedestrian stage increases vehicle delay and congestion, therefore, highway authorities should accommodate these two considerations, the pedestrian safety and intersection operational.

An important factor to minimize delay for both pedestrians and vehicles is to provide the intersection with a sequence of cycle lengths in a manner to cater both motorist and pedestrians.

This study tends to evaluate the service quality for pedestrian crossing in a signalized intersection in Dubai City named Union intersection. When pedestrians are crossing the intersection they become impatient and engage in risk-taking behavior due to wrong design of vehicular traffic and pedestrian cycle lengths.

Objectives

The objective of this research is to evaluate the service quality for pedestrian crossing through the mostly used crosswalk of a signalized intersection in Dubai CBD area named Union intersection. Crossing time for pedestrian will be measured to evaluate the maximum pedestrian flow, crossing speed, density, delay, and the adequacy of the geometric and location of signalized crosswalk. The signal timing for pedestrian and motorists will also be examined.

In conclusion, the signalized crosswalk performance will be examined if it can handle the pedestrians safely and efficiently.

Pedestrian flow behavior during crossing the signalized intersection

(HCM2000) stated that the signalized intersection pedestrian crossing is more complicated to analyze than a midblock crossing, because it involves intersecting sidewalk flows, pedestrians crossing the street, and others queued waiting for the signal to change. The qualitative measures of pedestrian flow are similar to those used for vehicular flow, such as the freedom to choose desired speeds and to bypass others. Other measures related specifically to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, to maneuver generally without conflicts and changes in walking speed, and the delay experienced by pedestrians at signalized and un-signalized intersections (HCM2000).

Pedestrian flow at signalized crosswalks can be uni-directional or bi-directional depending on pedestrian demand at both sides of the crosswalk. The majority of them are bi-directional due to the pedestrian demand from both sides. Pedestrian crossing time is basically a function of crosswalk length and walking speed. At bi-directional crosswalk, the crossing time increases due to the interaction between conflicting pedestrian flows. Crosswalk geometry play a main role in pedestrian crossing time and walking speed which are considered an important factors for assessing the signal timing and improving the geometric design and configuration of signalized crosswalks (Alhajyaseen, 2010).

Pedestrians delay and safety

The delay experienced by pedestrians is of practical importance in view of the time lost by delayed pedestrians, and because most pedestrians seek to minimize their waiting times by crossing in gaps in vehicle flow. Pedestrian delay at signal controlled intersections has been shown to be a function of signal timing, vehicle flow, and road width (Goldschmidt, 1977).

Pedestrian compliance with the signal can have a substantial impact on pedestrian delay, particularly at intersections with moderate to low vehicle flow (Al-Neami,1992).

(Retsko and androsch, 1974) observed that the signal timings will affect the proportions crossing during the red man and reported that signal timings which are disadvantageous to the pedestrian encourage wrong behavior. Such arise when pedestrian signal timings do not take proper account of pedestrian flow or when excessive green time is given to vehicular traffic in relation to the flow level.

These conclusions seems to be consistent with the majority of researches which suggest that the longer the vehicle green is, the more pedestrians will be likely to take risks and cross against the signal. This will lead to the fact that delay reduction and safety may be in conflict and the implication must be carefully balanced during the calculation of signal settings at crossings.

Pedestrians walking speed

Walking speed is an important element for the design and evaluation of pedestrian facilities. Pedestrian crossing speed is calculated according to the space mean speed criteria. It is defined as the average speed of all pedestrians occupying the pedestrian facility over a specified period of time and calculated based on the average travel time which is called the crossing time for the pedestrian to traverse a unit length of a pedestrian facility.

Pedestrian speed is the average walking speed for pedestrians which is typically about 4 ft/sec but varies with age and purpose of walking trip. It is highly dependent on the proportion of elderly pedestrians (65 years old or more) in the walking population. If 0 to 20 percent of pedestrians are elderly, the average walking speed is 4.0 ft/sec on walkways (HCM2000). If elderly people constitute more than 20 percent of the total pedestrians, the average walking speed decreases to 3.0 ft/sec. In addition, a walkway upgrade of 10 percent or more reduces walking speed by 0.5 ft/sec. On sidewalks, the free-flow speed of pedestrians is approximately 5.0 ft/sec (HCM2000). There are several other conditions that could reduce average pedestrian speed, such as a high percentage of slow-walking children in the pedestrian flow.

Crosswalk geometric and location

Characteristics of crosswalks including position and width define the vehicle's stop line position, and therefore the required all-red interval. As crosswalks become wider or their position become further upstream, cycle length will increase because of all-red time requirement. The width of a crosswalk depends primarily on the number of pedestrians who are expected to use the crosswalk at a given time. Manual on Uniform Traffic Control Devices (MUTCD) in the US recommends a minimum crosswalk width of 6ft (1.8m), (MUTCD 2003). Meanwhile the Japanese Manual on Road Marking (2004) recommends a crosswalk width of 4.0m and allows installation of crosswalks up to 3.0m wide when pedestrian demand is expected to be low (Alhajyaseen, 2010).

Data collection and analysis methodology

Site selection and description

A signalized intersection named Union Intersection locates at the CBD area in Dubai City, UAE was selected for the purpose of this study. It is 4-leg intersection formulated mainly by two main streets, Al Rigga and Omer Bin Al-Khatab streets. Al Rigga street is a three lane divided roadway connects the intersection from the north direction. While Omer Bin Al-Khatab street is

a five-lane divided roadway forms the East and West intersection approaches. The forth approach of the intersection (the south leg) is an entrance to a large parking lot for taxies and buses and a hospital allocated for foreign issues. These two facilities are considered as pedestrian attractive areas. At the other side on Al-Rigga street, there are well known shopping complexes, which are also considered highly pedestrian attractive areas. These two areas form the mostly crosswalk used by pedestrians in the intersection. Figure (1) shows the intersection layout. This layout was drawn from Google maps but it is not updated because in reality the south approach has two directions.

In conclusion, from the observed survey, the Union intersection serves high pedestrian flow and its traffic flow is also considerably high, therefore it is expected that there is a difficulty to find a safe, and convenient way for pedestrian to cross. This is the reason for selecting this intersection as a study area in this discipline.



Fig. (1):Union intersection layout

Data collection, abstraction, and analysis

Data collection consisted of videotaping for motorist and pedestrian behavior. Field observations were conducted on hot weekdays for both A.M. and P.M. periods on 20th, 22th July and 2nd August, 2010. The mostly used crosswalk is shown in Figure (2). The crosswalk of interest with its waiting areas were allocated by characters (A, B, C, D) to facilitate the analysis procedure. It is a bi-directional flow, multi-stage pedestrian crossing due to the three crosswalk parts' A-B, B-C, and C-D" and two waiting's areas in addition to the two sidewalks. Pedestrian demand flows from both sides of the interested crosswalks. When pedestrian flow is bi-directional, interactions between the subject and the opposite pedestrian flows become the main factor that control the total crossing time.

Video camera was set up on the sidewalk on two positions approximately 10 meters upstream from the intersection. One was on the sidewalk of the corner "A" and the second position was on the sidewalk of the corner "D". The camera was positioned so that the crosswalk was visible, and pedestrians in the crosswalk were walking either toward or away from the camera. The objectives were to obtain as much details as possible of pedestrian behavior, pedestrian-vehicle

interaction and change of traffic signal aspects. Activities at the selected crosswalk were recorded for two periods (morning and evening) of one hour session length each and for the two positions, A and D. these recording activities continued for three days.



Fig. (2): Intersection crosswalk of interest

Methodology of crossing pedestrian flow

The total time needed by a platoon of pedestrians to cross a signalized crosswalk from the beginning of the green man indication until the pedestrian's platoon reaches the other side of the crosswalk can be divided into two main parts: discharge time and crossing time. Discharge time is the necessary time for a pedestrian's platoon to move from the waiting area and step inside the crosswalk. While crossing time is the time, which is necessary to cross the crosswalk. Crossing time for pedestrian's platoon was measured as bulk that is the time starts computing from the first row of pedestrian stepping the crosswalk and ends when the last pedestrian in the platoon reaches the other side of the crosswalk.

To perform the objective of this research study the followings were abstracted from the videotaping using a computer program named "EVENTS" (AlNeami, 2000). This program was designed to abstract the required information from the raw data by allocating each successive event with its time in a file.

1. Number of pedestrians crossing the signalized crosswalk parts includes the number and percentage of non-compliance pedestrians.

- 2. Number of pedestrians waiting on the sidewalks and on the medians.
- 3. Traffic flow in the approaches interacts with the crosswalk of interest.
- 4. Intersection cycle length, signal timings for pedestrians in all crosswalk parts, and signal timing for the vehicular streams conflict with pedestrians.

The duration of an analysis period for pedestrians recommended by HCM2000 is typically 15 minutes. The recorded data were reduced into the recommended period session, which is considered enough to provide statistically meaningful samples and to prevent probable fluctuations that may occur in traffic and pedestrian flow. Finally, the short sessions minimize errors which may results from continuously watching video recording.

Pedestrian flow data

Table (1) shows the abstracted average observed numbers of pedestrian crossing the intersection through the crosswalk of interest for both morning and evening periods along the surveying three days. The pedestrian demand has a variety of age groups, gender, and are coming as a single or couple and many of them are coming as a groups. The following values represent the average for all these varieties.

| Crosswalk | Av. crossing | Non-compliance | Non-compliance |
|-----------|------------------|----------------|----------------|
| parts | ped. no./15 min. | no. | ratio |
| A-B | 241 | 60 | 24.89% |
| B-C | 292 | 142 | 48.63% |
| C-D | 229 | 85 | 37.11% |
| Average | 254 | 95 | 37.4% |

Table (1): Pedestrian flow sample size for the crosswalk of interest

The differences in the number of pedestrian observed in each part of the crosswalk are attributed to the existence of destinations for crossing pedestrians other than the interested crosswalk. While the high percentage of non-compliance pedestrian (37.4%) is attributed to the followings;

1. The wrong design of the signal timing for both, motorists and pedestrian timing as will be explained in details hereinafter.

2. Most of these non-compliance pedestrians do not have any regard to the traffic rules.

3. Some of them think that if the road is clear from vehicles, then he/she has the right to cross even though the man signal is red because he is only watching the clearance of the road. The tabulated data are also represented graphically as shown in Figure (3).

Fig. (3): graphical representation of pedestrian flow per 15 min.



Crosswalk geometric properties

Crosswalks are portions of roadway designated for the use of pedestrians to cross the street whenever they have the right of way. They significantly affect the performance of signalized intersections in terms of mobility and safety (3). When crosswalk width becomes larger for a specific demand, crossing time decreases until it becomes almost constant (free-flow condition). But when crosswalk width becomes smaller, crossing time increases, until it reaches a point where opposing flows block each other causing increase in crossing time due to the effects of bidirectional pedestrian flow. This would be reasonable if pedestrian had not the tendency to walk outside the crosswalk.

In this research study, this assumption is not occurring, because pedestrians try avoiding the interaction with bi-directional crosswalk and passing outside the crosswalk boundary. This is why the width of crosswalk parts in this study affects slight difference on the walking speed. Figure (4) indicates this behavior. Table (2) shows the dimensions for the interested crosswalk parts. Crossing time is dependent on pedestrian crossing speed, which is affected by the size of opposite pedestrian platoon and crosswalk width.

For the purpose of crossing speed comparison with the design speed as will be indicated later, the table is also include the flash green man timing for each part of the crosswalk.

| Crosswalk part | Length (m) | Width (m) | Flash green man, sec. | Expected design speed, m/s |
|-------------------|---------------|--------------|--------------------------|----------------------------------|
| A-B | 7.0 | 3.0 | N/A | N/A |
| B-C | 10.0 | 3.5 | 6 | 1.67 |
| C-D | 15 | 5.0 | 6 | 2.5 |

Table (2): Crosswalk geometry and flash green man time

Fig. (4): pedestrians crossing outside the crosswalk boundary to avoid conflict



Pedestrian speed profile

Pedestrian speed was calculated from the abstracted data for crosswalk parts A-B, B-C, and C-D. The distance walked by pedestrians is represented by the crosswalk length, while the crossing time which is considered the time that pedestrians step the crosswalk and start walking until they reach the other side of the crosswalk was also measured.

Variety of pedestrians were examined for computing the crossing times which include the single pedestrian, couples, families, pedestrian's platoon, with different age groups. Table (3) indicates the statistical results. The frequency distributions of the crossing speed for all crosswalk parts are graphically represented by figure (5). It is important to mention here that the

jam density cannot be computed because pedestrians crossing the road inside and outside the crosswalk width.

| Crosswalk | Sample | Mean | | Std | Min. | Max. |
|-----------|--------|------|------|-----------|------------|------------|
| part | size | m/s | f/s | deviation | value, m/s | value, m/s |
| A-B | 36 | 1.26 | 4.14 | 0.225 | 0.68 | 2.24 |
| B-C | 36 | 0.92 | 2.74 | 0.176 | 0.35 | 1.55 |
| C-D | 36 | 1.63 | 5.35 | 0.229 | 1.04 | 2.57 |
| Average | | 1.27 | 4.07 | 0.21 | 0.69 | 2.12 |

Table (3): Speed properties of interested crosswalk

The pedestrian design speed can be expected from the observed crosswalk length–green (man) time ratio which is expressed as m/s. As per table (2) above the expected design speeds are (1.67), and (2.5) for crosswalk parts B-C, and C-D respectively. The observed average values from table (3) are (0.92) and (1.63). These values are seemed under estimated compared with the expected design values. This is attributed to wrong design of pedestrian signal timings and the increased percentage of the non-compliance pedestrians. However the average observed walking speed is (4.07 f/s). this value matches the HCM recommended value (4.0 ft/sec) for 0 to 20 percent of elderly pedestrians. The observed proportion of elderly pedestrians was zero.



Fig. (5):- pedestrian crossing speed distribution for the interested crosswalk parts

To explain the effect of pedestrian behavior (compliance or non-compliance) on the value of crossing speed, Part C-D was selected for this purpose. The observed effect of this behavior on crossing speed is represented graphically in figure (6). From the figure it can easily be concluded that the non-compliance pedestrian have crossing speed values higher than the compliance pedestrians. This is attributed to the followings:

- 1) All of the non-compliance pedestrians are young people, which they have the ability to walk faster than others.
- 2) Despite of the little hesitations that observed at the site during the recording sessions, most of them were hurrying up to avoid the motorist interactions.
- 3) The non-compliance pedestrians are individually crossing the road, therefore, there is no interaction with others or opposed pedestrians.



Fig. (6):- Comparison between compliance and non-compliance crossing speed distribution in part C-D of the crosswalk.

Signal timings for pedestrian crossing

The signal timing for pedestrian crossing will be explained and compared with the signal timing for the vehicular traffic stream in conflict with pedestrian crossing. This will be an access to analysis the reason of the high percentage of non-compliance pedestrians.

Signal timings comparison is indicated in figure (7). Signal timings represent the actual cycle time at the period of recording. It was observed that the cycle time for the signalized intersection is (144) seconds. The Figure below clearly illustrates that the gap differences between the termination of green vehicular stream signal and initiation of green man signal is 25 seconds in case of part A-B. While, in case of part C-D, the red man signal starts with the initiation of the green signal for all vehicle movement types. The left turn movement green signal time is 25 seconds. The through and right turn movements signal has 97 seconds green time with high vehicular traffic volume only at the beginning of the signal. The difference between these two green signal movements is (72 sec.). This case will encourage pedestrians to cross at the red man signal.

Figure (8) represents four intervals for through and right movements selected from four cycle times of the signalized intersection. The figure indicates very light or no traffic after the first third part of the green interval.

The difference (allocated inside the arrows) that are located on the signal timing sketch of figure (7,a) is considered an additional delay for pedestrians which they already have red signals more than the recommended values. Highway capacity manual (HCM2000) recommends "When pedestrians experience more than a 30-s delay, they become impatient, and engage in risk-taking behavior".



Fig. (7):- Signal timing for pedestrians. And vehicles for the two end parts of the crosswalk



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Fig. (8):-Frequency of through and RT vehicle movements in green signal interval for part C-D of the crosswalk

Pedestrian delay computation

Highway capacity manual (HCM2000) computes the delay according to the following equation:

 $av. delay = 0.5 (C - g)^2 / C$(1)

Where: C is the cycle length of the intersection.

g is the effective green of the crossing pedestrians.

According to this equation and from the findings above, the average delay for pedestrians on the interested crosswalk parts is computed and indicated in the table (4). The evaluation of the service quality listed in the table depends on the criteria for pedestrians at signalized intersections adopted by HCM 2000, exhibit 18-9.

| Crosswalk part | Average delay, LOS s/p | | Likelihood of Noncompliance | |
|-------------------|---------------------------|---|--------------------------------|--|
| A-B | 10.12 | В | Low | |
| B-C | 46.7 | Е | High | |
| C-D | 32.6 | D | Moderate | |

Table (4):- service quality evaluation of the crosswalk.

Results and Conclusions

The results and conclusions of this research study can be summarized into the followings:

1. The average maximum pedestrian flow crossing the intersection through the crosswalk of interest during the observation periods is (1168 ped/hr).

2. The average percentage of non-compliance pedestrians is 37.4%

3. The average crossing speed is (4.07 f/s), this value matches the typical value recommended by the highway capacity manual (HCM2000).

4. The non-compliance pedestrians cross the road faster than the compliance pedestrians.

5. The crosswalk width has slight effect on the pedestrian capacity or its effect is unnoticeable. This is attributed to the fact that the majority of pedestrians cross outside the crosswalk boundary in case of increasing the crossing pedestrian capacity.

6. There is wrong design for the intersection cycle length and the signal timings for pedestrians and motorists; therefore, there is a need to redesign them to handle both pedestrians and motorists safely and efficiently.

7. The study indicates that only the first part of the crosswalk of interest has an acceptable delay, LOS, and likelihood of non-compliance which are (10.12 s/p, B, and low respectively). While part B-C has LOS "E" and high likelihood of non-compliance and the part C-D has LOS "D" and moderate likelihood of non-compliance pedestrians.

8. Research indicated that the average delay of pedestrians at signalized intersection crossings is not constrained by capacity.

Recommendations

1- According to the existing conditions, it is strongly recommended to redesign the cycle length of the signalized intersection in addition the signal timings for pedestrians and motorists to provide the intersection with a cycle length and share signal timings in a manner to cater both motorist and pedestrians.

2- The intersection capacity should be completely analyzed through studying the vehicular traffic volumes, pedestrian volumes and geometric design to set up new intersection design.

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