

Integrated Systems Methodology for Pedestrian Traffic Flow Analysis

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A typical urban pedestrian transportation system involves three basic elements: sidewalks or walkways; midblock or intersection corner, holding, or queuing areas; and pedestrian crossings of roads, railway lines, or other physical features of the transportation network. The pedestrians on sidewalks or walkways have operating characteristics analogous to motorized vehicles on roadways. The level of service and capacity analyses of sidewalks have been documented in the literature. In a similar manner, the concept of capacity and level of service have been individually applied to the street corner area and the crosswalk. Each critical pedestrian element has been considered individually, but not as a balanced system, especially at the most critical link—the signalized urban intersection. A methodology and guidelines are presented to analyze existing pedestrian elements at a signalized intersection, that is, the sidewalk, intersection corner, and crosswalk, with a systems approach that identifies key interrelationships of the individual elements. This systems approach can guide the design of a balanced at-grade pedestrian transportation system. It can be used to evaluate existing signalized at-grade intersection pedestrian elements, and to develop decision support tools to evaluate the potential need for a grade-separated pedestrian facility.

Travel by pedestrians is the most common mode of transportation throughout the world. Pedestrian traffic is a major component of traffic flow, especially in urban areas. It is also the most unpredictable component of the roadway environment due to the generally unrestricted mobility, travel paths, and actions that a pedestrian can perform. The effects of the behavior of pedestrians become most notable at the most critical part of the urban surface arterial network, the signalized intersection. In the United States the safe and efficient movement of motorized vehicles has been emphasized with the accommodation of pedestrians generally made a lower priority. Although the lowliness of pedestrian transportation in comparison with other modes of American transportation appears to be a modern problem, other views are possible (1).

The relegation of the pedestrian to a lower priority has forced the interaction of the pedestrian on a level with its most pervasive threat, the motorized vehicle. The pedestrians with their inferior operating characteristics are forced to enter the roadway, the domain of the vehicle, and complete.

Current analytical tools to evaluate pedestrian flow concentrate on walkways, queueing areas, street corners, and crosswalks. The walkway, street corner, and crosswalk comprise the pedestrian traffic system at a signalized intersection. Each element has been generally analyzed individually, but not as a system. The signalized intersection causes interrupted flow conditions for both the vehicle and pedestrians. This creates unique challenges in attempting to balance the level of service of the uninterrupted segments (sidewalks) with

the interrupted-flow segments of the system (corners and crosswalks at signalized intersections). Techniques are available to evaluate the level of service and capacity of the individual elements, but not the system as a whole. A methodology that integrates these elements is needed to help evaluate the pedestrian traffic system at a signalized intersection.

This study focuses on the interrelationships of the three elements of the pedestrian traffic system at a signalized intersection—the walkway, the street corner, and the crosswalk. Key factors that affect each element are identified. The methodology used to evaluate the level of service and capacity is described. After identification of the factors and methodologies associated with each pedestrian element, interrelationships are explored to develop an integrated pedestrian traffic analysis methodology at signalized intersections. This systems methodology will provide a decision support tool and guidelines to plan and design pedestrian elements at a signalized intersection.

BACKGROUND

Chapter 13 of the *Highway Capacity Manual* (HCM) (2,3) was found to provide the most relevant research pertaining to the pedestrian traffic system. Information relevant to pedestrians as part of the transportation system found in the literature relates to pedestrian safety, design, planning, and operations. With higher density land uses, major roadway facilities, and urban multilane arterials, “it is often extremely difficult to make adequate provisions for pedestrians” (4). It is also stated, “the transportation engineer is continually faced with the dilemma of how to allow for convenient and safe pedestrian crossings and maintain traffic capacity” (5,6).

The pedestrian traffic system is similar to that of motorized vehicles with analogous linkages between the traffic flow on roadways and sidewalks, queue or storage lane requirements and intersection corners, and the interrupted flow effects of vehicular traffic and crosswalks. The amount of pedestrian activity has a direct influence on vehicle-flow rates and is an important consideration for right-turning vehicles (3). Fruin and Benz (7) provided the basis for the preliminary (3) and current (2) versions of the HCM by developing procedures for determining levels of service at street corners and in crosswalks. This was seen as an improvement over previous TRB *Circular 212* (8) procedures. Tanaboriboon and Guyano (9) developed six levels of service for pedestrian facilities similar to the United States, but the pedestrian area occupancies are lower and the flows accommodated in each level of service (LOS) are higher.

Khisty (10) discussed the level of service guidelines established in the 1984 HCM, but proposed to take the LOS concept further by including a practical method of assessing pedestrian facilities by taking into account qualitative environmental factors, such as attractiveness, comfort, convenience, safety, security, system coherence,

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and system continuity. Sarkar (11) proposed an LOS evaluation for a macrodesign scale from A to D and F and quality of service (QOS) from A to D based on qualitative conditions assigned to each QOS for microdesign. The U.S. Department of Transportation (DOT) (12) recommended that an LOS analysis be conducted in a central business district, but did not discuss the pedestrian system at an urban signalized intersection. Seneviratne and Morrall (13) conducted pedestrian studies of sidewalks, malls, crosswalks, stairs, and ramps in Calgary, Alberta, Canada, and discussed levels of service and the alternative quality of service concept, also based on environmental factors. There was very little discussion in the literature about the planning and design of a balanced pedestrian system at signalized intersections relating to level of service of not only the individual elements, but also the system as a whole.

ELEMENTS OF URBAN INTERSECTION PEDESTRIAN SYSTEM

The main elements of urban pedestrian transportation systems are the sidewalk, the intersection corner or holding area, and the crosswalk (2). The sidewalk is to the pedestrian what the roadway is to the vehicle, and is one of the major elements of the pedestrian traffic system at a signalized intersection. The effective or clear width of the sidewalk is the major determinant of the level of service and capacity of the sidewalk. The clear or effective walkway width relates "to the portion of a walkway that can be effectively used for pedestrian movements" (2). The methodology developed in the HCM (2) describes analytical procedures that can be utilized in analyses to determine deficient sidewalk locations. Levels of service and capacities can be calculated based on pedestrian flow rates, pedestrian densities, and the effective width of sidewalks. The effective sidewalk width takes into account the reduction in available physical sidewalk width due to fixed or moveable obstructions. The effective sidewalk width is one of the three basic elements of pedestrian traffic flow at signalized intersections.

The second major element of the pedestrian traffic system at signalized intersections is the corner or holding area. The corner area involves uninterrupted (sidewalk) flow, interrupted flow (crosswalks), and pass-through traffic. The "sidewalk flows, pedestrians crossing the street, and others queued waiting for the signal to change" mix in the corner area, creating a critical link between the sidewalk and the crosswalk, (2). Two corner area needs are the holding area for pedestrians waiting for the signal to change and the circulation area for pedestrians crossing with the green interval, coming off the street in the crosswalk, coming from the sidewalk into the corner, and pedestrians not crossing the street, but moving between adjoining sidewalks. These combinations create rather complex movements. The HCM uses a time-space concept (2). It assumes that pedestrians waiting for the signal to change occupy about 5 ft²/pedestrian (ped) in the holding area. It also assumes that the average time that pedestrians occupy the corner area is in the range of 3 to 5 sec. The data the HCM method requires are sidewalk widths, the corner radius, the roadway width, signal-cycle length with splits, green-amber times for the major and minor streets, and 15-min peak pedestrian counts.

Within the signalized intersection, the crosswalk is the third major element of the pedestrian traffic system. The crosswalk traverses the domain of the vehicle, so the pedestrian traffic flow is interrupted. Otherwise, the characteristics of uninterrupted flow on crosswalks are similar to sidewalks. The major differences of pedestrian-flow

analysis between sidewalks and crosswalks are attributable to signal timing and turning vehicles that interfere with the pedestrian green, or Walk, and flashing Don't Walk (pedestrian clearance-time) phases. The time-space concept is applicable in the analysis of the crosswalk. This time-space is the Walk-phase time less the platoon start up time (assumed to be 3 sec in the HCM) and the crosswalk area. The demand for the space is the product of the pedestrian crossing flow and the average crossing time. The available time-space divided by the demand provides the space per moving pedestrian available during the green phase. This value can be compared with the LOS criteria table. The negative effect of turning vehicles can be estimated by assuming a vehicle swept-path area and time per turning vehicle in the crosswalk.

Zegeer (14) recognized that "the safe and efficient movement of pedestrians on sidewalks requires the proper placement of street furniture (e.g., newspaper racks, telephone booths, benches)." The problem with sidewalk restrictions was discussed in research conducted by DOT (15), which said, "the potential pedestrian capacity of CBD sidewalks is reduced further by the intrusion of refuse cans, fire hydrants, fire alarm boxes, parking meters, traffic signals and poles, newsstands, telephone booths, mailboxes, planters, sewer and ventilation gratings and other devices." In addition to the adverse effect on sidewalk capacity, this research recognized that "space is needed at intersections for the accumulation of pedestrians waiting for traffic signals and the weaving of pedestrian flows" and that "the pedestrian is further harassed by vehicles stopped in the crosswalk or turning into the path of crossing pedestrians." Similarly, handbill distributors, sidewalk performers, entertainers, and vendors adversely affect capacity, safety, and level of service.

Right-Turning Vehicles

Research by Luh and Lu (16), Virkler and Maddela (17), Perez (18) and TRB (2,3) confirms that the allowance of right-turn movement during the concurrent pedestrian phasing detrimentally affects the level of service and capacity of the crosswalk. This impact is determined quantitatively by "assuming an average area occupancy of a vehicle in the crosswalk, based on the product of vehicle swept-path and crosswalk widths, and an estimate of the time that the vehicle preempts this space" (2).

CONSIDERATIONS FOR DEVELOPMENT OF AN INTEGRATED SYSTEMS METHODOLOGY

The LOS of a pedestrian element defines a range of flow rates, speeds, and space per pedestrian. LOS levels in the HCM range from A (best) to F (worst). The space and average speed decline from LOS A to F, whereas the flow rate and volume to capacity ratio increase, as shown in Table 13-3 of the HCM (2). Unfortunately, the HCM methodology assumes a walking speed of 1.37m/sec (4.5 ft/sec). Vehicular traffic can affect the LOS of a crosswalk due to adverse effects caused by turning vehicles traversing the crosswalk during concurrent right-turn or left-turn movements. Theoretically, with exclusive or protected left-turn phasing, the left-turn interference is eliminated. A heavy right-turn movement can directly affect the LOS of a crosswalk by reducing the crossing time and crosswalk space available for pedestrians.

To develop a systems methodology, the key variables that relate to each of the three elements need to be identified and their

interrelationships considered. As a system, these groups of variables affect the LOS of each element and the ability to balance the pedestrian system at a signalized intersection. The key variables that affect the system are listed in the geometric, traffic signal operation, and traffic groups shown in Figure 1.

The interrelationships of the key elements (sidewalk, corner area, and crosswalk) show that a balanced increase in the width of the sidewalk and crosswalk, and an increase in the holding area of the corner, will help improve the LOS of the system. Other fundamental interrelationships exist between the variables of the three groups. An increase or decrease in one variable will directly or indirectly cause concurrent changes in the values of other variables to ensure that the desired LOS is maintained. Interrelationships exist between the following variables as follows:

1. Pedestrian red time and holding area. As the red time for pedestrian movement increases, the holding area size must increase to accommodate a larger platoon of pedestrians. The opposite effect is true with more pedestrian green time. If the pedestrian red time is held constant, the holding area size must increase to improve the level of service. If the holding area is held constant, then the pedestrian red time must decrease to improve the level of service. These relationships are shown schematically in Figure 2 by vertical and horizontal lines.

2. Pedestrian red time and crosswalk width. With larger platoons, the surge condition in the crosswalk increases, thereby causing the need for a wider crosswalk. The opposite effect is true with more pedestrian green time. If the pedestrian red time is held constant, then the crosswalk width must increase to improve the level of service. If the crosswalk width is held constant, then the pedestrian red time must decrease to improve the level of service. These relationships are also shown in Figure 2.

3. Crosswalk width and vehicular right turns. An increase in the vehicular right-turn movement traversing a crosswalk during a concurrent phase will cause an increase in crosswalk width to offset the loss of time-space due to the right-turn movement, if additional green time is not available.

4. Pedestrian green and vehicular right turns. An increase in the vehicular right-turn movement traversing a crosswalk during a concurrent phase will cause an increase in pedestrian green time to offset the loss of time-space due to the right-turn movement, if additional crosswalk width is not available.

5. Pedestrian green time and the elderly, young, and disabled. A higher composition of the elderly, young, and disabled will cause a slower walking speed, thus increasing the time needed to cross a street. This increase creates a higher time-space demand. Additional pedestrian green time will be needed to accommodate the pedestrian crossing.

6. Pass-through pedestrian traffic and holding area. The higher the proportion of pass-through traffic, that is, pedestrian traffic crossing the corner area only from adjoining sidewalks without crossing the street, the smaller the holding area available to accommodate waiting pedestrians will be needed.

An understanding of these interrelationships is important in the tasks of planning and design of an LOS-balanced pedestrian system at signalized intersections.

DEVELOPMENT OF AN INTEGRATED SYSTEMS METHODOLOGY

A planning methodology is needed to link the sidewalk, corner area, and crosswalk elements by LOS. In the descriptions provided of the LOS criteria (2), LOS C is the lowest LOS that allows normal walking speeds and reasonable maneuverability. Pedestrian behavior below this level becomes more unpredictable and stressed due to restrictions in speed and maneuverability. The methods using individual key elements did not provide a balanced-system LOS. The LOS of the system and its elements should be the same to optimize and balance pedestrian flow. Thus,

$$\begin{aligned} \text{LOS (pedestrian traffic system at signalized intersection)} \\ = \text{LOS (sidewalks)} = \text{LOS (corner area)} = \text{LOS (crosswalks)} \end{aligned}$$

The sidewalk at a signalized intersection is similar to the roadway leg of the signalized intersection. Volumes of approaching vehicles are used to determine adequate levels of service for vehicles. Similarly, the volumes of pedestrians proceeding to and from a signalized intersection provide the basis for the design of the pedestrian traffic system. The sidewalk is the uninterrupted pedestrian flow segment of the pedestrian traffic system.

The corner areas and crosswalk areas are analyzed using the time-space concept. This must be done due to interruptions in

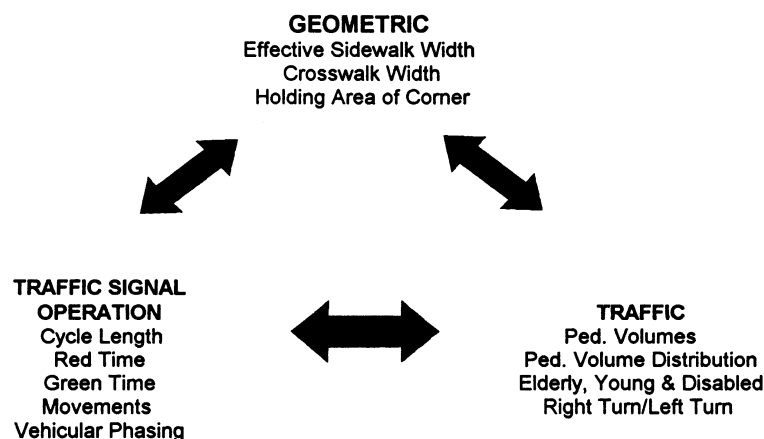


FIGURE 1 Interrelationships of groups of variables.

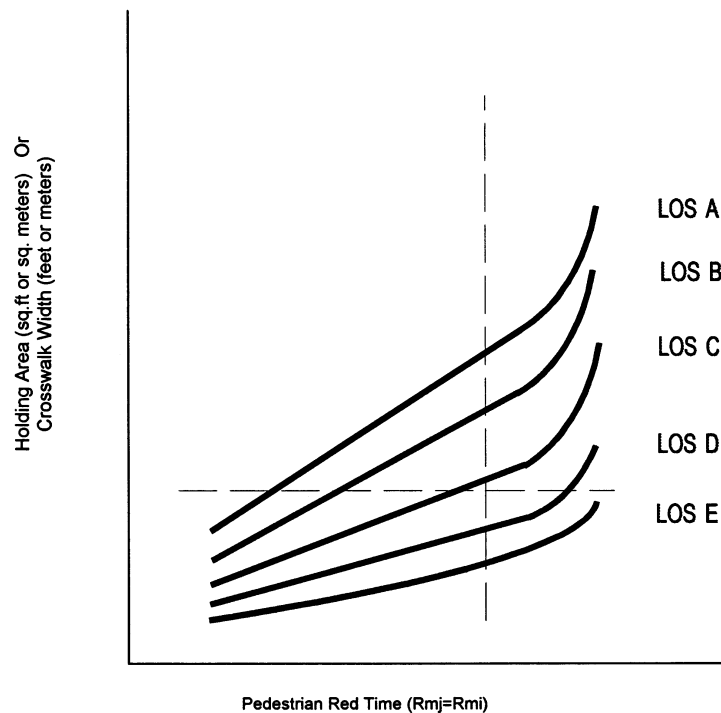


FIGURE 2 Interrelationships between holding area, crosswalk width, and pedestrian red time.

pedestrian flow caused by the operation of the traffic signal. The cycle length of the traffic signal and the time provided for the pedestrian phase intervals (Walk, flashing Don't Walk, and Don't Walk) directly affect the LOS of the crosswalk and corner area. With an assumed or selected LOS, effective sidewalk width, signal cycle, and the following assumptions, the pedestrian traffic system can be planned. Most of these assumptions are the same as those used in the HCM (2).

1. The bidirectional pedestrian traffic flow on crosswalks is approximately equal. In Figure 3, the inbound pedestrian flows to the corner are identified as v_{ci} and v_{di} . The pedestrian flows outbound from the corner are identified as v_{co} and v_{do} . It is assumed that $v_{ci} = v_{co}$ and $v_{di} = v_{do}$ (ped/cycle).

2. Platooning does occur in the pedestrian flow due to the interruption of the operation of the traffic signal.

3. On corner areas, pedestrians are either standing and holding, or circulating and moving.

4. A standing pedestrian on a corner occupies an average area of 0.46 m^2 (5 ft^2) per pedestrian.

5. The average time that moving pedestrians occupy the corner, that is, passing through, is in the range of 3 to 5 sec. The time taken by a pedestrian to pass through the corner is a function of intersection geometry and walking speed.

6. The average walking speed in the crosswalk, S_p , is assumed to be 1.37 m/sec (4.5 ft/sec) in accordance with the HCM, but it can be varied as appropriate.

7. The platoon start-up time of pedestrians is 3 sec.

8. The pedestrian traffic, or pass-by or pass-through traffic, between adjoining sidewalks, but not crossing the street, is identified as v_{ab} . Further research is needed to refine this planning procedure value.

9. Uniform arrivals of crossing queues in the corner area.

10. The same effective width of sidewalk is used for both sidewalks intersecting at a corner. The larger effective width is used for both sidewalks A and B in the planning procedure.

With these assumptions, the following methodology is used:

Sidewalk Width

Step 1. If it is desired to balance the LOS of an assumed effective sidewalk width (W_E), then use the following planning procedure. Determine the high end of the flow rate (v) from Table 13-3 of the 1994 HCM (2). For example, at LOS C it would be $10 \text{ ped/min/0.3048m}$ (10 ped/min/ft). Assume that this flow rate represents platoon conditions, where $v_p = v + 4$. The average flow rate would be lower, but the design is for platoon conditions, because of the proximity of a signalized intersection. For the total flow of the sidewalk A and B, calculate the following, respectively:

$$W_{EA} \times v_{PA} = V_{TA}$$

$$W_{EB} \times v_{PB} = V_{TB}$$

where

W_{EA} = effective walkway width of sidewalk A,

W_{EB} = effective walkway width of sidewalk B,

v_{PA} = flow rate of pedestrians on sidewalk A per foot (0.3048 m) of width (ped/min/ft),

v_{PB} = flow rate of pedestrians on sidewalk B per foot (0.3048 m) of width (ped/min/ft),

V_{TA} = pedestrian flow for sidewalk A (ped/min), and

V_{TB} = pedestrian flow for sidewalk B (ped/min).

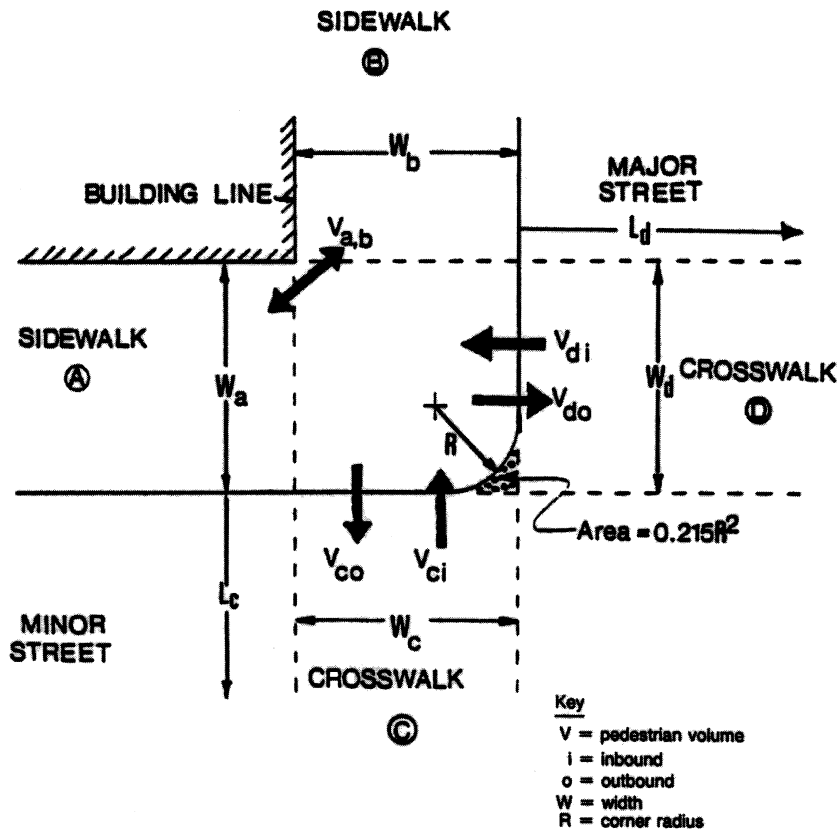


FIGURE 3 Intersection corner geometrics and pedestrian movements (2).

The total volume of the two sidewalks to and from the street corner is

$$V_{TA} + V_{TB} = V_{TOTAL} = V_t$$

If the actual volumes are known, then the sidewalks need to be sized in width for the LOS desired for platoon conditions where

$$v_p = v + 4$$

$$W_E = \frac{V_t}{15(v_p - 4)}$$

where v_p is the higher flow rate from Table 13-3 of the HCM (2) for the selected LOS and represents the platoon flow rate.

Step 2. If planning is based on an effective walkway width (W_E), then use this planning procedure. The total volume of the two sidewalks is $v_t = v_{ab} + v_{ci} + v_{co} + v_{di} + v_{do}$. Assuming equal bidirectional flow, then $v_{ci} = v_{co}$ and $v_{di} = v_{do}$. Assumptions can be made from whatever information is known of the values of v_{ab} , v_{ci} , v_{co} , v_{di} , and v_{do} . These relationships can be used to calculate the volumes in and out of the corner area and the pass-by pedestrian volume (v_{ab}). If actual values of v_{ab} , v_{co} , v_{ci} , v_{di} , and v_{do} are available, then use these values.

Crosswalk Width

Step 3 (crosswalk). Calculate the crossing time. The roadway widths must be known or assumed to determine L_c and L_d . Assume

a walking speed (S_p) of 1.37 m/sec (4.5 ft/sec) per the HCM (2). Determine the average time spent by a pedestrian in the crosswalk, t_{wc} and t_{wd} (sec), as follows:

$$t_{wc} = L_c / S_p$$

$$t_{wd} = L_d / S_p$$

Step 4 (crosswalk). Calculate the total crosswalk occupancy time, T_{wc} and T_{wd} (ped-min):

$$T_{wc} = (v_{ci} + v_{co})(t_{wc}/60)$$

$$T_{wd} = (v_{di} + v_{do})(t_{wd}/60)$$

Step 5 (crosswalk). Calculate the maximum number of pedestrians (surge) occupying the crosswalk V_{mc} and V_{md} (ped/min):

$$V_{mc} = (v_{ci} + v_{co})(R_{mi} + 3 + t_{wc})/60$$

$$V_{md} = (v_{di} + v_{do})(R_{mj} + 3 + t_{wd})/60$$

where R_{mi} and R_{mj} are the minor and major street red phase, or Don't Walk phase, respectively (sec).

Step 6 (crosswalk). Calculate the crosswalk needed for LOS (average pedestrian space and LOS) by the following process. The following values are given, known, or calculated: L_c , L_d , G_{mi} , G_{mj} , M_c , M_d , max M_c , max M_d , T_{wc} where L_c and L_d are the known roadway widths, G_{mi} and G_{mj} are the known Walk intervals, and M_c , M_d , max M_c , and max M_d (m²/ped [ft²/ped]) are obtained from Table 13-3 of

the HCM (2). T_{wc} is calculated in Step 4. For example, for crosswalk C, which has a width of w_c (m [ft]), the equations for the area of the crosswalk, A_c (m^2 [ft²]) are as follows:

$$A_c = L_c W_c$$

Calculate the total time-space available for circulating pedestrians, TS_c (m^2 -min [ft²-min])

$$TS_c = L_c W_c (G_{mj} - 3)/60.$$

Rearranging the expression yields the following:

$$W_c = \frac{60 TS_c}{L_c (G_{mj} - 3)} \quad (1)$$

$$M_c = TS_c / T_{wc}$$

Therefore,

$$TS_c = M_c T_{wc} \quad (2)$$

If there is a significant right-turn movement, a deduction from the crosswalk time-space available (TS_c) should be considered. As in the HCM, using an average swept-path of 2.44 m (8 ft) and an approximation that the right-turning vehicle occupies the crosswalk for 5 sec, a preemption per vehicle can be estimated as follows ($0.0929 m^2$ -min/vehicle [ft²-min/vehicle]):

$$(8 \text{ ft} \times W_c \times 5 \text{ sec/vehicle})/60 = 0.66 W_c \text{ ft}^2\text{-min/vehicle}$$

The total available time-space deduction equals the product of the number of right-turning vehicles during the pedestrian phase and the preemption per vehicle. This number is subtracted from TS_c .

$$T_{wc} = TS_c - 0.66nW_c$$

where n is number of right-turning vehicles. Substituting Equation (2) into Equation (1) gives

$$W_c = \frac{60 M_c T_{wc}}{L_c (G_{mj} - 3)} = \text{crosswalk width (average)}$$

Step 7 (crosswalk). Calculating the crosswalk width for the higher value of pedestrian space at the LOS follows. For example, for crosswalk C,

$$\max M_c = A_c / V_{mc} \quad (V_{mc} \text{ was calculated in Step 5})$$

$$A_c = L_c W_c, \text{ therefore substituting gives,}$$

$$\max M_c = L_c W_c / V_{mc}$$

Rearranging terms gives,

$$W_c = \frac{\max M_c V_{mc}}{L_c} = \text{crosswalk width}$$

Use the higher value of the square feet (square meters) per pedestrian for the LOS selected from Table 13-3 of the HCM (2). From this analysis, the appropriate crosswalk width for the LOS operation on the sidewalk can be determined. This provides a balanced

LOS operation for two of the elements of the pedestrian traffic signal system at a signalized intersection. The corner analysis procedure follows.

Corner Areas

Step 3 (corner). Calculate the total circulation volume. From Step 2 the values of v_{ci} , v_{co} , v_{di} , v_{do} , and v_{ab} (ped) are known. The planning procedure is

$$v_c = v_{ci} + v_{co} + v_{do} + v_{di} + v_{ab}$$

If actual volumes are known, use them.

Step 4 (corner). Calculate the total circulation time.

$$t_c = v_c \times C_{av}/60$$

where C_{av} is assumed to be 4 sec HCM (2).

Step 5 (corner). Calculate the holding area waiting times (ped/cycle).

$$Q_{tco} = [(v_{co})(R_{mj}/C)(R_{mj}/2)]/60$$

$$Q_{tdo} = [(v_{do})(R_{mi}/C)(R_{mi}/2)]/60$$

where Q_{tco} is the total time spent by pedestrians waiting to cross the minor street during one signal cycle (ped-min) and Q_{tdo} is the total time spent by pedestrians waiting to cross the major street during one signal cycle (ped-min).

Step 6 (corner). Calculate the holding area time-space. (TS_h , $0.0929 m^2$ -min [ft²-min])

$$TS_h = 5 \text{ ft}^2 (Q_{tco} + Q_{tdo})$$

Step 7 (corner). Calculate the gross corner area and net corner area. Determine M from Table 13-3 of the HCM (2) (t_c and TS_h have been previously calculated; C , W_a , W_b , R are known).

$$TS_c = M(t_c)$$

$$TS = TS_c + TS_h$$

$$AG = \frac{60TS}{C} = \text{gross corner area}$$

The net corner formula calculation is

$$A = W_a W_b - 0.215 R^2, \quad (3)$$

where

W_a = width of sidewalk A,

W_b = width of sidewalk B, and

R = radius of corner.

Equation 3 was found not to be useful, because it results in negative numbers. This may perhaps be due to the formula not taking into account the typical geometric design on a street corner where the sidewalks intersect.

A step-by-step Pedestrian Systems Method Flow Chart has been developed to summarize the process described, as shown in Figures 4 and 5. After the second step, either the gross corner area or the

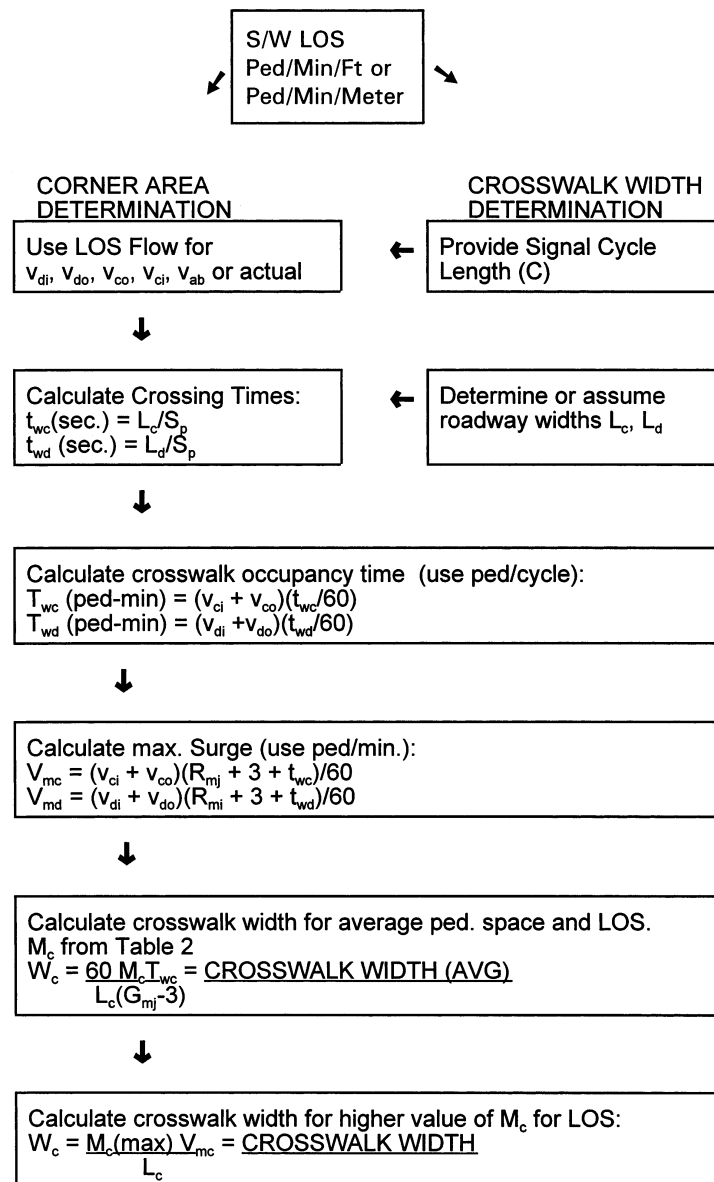


FIGURE 4 Step-by-step pedestrian systems method flow chart (2).

average or surge crosswalk width can be calculated to provide a balanced LOS pedestrian transportation system.

CONCLUSIONS AND RECOMMENDATIONS

The sidewalk, corner area, and crosswalk elements must be balanced to improve the level of service, capacity, and safety of the pedestrian transportation system. An integrated systems methodology has been developed to address this need. The integrated systems approach realizes that the sidewalk and signal phasing are the keys to the balanced system. Generally, the sidewalk provides an uninterrupted pedestrian flow that interfaces with the corner area, where interrupted and uninterrupted conditions exist, and the crosswalk area, where interrupted pedestrian flow conditions exist due to the operation of the traffic signal. The sidewalk element, especially an effective sidewalk width at an acceptable LOS

(probably LOS C) sets the basic criterion for the system, whereas the signal phasing and timing affect the design of both the corner area and crosswalk width.

This systems methodology could be used to develop a balanced LOS system based on a desired LOS, corresponding pedestrian flow rate, and effective walkway width (planning procedure) or could be used if actual conditions are known. The assumptions of the pedestrian volumes can be varied depending on engineering or planning judgment. A step-by-step methodology and flow chart were developed. It was concluded that the net corner area formula was flawed in that it probably does not accurately reflect the geometric design of a sidewalk around an intersection curb return. The methodology does recognize the effect of right-turning vehicles, although further refinement in this area is needed.

The integrated systems method provides a tool from which various tables or charts can be generated. Through iterations of various sidewalk widths and signal phasing, charts or software programs can

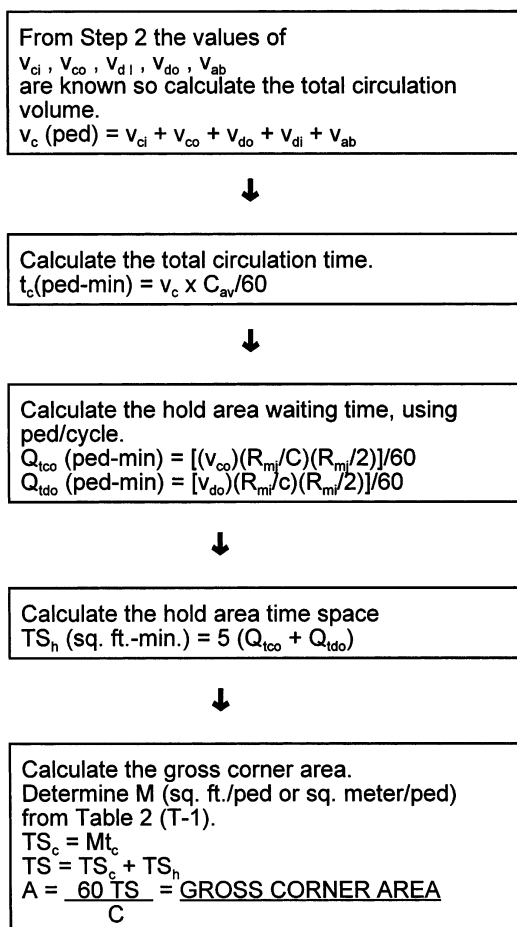


FIGURE 5 Continuation of flow chart for corner area determination.

be developed that indicate the appropriate corner area and crosswalk width. From a review of past research this type of guideline or decision-support tool does not exist.

The current practice of sizing crosswalks by Manual on Uniform Traffic Control Devices minimums, typically 3.048 m (10 ft), and the sizing of the corner areas and sidewalk widths by minimum AASHTO criteria can be replaced by this support tool, which provides a design tool for the planning of an integrated, balanced pedestrian traffic system at urban signalized intersections. Charts can be developed in recognition of local practices that, perhaps, accept LOS C or D for the design of pedestrian facilities. Other local parameters can also be established, allowing flexibility with this methodology.

At heavily traveled intersections, the conflicts of heavy pedestrian volumes and heavy vehicular traffic volumes can quickly overcome the ability of a traffic signal with pedestrian signal indications to efficiently and safely control both flows. Heavy pedestrian traffic can severely limit the level of service and capacity of the vehicular traffic at signalized intersections. This method can be used as a decision-support tool to guide in the evaluation and decision-making process regarding the consideration of pedestrian grade separations. When restrictions or constraints prevent the development or attainment of LOS E with one or more of the three elements by physical limitations, then alternatives, such as pedestrian grade separations, should be considered. Obviously, other constraints, especially fiscal factors, reduce the potential application of this option. The use of the

integrated systems methodology can show that, despite attempts at LOS E to balance signal phasing and timing with the other elements, if LOS F conditions exist, then support is provided for other alternatives, such as pedestrian grade separations or a decision to prohibit and prevent pedestrian crossings. The construction of a pedestrian grade separation can provide an obvious improvement by the elimination of vehicle-pedestrian conflicts and a significant benefit by the reduction of vehicle delay.

Further research is needed to evaluate the relationship between pedestrian accident experience at urban signalized intersections and the LOS of the pedestrian elements. It may be found that there is a definite relationship between significant pedestrian accident experience locations and pedestrian facilities with deficient LOS.

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