PEDESTRIAN BEHAVIOR AND LOS STANDARDS IN MIXED TRAFFIC CONDITION*

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1. Introduction

Several studies on pedestrian planning started at the end of 1960's focusing on the basic principles of pedestrian traffic flow of sidewalk by several researchers. These researches are mainly summarized by Fruin[1] and Pushkarev and Zupan[2] which were adopted as national standards on pedestrian facilities planning in the United States Highway Capacity Manual(US HCM)[3]. This gives general guidelines for the capacity and level of service(LOS) standards on sidewalks which consider several factors such as space module per pedestrian, average speed and flow rate.

In the case of Japan, most of the roads are very narrow as shown in Tab-1. The total length of roads in Japan is 1,125,482 kms by the end of 1993, but the length of roads with sidewalk is about 119,500 kms which is only about 10.6% of total roads. With respect to the road classification, "Municipal, Town, and Village Roads" are about 948,642 kms which occupy 84.2% of total roads. In these types of roads, 86.5% are very narrow sections less than 5.5 m in width and 99.6% are narrow sections less than 13.0 m in width as well. Therefore, narrowness of the roads closely interacts with daily living and very important to the pedestrians in Japan.

Tab-1 Length of roads in Japan by types and width

(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

Reference : Japan Ministry of Construction[4]

This paper surveys several sections of narrow streets in Japan where pedestrians and vehicles are composing mixed traffic conditions. Several characteristics of pedestrian, bicycle, and vehicle traffic flow in these narrow streets are analyzed for the elementary research on the field of narrow streets. The mixed traffic flow in narrow streets is also very important to the most of Asian countries where the pedestrian spaces were not secured in spite of rapid motorization with high economic growth.

*Keywords: pedestrian, mixed traffic, narrow street
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2. Study Area and Data Collection

(1) Study Area

The study areas are located around private railway stations in the southwest parts of Tokyo Metropolitan Area. The widths of roads are less than 10m including sidewalks, some of them with separated sidewalk and some of them without. Tab-2 shows general description of the roads selected and surveyed for this study.

Tab-2 Description of the surveyed roads

Roads Name	Separation Type	Road Width*
Ookayama St.	Mounted Sidewalk	4.1m(1.1m)
Midorigaoka St.	Lined Sidewalk	4.5m(2.5m)
Jiyu St.	Lined Sidewalk	5.3m(2.2m)
Blue Pearl St.	Mounted/Poled Sidewalk	5.6m(3.1m)
Hirokoji St.	Lined Sidewalk	3.1m(2.6m)
Sky Plaza St.	Lined/Colored Sidewalk	3.1m(3.3m)

* Represents the street section for vehicles and figures inside of parenthesis indicate sidewalk width

(2) Data Collection

Video recording was undertaken at an elevated point from 30 minutes to 2 hours depending on the situation, most of them 3 times a day, that is morning time(07:00-09:00), noon time(12:00-14:00), and evening time(17:00-19:00) for both weekday and weekend during the month of June and July of 1996. Video footages were taken at selected sections of narrow streets where there is a clear view of the movement of pedestrians and vehicles as Fig-1.

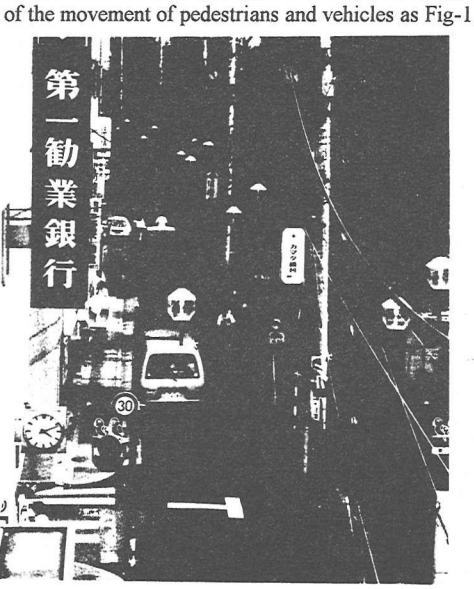

Fig-1 Views of Ookayama Street

3. Analysis of Pedestrian, Bicycle, and Vehicle Traffic Flow in Narrow Street

(1) Walking Speed of Pedestrian

Walking speed is used in a number of pedestrian studies as a basic parameter. Examples include gap acceptance, school crossing, and signal timing studies. Walking speeds are affected by a number of factors, including volume, age, sex, physical fitness, degree of grade, width, oncoming vehicle, weather condition, as so on[5].

This paper attempts to examine the variation of walking speed by the time of trip, and the type of pedestrian separation. To measure the speed of pedestrian correctly, an RC time cord was utilized during the record of video for analysis of slow motion of pedestrians and vehicles was based on each video comma. It could be possible to stop and review one thirtieth of a second in RC time cord to calculate the speed of pedestrians for a designated section of the road.

Fig-2 shows the accumulation curve of walking speed of pedestrians by the time of the day. From survey results, the walking speed of pedestrians in the morning is highest which is followed by the speed of pedestrians in the noon and evening. Usually, the average walking speed and its distribution is decided by the composition of pedestrians.[6][7] The trip purpose of most pedestrians in the morning is work and school, and they are supposed to be at office before their working and class hours and usually, they walk individually and not groups.

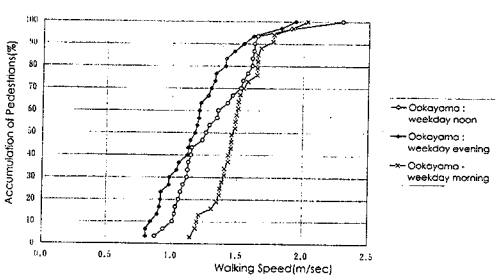

Fig-2 Accumulative pedestrian walking speed

(2) Interaction between Pedestrians and Vehicles

Pedestrians and vehicles interact in mixed traffic conditions, each of them is likely to avoid conflicts for safety and comfort.

In this paper, an influential distance(S_i) is defined as a measured distance between a vehicle and a pedestrian where they take some actions to avoid conflict with each other. An influential distance could be different by the standpoint of pedestrians and vehicle drivers with their position to others. An influential distance is measured between pedestrians and vehicles by the observation of recorded video with different situations such as moving direction of pedestrians and vehicles, position of pedestrians and vehicles, and the view point of pedestrians and vehicles.

Fig-3 shows lateral distances which is one of the influential distances mainly decided by vehicles. The lateral distance means the distance between vehicle and pedestrian which might be changed with the different situation. Regression results show that it is proportional to the speed of vehicles.

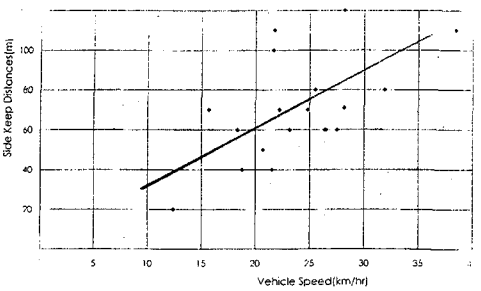

Fig-3 Lateral Distances between peds. and vehs

(3) Behavior Changes of Pedestrians with Road and Traffic Conditions

Pedestrians and vehicles assumed to affect each other in their behavior. Pedestrians likely to walk more freely without the hindering of vehicles and vehicles tend to move faster with few pedestrians. These behavior changes are observed and summarized results are plotted in Fig-4.

Refering to the Fig-4, the effects of sidewalks types to pedestrian sidewalk route are analyzed in the viewpoint of walking position of pedestrians at different places. The analysis results show that the share of pedestrian walking in sidewalk with few traffic flows are bigger than that of congested traffic flow during pedestrian paradise.

(4) Time and Space Concept for the New Occupancy Index

Tsukaguchi and Mouri[8] defined time occupancy index(Q_{ti}) and space occupancy index(Q_{si}) of residential street for pedestrians, bicycles and vehicles for the concept of occupancy with respect to the time and space, respectively.

$$Q_{si} = (1/l \cdot d)\sum_{j=1}^{n} A_{ij} \quad \cdots\cdots (1)$$

$$Q_{ti} = (1/t)\sum_{j=1}^{n} t_{ij} = (1/t)\sum_{j=1}^{n} (l/v_{ij}) \quad \cdots\cdots (2)$$

where, i is traffic modes(pedestrians, bicycles, and vehicles), l is length of street section, d is width of street, n is the number of traffic mode i, A is occupied area of traffic mode, and t is observed time. The occupancy indices could be applied to the suitable spatial assignment of street spaces, level of street infrastructure supply, and evaluation of pedestrian safety and comfort.

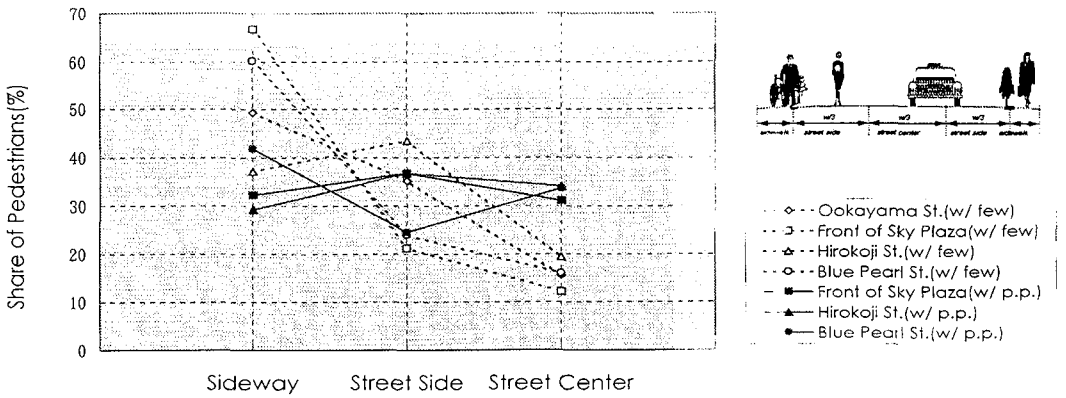

Fig- 4 Pedestrian walking position according to traffic condition

Now, the new index of time-space occupancy($Q_{t\text{-}si}$) is defined considering the time and space occupancies at the same time to analysize three modes of traffic flows with different speed and space.

$$Q_{t\text{-}si} = (1/l \cdot d \cdot t) \sum_{j=1}^{n} (A_{ij})(t_{ij}) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

The results of calculation for these indices for the parts of surveyed streets of weekdays and sundays are plotted on Fig-5 with time occupancy and space occupancy indices. For the calculation of space occupancy index, the occupancy space used for each modes are 16.5 m^2 per passenger vehicle, 12.8 m^2 per bicycle, 5.0 m^2 per pedestrian which is suggested by Tsukaguchi[5].

It can be explained that the share of the number of traffic modes, the share of time, the share of space, and time-space share of each mode by above indices for the interpretation of their occupancy in several aspects. At most surveyed streets, the share of vehicle is less than 20% in number and the share of time occupancy is less than 10%, but most of them occupy around 40-70% in terms of space occupancy. The graph shows that the share of vehicles in time-space occupancy in the values between Q_s and Q_t. It is clear that all of the four indices should be considered for the planning, construction, and operation of the pedestrian spaces in mixed traffic in streets.

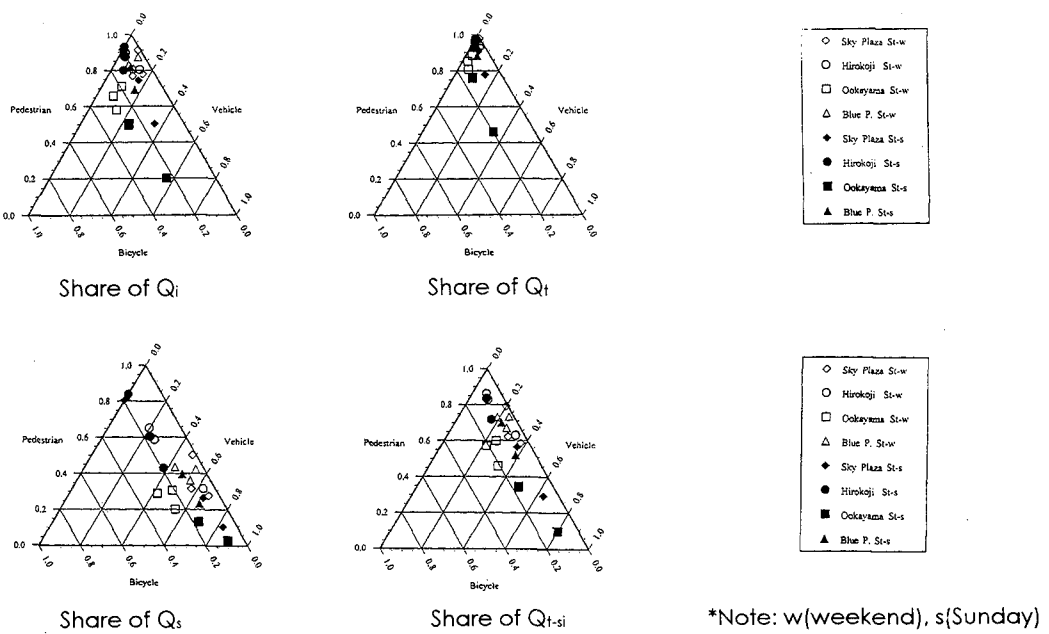

Fig-5 Share of occupancy indices of pedestrian, vehicle, and bicycle

4. Level of Service Standards for the Pedestrians in Mixed Traffic Condition

US HCM adopted methodology for the LOS criteria of sidewalk and queuing area which is useful to evaluate and improve pedestrian spaces. Recently, some researches on the level of service for sidewalks are expanding its methodology of measurement with the new concept. Kisty, C.J.[9], Dixon, L.B.[10], and Sarkar, S.[11] defined more comprehensive meaning of LOS which considers more qualitative factors.

Now, this paper define the level of service standard for the mixed traffic condition in narrow streets. The basic concept used is similar with US HCM but amended for mixed traffic which considers both pedestrians, bicycles, and vehicle traffic flow.

US HCM defines the general concept for standards of level of service for pedestrians for the exclusive sidewalk. With these criteria, the standards of mixed traffic condition's level of service for pedestrians are suggested on Tab-3. The factors for the level of service criteria are the sidewalk types, the flows of vehicles(Q_v), the flow of bicycles(Q_b), and the flow of pedestrians(Q_p). The suggested figures in the Tab-3 are based on the repeated observation of the recorded video with the author's judgment for work and school trips. The service level for other trips such as shopping, event, or leisure should be modified based on the suggested figures.

Tab-3 Standards of LOS for the pedestrians in mixed traffic condition(work/school trip)

LOS*	Sidewalk Types	Q_v**(Vehs/min/3m)	Q_b (Bics/min/3m)**	Q_p(Peds/min/m)**
A	Mounted or polled	$Q_v = 0$	$Q_b \leq 1$	$Q_p \leq 27$
B	Mounted or polled	$0 < Q_v \leq 1$	$1 < Q_b \leq 2$	$27 < Q_p \leq 51$
C	Distinct pavement	$1 < Q_v \leq 2$	$2 < Q_b \leq 4$	$51 < Q_p \leq 71$
D	Distinct pavement	$2 < Q_v \leq 4$	$4 < Q_b \leq 7$	$51 < Q_p \leq 87$
E	Lined only	$4 < Q_v \leq 7$	$7 < Q_b \leq 12$	$87 < Q_p \leq 100$
F	Lined only	$7 < Q_v$	$12 < Q_b$	$100 < Q_p$

* Same concept as the description of sidewalk levels of service of pedestrians as US HCM.

** The figures for each levels of service are decided by the decision of authers by the concept of US HCM.

5. Conclusions

This paper focused on the mixed traffic of pedestrians, bicycles, and vehicles to formulate the guidelines for evaluation and improvement of existing pedestrian facilities. There is a lot of literature on the field of pedestrian traffic flow in different countries with various traffic conditions, but few studies dealt with the conditions of mixed traffic of pedestrians, bicycles, and vehicles. As explained initially, the mixed traffic in narrow streets is very important to many Asian countries where the pedestrian spaces were not secured in spite of rapid motorization with economic growth.

With this background, the paper analyzed the interaction phenomena between pedestrians and vehicles within the influential distance, behavior changes of pedestrians with road traffic conditions, and time and space concept for occupancy indices. Finally, level of service standrads for mixed traffic conditions are suggested for the evaluation of these road facilities.

Further surveys and analysis will be carried out for the generalization of the concept of level of service. These will include simulation for various situations of different traffic flow composition and various road environment conditions.

To improve these streets, traffic calming measures for mixed traffic should be considered in the form of traffic cell, transit mall, shopping mall and so on. Pedestrian paradise could be one of the choice.

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