PEDESTRIAN BEHAVIOR AND PLANNNING CONCEPTS IN THE MIXED TRAFFIC OF NARROW URBAN STREETS*

by Young-in KWON**, Shigeru MORICHI***, Tetsuo YAI****

1. Introduction

In the late 1960's, several studies on pedestrian planning began to focus on the basic principles of pedestrian traffic flow on sidewalks. These studies have been largely summarized by Fruin[1] and Pushkarev and Zupan[2], and have been reflected in national standards on pedestrian facilities planning in the United States Highway Capacity Manual (US HCM)[3]. This manual gives general guidelines for the capacity and level of service (LOS) standards on sidewalks, using several factors such as space module per pedestrian, average speed, and flow rate.

In the case of Japan, the road environment is much different than that of many western countries. Most Japanese roads are very narrow, as shown in Table 1. In 1993, the total length of roads in Japan was 1,125,482 kms, but the length of roads with sidewalk was about 119,500 kms – approximately 10.6% of all roads[4]. With respect to road classification, "Municipal, Town, and Village Roads" total 948,642 kms, accounting for 84.2% of all roads by length. Of these roads, 86.5% feature very narrow sections of less than 5.5 m in width, while 99.6% are less than 13.0 m in width. Therefore, narrow roads interact closely with daily living and are very important to pedestrians in Japan. The aim of this paper is to identify pedestrian behavior and suggest concepts for planning pedestrian traffic flow in narrow urban streets. Several parameters were developed and used to analyze pedestrian behavior: pedestrian paths around obstacles, share of pedestrian using sidewalks by street and traffic conditions, "influence distance" of and for pedestrians, and time-space occupancy of traffic modes in mixed traffic conditions. Also, a new concept for pedestrian level of service (LOS) standards in mixed traffic conditions is considered which employs the concept of time-space occupancy, pedestrian density, and hindrances or conflicts between modes.

Table 1 Length of roads in Japan by type and width[4]

(kms, as the end of 1993)

Types	- 5.5m	5.5-13.0m	13.0m -	Total
National	7,222	40,945	5,137	53,304
Prefecture	52,068	67,816	3,652	123,536
Municipal	820,984	123,456	4,202	948,642
Total	880,274	232,217	12,991	1,125,482

2. Pedestrian Behavior and Interaction

(1) Data Collection

The data for the analysis of pedestrian behavior and interaction with other traffic modes such as bicycle or car were collected around urban railway stations in the Tokyo area. Video recording was undertaken at elevated points such as the tops of 3 to 8 story buildings or elevated station platforms for 30 minutes to 2 hours, depending on the level of traffic flow. During the recording, selected sections of narrow streets where there is a clear view of the movement of pedestrians, bicycles, and cars were marked in the every 10 cm in the lateral direction and every 50 cm in the longitudinal direction.

One of the picture of a typical surveyed street is shown as Figure 1. The video recordings were analyzed with the one thirtieth seconds of recording time, which could considers the movement of pedestrians, bicycles, and cars in slow motion.

Figure 1 View of a typical surveyed street

(2) Pedestrian Path around Obstacles

The traffic modes in narrow streets are apt to conflict stationary obstacles such as street furniture and parked bicycles or cars. The traffic modes tend to avoid conflict with these obstacles and maintain a safe and comfortable distance. The effect of obstacles on the traffic flow may be expressed in terms of the dimensions in Figure 2.

* Keywords: pedestrian, mixed traffic, narrow street
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In Figure 2, α is the starting point of the route change, and β is the ending point of influence upon the path of pedestrian traffic flow. γ is the lateral distance to the obstacle from the pedestrians. These parameters were calculated based on the observation of video with markings of distance every 10 centimeters on the street surface. The stationary obstacles could be an electric pole, a parked car, or a parked bicycle. The parameters were recorded at one of the surveyed streets located around Midorigaoka and Jiyugaoka urban railway stations.

Table 2 shows survey results for the influence distance of stationary obstacles on pedestrians. The mean values of α and β are 4.8 m and 4.7 m, and γ is 0.29 m. This value for the parameter α is similar to the result of experimental research by Tatebe and Nakajima[5]. According to their research results of 103 male adults, the mean value of α for pedestrians approaching an electric pole was 5.2 meters and consisted of the distance to keep personal space (B_f) and the distance caused by the pedestrian's forward movement (T_p). Figure 3 depicts the distribution of α, β, and γ which shows that the maximum value of α and β are around 10 meters and γ is around 1.0 meter.

(3) Sidewalk Using Behavior of Pedestrians

It may be assumed that pedestrians prefer to walk along streets that are safe and comfortable for walking. Considering this, the sidewalk and street use behavior of pedestrians was observed for different street environments and different traffic flow conditions. While the decision by pedestrians to either use the sidewalk or the street more stochastic than deterministic, and this paper tries to find any trends or parameters which reflect these behavioral characteristics.

Factors influencing the walking position of pedestrians were observed for survey streets that had various street environment conditions and level of traffic. Figure 4 shows the relationship between the share of pedestrians walking on the sidewalk and the adjacent street's car speed, car flow per lane, and pedestrian flow per unit sidewalk width. This result shows that the share of pedestrians using the sidewalks increases with increased car speed and car traffic flow. However, it decreases with an increase in pedestrian traffic flow because the pedestrians tend to avoid conflicts with others.

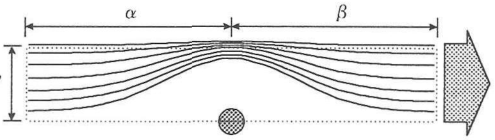

Figure 2 Influence of obstacles on pedestrian paths

Table 2 Mean values and sample size for α, β, and γ

Parameters	α	β	γ
Mean Values	4.8 m	4.7 m	0.29 m
Samples	46	33	44

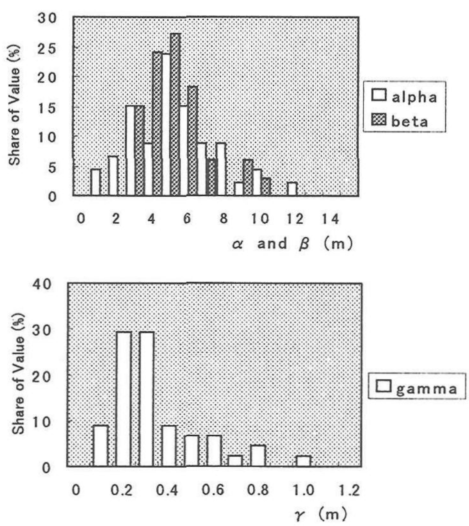

Figure 3 The distribution of α, β, and γ

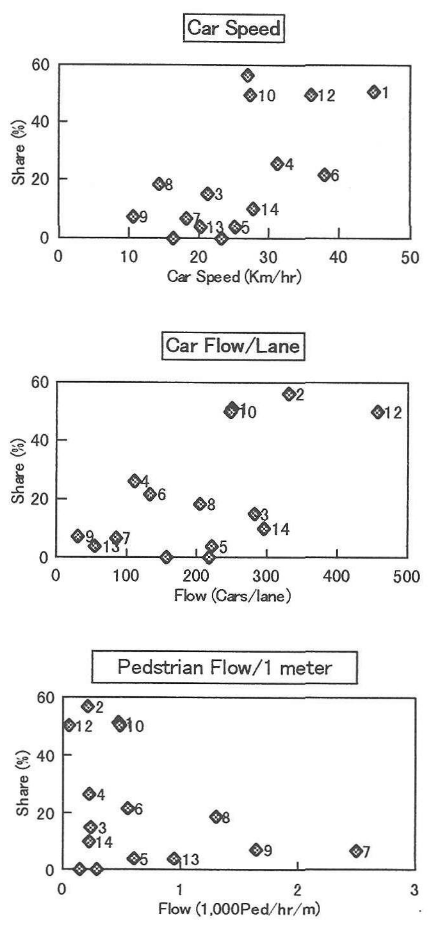

Figure 4 Share of pedestrians walking on sidewalk under different street environments

(4) Influence Distance of and for Pedestrians

The influence distance (D_i) is defined as the distance at which one mode of traffic takes an action to change its direction or speed with the purpose of preventing conflict and keeping a safe and comfortable distance from other traffic modes. To determine this distance, observation were recorded using a video camera with an RC recording function that could show traffic flows in one thirtieth second comma basis.

Not only pedestrians but also bicycles and cars try to prevent conflicts. Their behavior depends on many parameters, including the street and traffic conditions as well as the psychological condition of pedestrians, riders, and drivers. Figure 5 and Figure 6 show some relationships between traffic modes in this situation. The influence distance is linearly proportional to the speed of car and bicycle. The influence distance of cars for pedestrians is larger than that of bicycles. The influence distance of pedestrians for bicycles is a little higher than that for cars but the difference is not so great.

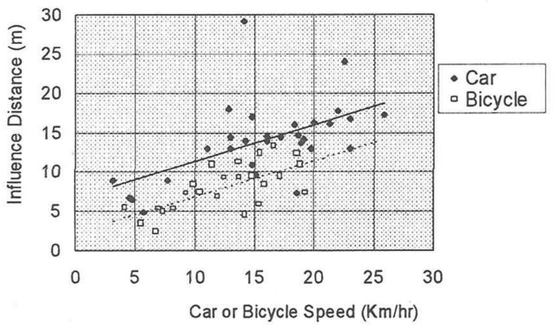

Figure 5 D_i of car & bicycle for pedestrian

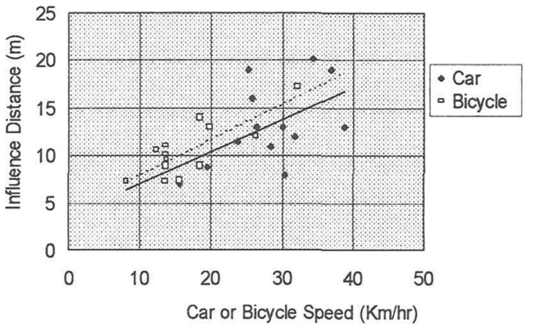

Figure 6 D_i of pedestrian for car & bicycle

3. Time-Space Occupancy Index of Mixed Traffic

(1) Origin of the Idea

Tsukaguchi and Mori[6] defined the time occupancy index (Q_{ti}) and the space occupancy index (Q_{si}) of residential streets for pedestrians, bicycles, and cars based upon the concept of occupancy with respect to time and space:

$$Q_{ti} = (1/t)\sum_{j=1}^{n} t_{ij} = (1/t)\sum_{j=1}^{n} (l/v_{ij}) \quad (1)$$

$$Q_{si} = (1/l\cdot w)\sum_{j=1}^{n} A_{ij} = (q_i \cdot A_i)/(w \cdot v_i) \quad (2)$$

where, i indicates the transport mode such as pedestrians, bicycles, and cars, t is total observed time, t_{ij} is time occupied by mode i, n is the traffic volume of mode i and equal to q_i, and v_{ij} is the speed of traffic mode i. l is the length of the street, w is the width of the street, A_{ij} is the area occupied by traffic mode i, and A_i and v_i are average value of the occupied area and speed of traffic mode i.

The above equations may be explained using Figure 7, where traffic modes m_1, m_2, and m_3 are moving along a given street section of $(Y_b - Y_a)$ during time section of $(T_b - T_a)$. t_1, t_2, t_3 and y_1, y_2, y_3 denote the time and distance occupied by the traffic modes. Assuming w_1, w_2, and w_3 are the occupied widths of the traffic modes, time occupancy (Q_t) and space occupancy (Q_s) of traffic modes at the given time and space section could be expressed as follows:

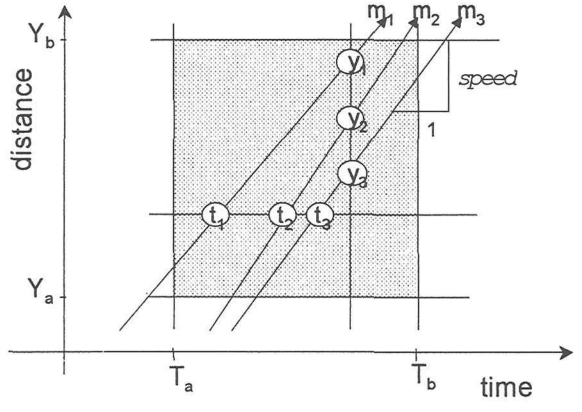

Figure 7 The concept of time-space occupancy

$$Q_t = (t_1 + t_2 + t_3)/(T_b - T_a) \quad (3)$$

$$Q_s = (y_1 \cdot w_1 + y_2 \cdot w_2 + y_3 \cdot w_3)/\{(Y_b - Y_a)\cdot w\} \quad (4)$$

where, $y_1 \cdot w_1$, $y_2 \cdot w_2$, and $y_3 \cdot w_3$ are the space occupied by each traffic mode m_1, m_2, and m_3 at the given time section.

The authors further define a new index of time-space occupancy ($Q_{t\text{-}si}$), which incorporates both time and space occupancy in order to analyze different modes of traffic flow with different speed and space occupancies.

$$Q_{t\text{-}si} = \sum_{j=1}^{n} \{(A_{ij}) \cdot (t_{ij})\} / (t \cdot l \cdot w) \qquad (5)$$

This index, using the example of Figure 7, could be expressed as follows:

$$Q_{t\text{-}si} = \frac{(y_1 \cdot w_1 \cdot t_1' + y_2 \cdot w_2 \cdot t_2' + y_3 \cdot w_3 \cdot t_3')}{(T_b - T_a) \cdot (Y_b - Y_a) \cdot w} \qquad (6)$$

where, t_1', t_2', and t_3' are the times each traffic mode takes to pass in a given street section. This concept is based on the idea that both space and time occupancy should be considered for the evaluation and planning of spatial assignment of streets. The new index of $Q_{t\text{-}si}$ could be applied for the design of planned streets and the evaluation of street space improvements. It is an efficient method for designing the street section considering not only traffic flow but also the physical size of traffic modes and the time needed to traverse the street. Figure 8 and Figure 9 show the change of time occupancy (Q_{tc}), space occupancy (Q_{sc}), and time-space occupancy ($Q_{t\text{-}sc}$) of a car as they vary with car speed. The time occupancy was calculated by the time needed to traverse 10m of street and the space occupancy was calculated by following equation.

$$Q_{sc} = (L_c + D_s) \times W_c \qquad (7)$$

where, L_c is the car length, D_s is the safe stopping distance, and W_c is the occupied car width.

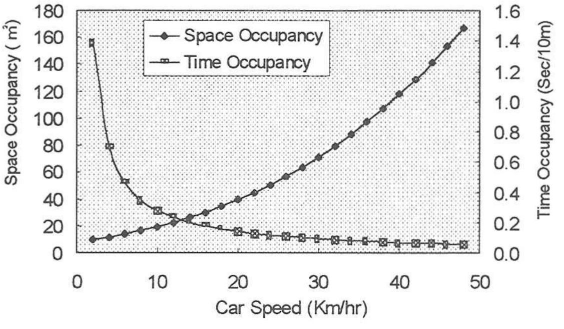

Figure 8 Space occupancy and time occupancy for cars

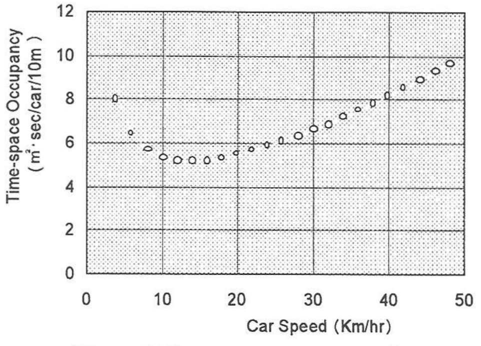

Figure 9 Time-space occupancy for cars

(2) Application of the Concept

In order to apply the time-space concept, data from the Japanese Ministry of Construction's "Road Traffic Census" were used for the years of 1983, 1985, 1988, 1990, and 1994[7]. From this data source 333 streets of less than 10 meters in width and located in the 23 Wards of the Tokyo metropolitan area were selected. The space occupancy parameters for pedestrians and bicycles are the same those used in the research of Tsukaguchi[8]: 6.0 m^2 for pedestrians and 12.8 m^2 for bicycles. The space occupancy of a car was calculated by the equation-7, as explained above. For the calculation of the time occupancy, pedestrian, bicycle, and car speeds are assumed to be 1.35 m/sec, 3.86 m/sec, and 8.33 m/sec, respectively. However, the car speeds varied by year, street, and time of the day. As the surveyed car speeds were only for the peak hour, it was not possible to use this data in the calculation.

The overall traffic mode share, time occupancy (Q_t) mode share, space occupancy (Q_s) mode share, and time-space occupancy ($Q_{t\text{-}s}$) mode share are shown in Figure 10. By plotting of the data, it can be seen that the share dominates the space occupancy index because the space occupied by a car is relatively high compared to that of a pedestrian or a bicycle. However, the car share of time occupancy and time-space occupancy is relatively higher than its traffic share, while its share of space occupancy is relatively lower. These results indicate that the pedestrian and car shares of time-space occupancy ($Q_{t\text{-}s}$) fall between their respective shares of time occupancy (Q_t) and space occupancy (Q_s).

Figure 11 illustrate the pedestrian share of traffic, Q_t, Q_s, and $Q_{t\text{-}s}$ with respect to the sidewalk area factor for the surveyed streets. The "sidewalk area factor" is defined as the ratio of the area of sidewalk to the total area of the given street section. About 26 % of the surveyed streets do not have any separated pedestrian space, that is, no sidewalk for pedestrians.

According to Table 3, 30.9 % of the streets have a ratio of "sidewalk area factor" to pedestrian share of traffic of less than 0.5, meaning that the sidewalk installed is only half of the need in terms of the pedestrian share of traffic. But this ratio

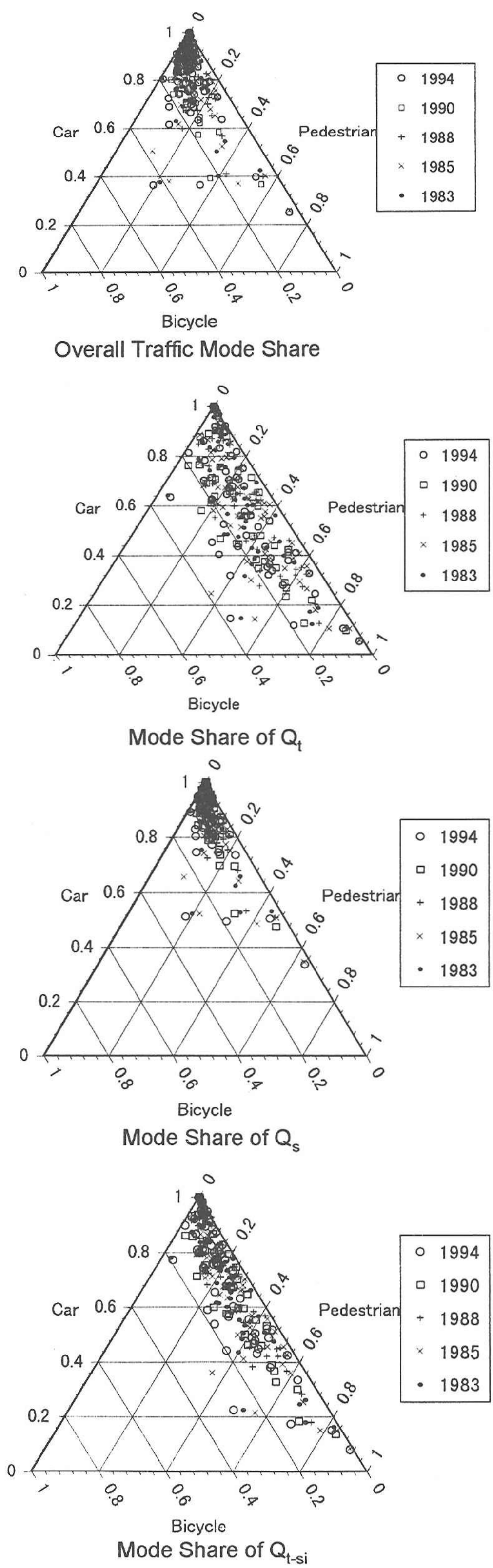

Figure 10 Share of occupancy indices of pedestrian, vehicle, and bicycle

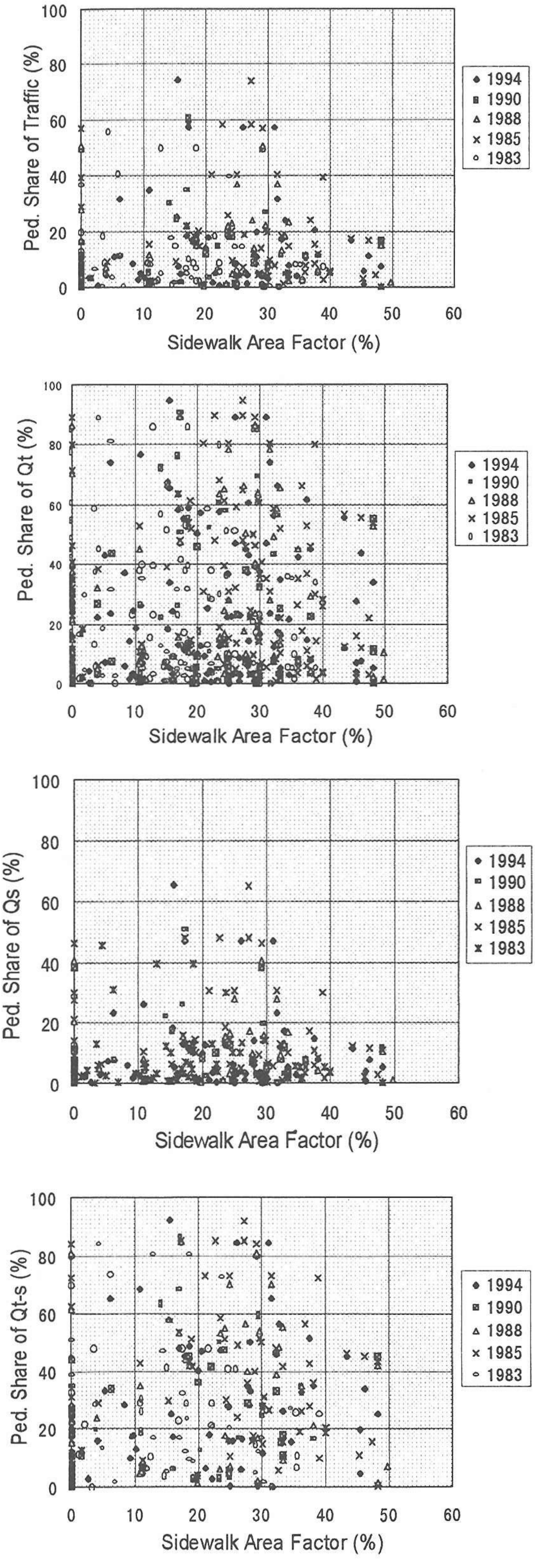

Figure 11 Pedestrian share of traffic, Q_t, Q_s, and Q_{t-s} vs. "sidewalk area factor"

increases to 52.0 % in terms of the pedestrian share of time occupancy and 46.8 % in terms of pedestrian share of time-space occupancy. Table 3 shows that, in terms of pedestrian share of traffic, time occupancy, space occupancy, and time-space occupancy, many of the surveyed streets require more sidewalks.

However, each of the indices has different meanings and differs with each traffic situation. Thus, they should be considered individually when planning for the construction and operation of pedestrian spaces in mixed traffic of narrow urban streets.

Table 3 Share of streets with different sidewalk ratio

Ratio of "sidewalk area factor" to pedestrian share (of traffic share, Q_s, Q_t, or $Q_{t\text{-}s}$)	Share of surveyed streets having the ratio on left in term of:			
	traffic share	Q_s	Q_t	$Q_{t\text{-}s}$
＜0.5	30.9 %	29.4 %	52.0 %	46.8 %
0.5-1.0	11.1 %	8.7 %	19.5 %	16.0 %
1.0＞	58.0 %	61.9 %	28.5 %	37.2%

4. Level of Service (LOS) Concept for the Pedestrians in Mixed Traffic Condition

(1) Necessity for the Standards

The US HCM has adopted a concept for level of service standards for sidewalks and queuing areas that is useful for the evaluation of pedestrian traffic flow. Recently, some researchers are expanding upon this methodology of measurement with new concepts for sidewalk level of service standards. Khisty[9], Dixon[10], and Sarkar[11] have defined a more comprehensive definition of LOS that considers more qualitative factors rather than only quantitative measure of effectiveness.

This paper expands upon level of service concept with respect to mixed traffic condition of narrow urban streets. The US HCM defines the general concept for level of service standards that are applicable to one way pedestrian traffic flow of sidewalk. The basic concept used herein is similar to that of the US HCM but amended for mixed traffic including not only pedestrians, but also bicycles and cars.

(2) Density of Occupied Traffic Modes

The "density" of traffic flow on freeways, rural highways, and urban streets including sidewalk was used as a parameter for the LOS standards since they were first adopted by the US HCM in 1965. Density was related to the volume and speed of the traffic flow, and was used as barometer of LOS.

In this paper, the authors suggest the level of service in mixed traffic conditions be measured in terms of the occupancy concepts described in the previous section. In the case of Japanese pedestrian traffic flow, Yoshioka has suggested the work trip level of service standards shown in Table 4. These standards depend on the density of pedestrians per area[12].

Table 4 LOS standard for work trip pedestrians[12]

LOS	Density	Average speed
A	below 0.3 Ped/m^2	1.65 m/sec
B	0.3-0.6 Ped/m^2	1.61 m/sec
C	0.6-0.9 Ped/m^2	1.55 m/sec
D	0.9-0.12 Ped/m^2	1.48 m/sec
E	0.12-1.5 Ped/m^2	1.05 m/sec
F	above 1.5 Ped/m^2	0.95 m/sec

*Detailed description of the LOS omitted here.

A level of service standard for pedestrians in mixed traffic conditions could be defined in a similar fashion. The summation of space occupancy ($Q_{s\text{-}b\text{-}c}$) of bicycle and car could be calculated using the space occupancy of bicycles ($Q_{s\text{-}b}$) and cars ($Q_{s\text{-}c}$) as follows.

$$Q_{s\text{-}b\text{-}c} = Q_{s\text{-}b} + Q_{s\text{-}c}$$

$$= A_b \times N_b + A_c \times N_c \qquad (8)$$

where A_b and A_c are the respective average area occupied by bicycles and cars. N_b and N_c are the number of bicycles and cars to traverse the road during the period of study. If we have an available street section of l with street width w, the unit space per pedestrian (U_p) on this street could be calculated by equation (9) and applied in a similar fashion to Table 4. For example, the available space per pedestrian (U_p) could be transformed into the number of pedestrians per square meter (m^2) as in Table 4, and an LOS could be determined based upon its magnitude.

$$U_p = \{l \cdot w - (A_b \times N_b + A_c \times N_c)\}/N_p \qquad (9)$$

(3) Hindrance/Conflict Concept

The LOS concept described above assumes that reserved pedestrian space is proportional to the safety and comfort of pedestrians. But in the case of mixed traffic flow, the direction of each mode could be two-way rather than one-way, and this may cause hindrances or conflicts between the modes. Figure 12 illustrates how possible hindrances to pedestrians could occur from both directions and result from pedestrians or other travel modes. Theories of traffic flow could be employed to estimate the likely frequency of such hindrances.

First, the frequency of hindrance between pedestrians traveling in the same direction ($F_{p\text{-}by\text{-}p}$) could be calculated by equation (10) assuming that the speed distribution of pedestrians follow a normal distribution. Values for the pedestrian traffic flow (Q_p), standard deviation (σ), and average pedestrian speed (U_p) are needed for the calculation. Second, the frequency of being passed by a bicycle or car ($F_{p\text{-}by\text{-}b}$ and $F_{p\text{-}by\text{-}c}$) could be calculated by equation (11) and (12) with the bicycle and car traffic flow (Q_b & Q_b) and average speed of bicycle and car (U_b & U_c). Third, the frequency to meet opposing traffic modes of pedestrians, bicycles, and cars ($F_{p\text{-}to\text{-}p}$, $F_{p\text{-}to\text{-}b}$, and $F_{p\text{-}to\text{-}c}$) could be calculated by equation (13) through (15) with similar variables.

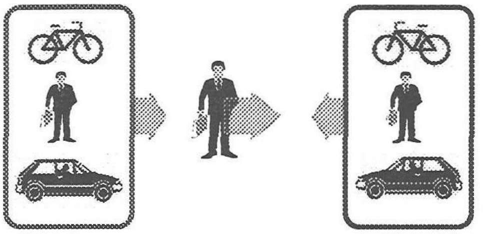

Figure 12 Possible hindrance between traffic modes

$$F_{p\text{-}by\text{-}p} = 2 \cdot Q_p \cdot \sigma /(U_p \cdot \pi^{0.5}) \quad (10)$$

$$F_{p\text{-}by\text{-}b} = Q_b \cdot (1 - U_p/U_b) \quad (11)$$

$$F_{p\text{-}by\text{-}c} = Q_c \cdot (1 - U_p/U_c) \quad (12)$$

$$F_{p\text{-}to\text{-}p} = Q_p \cdot (1 + U_p/U_p) \quad (13)$$

$$F_{p\text{-}to\text{-}b} = Q_b \cdot (1 + U_p/U_b) \quad (14)$$

$$F_{p\text{-}to\text{-}c} = Q_c \cdot (1 + U_p/U_c) \quad (15)$$

The weight of each hindrance between traffic modes is quite different, and the influence distance between traffic mode or the difference of space occupancy of each traffic mode could be used for the practical use of this concept[13].

With these formulae, the LOS for bi-directional pedestrian movements can be calculated based on the existing LOS standards for one-way directional pedestrian movement suggested[12]. The results of these calculations are shown in Figure 13 that denotes LOS ranges with varying pedestrian traffic flows and bi-directional pedestrian traffic split.

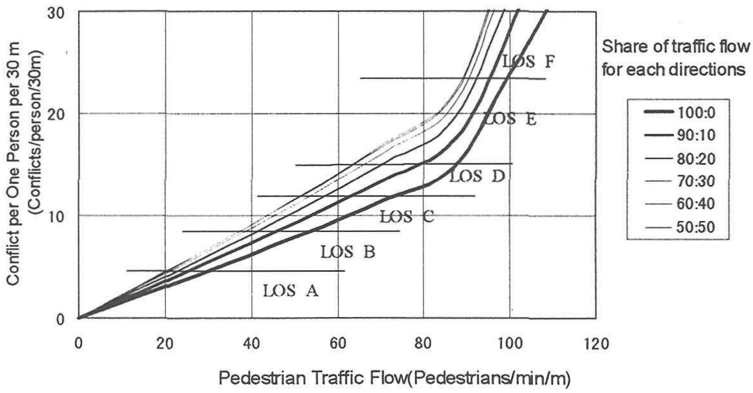

Figure 13 LOS standards for bi-directional pedestrian traffic

5. Conclusions and Further Research

This paper focused on the behavior of and interaction between pedestrians, bicycles, and cars in mixed traffic, which is an elementary study in this field of research. The paper also suggests concepts for using time-space occupancy indices for traffic modes in mixed traffic on narrow streets in order to evaluate and plan for urban streets.

There have been a number of research studies on the topic of pedestrian traffic flow in different countries under various traffic conditions, but few studies have been dealt with conditions of mixed traffic of pedestrians, bicycles, and cars. As explained initially, mixed traffic in narrow streets is very important to many Asian countries where pedestrian spaces have not been secured in spite of rapid motorization and economic growth.

With this background, this paper has analyzed the interaction phenomena among pedestrians, bicycles and cars in terms of influence distances, behavioral changes of pedestrians with road traffic conditions, and time and space concepts for road occupancy indices. Finally, level of service (LOS) standards for mixed traffic conditions have been suggested to assist with the evaluation of these road facilities.

Further surveys and analysis are needed in order to generalize for practical use of the concepts of time-space occupancy index and level of service standards based on occupied densities and hindrance/conflict concepts. This analysis may include more surveys and computer simulations of various traffic flow composition and road environment conditions. Several traffic calming measures for mixed traffic may hold promise for improving conditions for pedestrians. Such measures may include traffic cells, transit malls, shopping malls and so on. The car-free city center could be one of the choices.

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狭幅員道路での混合交通流における歩行者の行動と計画基準に関する研究*

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本研究では，今後必要性が高まると予想される歩行者空間整備の計画基準の提案を目的として，都市内狭幅員街路における歩行者，自転車，自動車交通からなる混合交通流内の歩行挙動の分析を行った．歩行挙動については，交通・街路環境により変化する歩道の利用行動，歩行者の障害物の回避行動等を取り扱っている．分析には，都内より抽出した 15 街路をビデオ撮影し，実現象を数値化したデータを用いた．計画基準については狭幅員道路を通行する交通手段に対し，時間と空間のオキュパンシーを同時に扱うことを可能とする時間・空間オキュパンシー指標を提案している．併せて，混合交通流におけるサービス水準の評価指標として空間オキュパンシーとすれ違い，錯綜の程度の使用を提案している．

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*Pedestrian behavior and plannning concepts in the mixed traffic of narrow urban streets**

by Young-in KWON**, Shigeru MORICHI***, Tetsuo YAI****

The aim of this paper is to examine pedestrian behavior and suggest guidelines for analyzing pedestrian traffic flow in narrow urban streets with mixed traffic. For the analysis of pedestrian behavior, 15 streets around urban railway station in Tokyo were surveyed and several parameters obtained such as: pedestrian paths around stationary obstacles; share of pedestrians using the sidewalk as a factor of street environment and traffic conditions; and influence distance of and for with respect to bicycles and cars. In terms of planning guidelines, the authors have defined simultaneously a new index of time-space occupancy ($Q_{t\text{-}si}$) of traffic modes in mixed traffic conditions which considers the occupancy of time and space in the time-space diagram. Also, a new concept for level of service (LOS) standards has been suggested for mixed traffic conditions, which employs concept of time-space occupancy of each modes and hindrance/conflict between modes.
