PEDESTRIANS AND VEHICLES TRAFFIC FLOW IN MIXED TRAFFIC CONDITIONS OF NARROW STREET

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Abstract : The total length of road in Japan is 1,125,482 kms, but the length of road with sidewalk is only 119,500 kms. In terms of road width, 86.5% consists of very narrow sections less than 5.5 m and 99.6% are narrows section less than 13.0 m in width. Therefore, the share of roads with narrow width is quite high in Japan. In this paper, several sections of narrow streets in Japan are surveyed and several behavioral characteristics of pedestrians and vehicles in narrow streets are analyzed, and finally the of level of service standards are suggested.

1. INTRODUCTION

Several studies for the pedestrian planning started at the end of 1960's focusing on the basic principles of pedestrian traffic flow by several researchers. These researches are mainly summarized by Fruin(1971) and Pushkarev and Zupan(1975) which were adopted as national standards on pedestrian planning in the United States Highway Capacity Manual(See TRB, 1985). TRB gives guidelines for the capacity and service level of sideways which consider several factors such as space module per pedestrian, average speed and flow rate.

In case of Japan, most of roads are very narrow as shown in Table-1. The total length of road in Japan is 1,125,482 km by the end of 1993, but the length of road with sidewalk is about 119,500 km which is only about 10.6% of total road. With respect to the road classification, "Municipal, Town, and Village Roads" are about 948,642 km which occupy 84.2% of total road. In these types of road, 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 road closely interacts with daily living and very important to the pedestrians in Japan.

Table 1. Length of roads in Japan by type and width

(as the end of 1993)

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

Reference : Japan Ministry of Construction(1995)

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

Most concerns of the paper are focused on the mixed traffic of pedestrians and vehicles to formulate guidelines for evaluation and improvement. There are lots of researches on the pedestrian traffic flow in different countries with various traffic conditions, but few

researches have dealt on the mixed traffic conditions.

2. LITERATURE REVIEW ON PEDESTRIAN TRAFFIC FLOW

Pedestrian flow could be categorized into two groups, that is (1) free flow and (2) platoon flow. At free flow, pedestrians basically move in desired paths without altering their movements in response to other pedestrians. Walking speed are freely selected, and conflict between pedestrians are unlikely. In case of less congested area with pedestrian, each pedestrian should be considered individually as free flow.

At platoon flow, a number of pedestrians walking together in a group forming a stream, usually involuntarily, because of overflow, signal control and others. In this case, the quantitative measures of pedestrian flow similar to those used for vehicular flow. The fundamental relationship between speed, density, and volume for platoon flow of pedestrians is analogous to vehicular flow. As volume and density increase, pedestrian speed declines. As density increases, and pedestrian space decreases, the degree of mobility afforded the individual pedestrian declines, as does the average speed of the pedestrian stream.

Table-2 shows several researches' results on the relationships between pedestrian speed and density of researches of different cities of different countries. Most of adopted speed-density models were Greenshield's type which is linear relationship. At the equation, the constant means free walk speed which is the maximum speed without any constraint for the pedestrians. By these research results, it is obvious that the variation of speed and flow is much bigger than that of vehicle traffic flow. These variations are mainly because each pedestrian have different movement characteristics.

Table 2. Researches on relationships between walking speed(S) and density(D)

Countries	Cities	Researchers	Year*	Equation of Relations	Remarks
America	New York	Fruin(1971)	1970	$S=81.4-20.4D$	Commuters
	Colombia	Virkler & Elayadath (1993)	1992	$S=55.6\exp(-0.162D^2)$ $S=63.97-17.12D$	Event(After Football Game)
	Wash. D.C.	Navin & Wheeler(1969)	1969**	$S=97.5-36.2D$	Students
England	London	Older(1968)	1968**	$S=78.7-20.2D$	Shoppers
Hong Kong	Hong Kong	Lam, Morrall & Ho (1995)	1991	$S=77.4-21.5D$ $S=\exp(4.47-0.572D)$	Indoor Walkway Outdoor Walkway
Indonesia	Jakarta	Widjajanti(1994)	1994	$S=82.0-22.3D$***	CBD
	Yogyakarta	Lulie(1995)	1994	$S=52.0-10.76D$	CBD
Israel	Haifa	Polus et al(1983)	1983**	$S=78.78-15.96D$	CBD
Japan	Tokyo	Yoshioka(1979)	1978	$S=96.6-19.8D$	Commuters
			1978	$S=81.7-22.8D$	Event
			1978	$S=67.8-16.8D$	Shoppers
	Osaka	Tsukaguchi(1981)	1975	$S=88.8-12.2D$ & $S=79.2\log(9.16/D)$	CBD($D<1.5$) CBD($D\geqq 1.5$)
	Nagoya	Takeuchi(1977)	1977**	$S=90.0-22.8D$	Residential Area
Jordan	Irbid	Al-masaeid et al(1993)	1991	$Q=19.1+2.05S-0.026S^2$	CBD, Q is flow
Korea	Seoul	Kwon(1995)	1995	$Q=89.7-16.7D$ $Q=84.6-15.0D$	Commuters(a.m.) Commuters(p.m.)
Philippines	Manila	Gerilla(1995)	1994	$S=83.23-23.11D$	Commuters
Singapore	Singapore	Tanaboriboon(1986)	1986**	$S=73.9-15.3D$	CBD
Thailand	Bangkok	Tanaboriboon & Guyano (1989)	1989**	$S=72.85-13.13D$	CBD

* The year of data surveyed, ** The year of paper presented, *** Suggest 2 more formula for other sites.

Institute of Transportation Engineers(see ITE, 1994) mentioned that the walking speeds are a function of volume, density, age, physical fitness, and sex of pedestrians, degree of grade, width of crossing, width of sideways, distance and speed of oncoming vehicles, and weather conditions. Some of those factors are approved to be factors by several researches but some are not. This research try to prove some of these factors which is not proved by previous researches with the observed video recordings.

Figure-1 shows several research results on the relationships between pedestrian flow and density. Maximum pedestrian flows are about 60 to 120 pedestrians per minute per meter of sidewalk with the density of about 2 to 3 pedestrian per square meters. The difference of these researches are due to the difference of culture, climate, trip purpose, time of day, and so on. The highest pedestrian flows are seen in the city of Tokyo, Osaka, and Seoul, and the lowest ones in Hong Kong and Jordan, and Washington, D.C.

As mentioned at the beginning of the paper, several research results are adopted as the standards at the third edition of Highway Capacity Manual published by Transportation Research Board(see TRB, 1985) which is under renewal now.

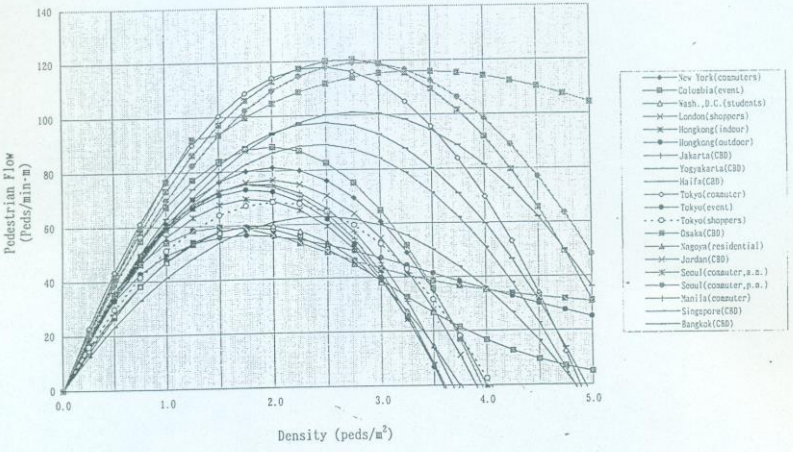

Figure 1. Relationships between pedestrian flow and density

3. STUDY AREA AND DATA COLLECTION

3.1 Study Area

The study area are around the urban private railway stations which is located south-east of Tokyo Metropolitan area. The widths of roads are less than 10m including sideways, some of them with separated sidewalk or some of them without. Table-3 shows general description of the roads selected and surveyed for this study.

Table. 3 General description of the roads in study area

Roads Name	Separation Type	Width of Road*	Pedestrian**	Vehicle**	Bicycle**
Ookayama Street	Mounted Sidewalk	4.1m(1.1m)	216 Peds/h.	30 Vehs/h.	60 Bis/h.
Midorigaoka Street	Lined Sidewalk	4.5m(2.5m)	230 Peds/h.	110 Vehs/h.	220 Bis/h.
Jiyu Street	Lined Sidewalk	5.3m(2.2m)	488 Peds/h.	240 Vehs/h.	154 Bis/h.
Blue Pearl Street	Mounted/Poled Sidewalk	5.6m(3.1m)	1,404 Peds/h.	84 Vehs/h.	24 Bis/h.
Hirokoji Street	Lined Sidewalk	3.1m(2.6m)	2,496 Peds/h.	84 Vehs/h.	288 Bis/h.
Front of Sky Plaza	Lined/Colored Sidewalk	3.1m(3.3m)	1,296 Peds/h.	204 Vehs/h.	192 Bis/h.

* Represent the street section used only for vehicle and figures inside of ( ) are width of sidewalk
** Pedestrian and vehicle flow represents maximum flow rate during the survey period.

3.2 Data Collection

Video recording were undertaken at an elevated point from 30 minutes to 2 hours depending on the situation, most of them are 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) of the both weekday and weekend in the June and July of 1996 as shown in Table-4. Video footages were taken at selected section of narrow streets where there are a clear view of the movement of pedestrians and vehicles. Figure-1 shows two places of these streets.

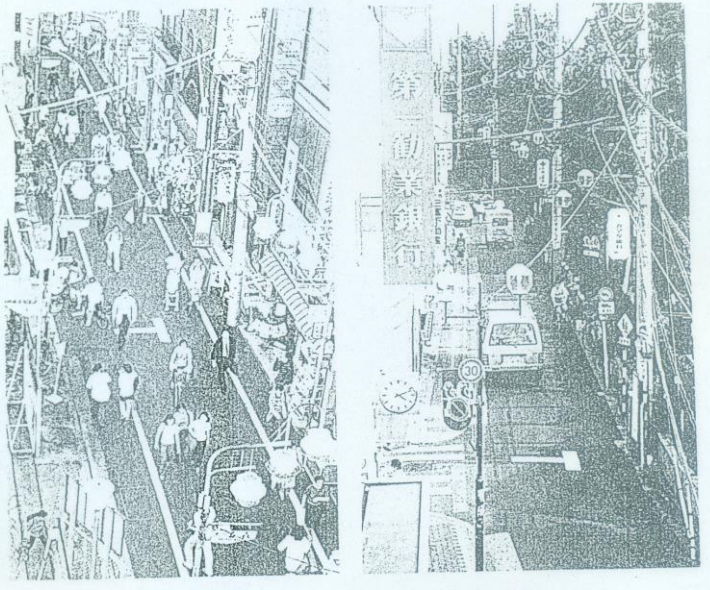

Figure. 2 Views of narrow street of Ookayama and Hirokoji Street

Table. 4 Date, day and weather conditions of the survey

Roads Name/Locations	Survey Date/Day	Weather	Temperature*
Ookayama Street	Jun. 09, 1996(Sun.)	Cloudy	17-21 °C
	Jun. 14, 1996(Fri.)	Sunny	19-25 °C
Hirokoji Street	Jun. 16, 1996(Sun.)	Sunny	18-23 °C
	Jun. 20, 1996(Thu.)	Sunny	21-29 °C
Front of Sky Plaza	Jun. 16, 1996(Sun.)	Sunny	18-23 °C
	Jun. 20, 1996(Thu.)	Sunny	21-29 °C
Midorigaoka Street	Jun. 30, 1996(Sun.)	Cloudy	22-29 °C
Jiyu Street	Jun. 30, 1996(Sun.)	Cloudy	22-29 °C
Blue Pearl Street	Jul. 01, 1996(Mon.)	Cloudy	22-29 °C
	Jun. 30, 1996(Sun.)	Coludy	22-29 °C

* Temperature represents the minimum and maximum figures of the day.

4. DATA ANALYSIS OF PEDESTRIANS AND VEHICLES BEHAVIOR

4.1 Walking Speed and Vehicle Speed

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(see ITE, 1994).

This paper try to examine the variation of walking speed by the time of trip, the day of trip and the type of pedestrian separation. To measure the speed of pedestrian correctly, a RC time cord was inserted while the record of video for analysis of the slow motion of pedestrian and vehicle based on each video comma. It could be possible to be stopped and reviewed one thirties of a second in RC time cord to calculate the speed of pedestrians and vehicles.

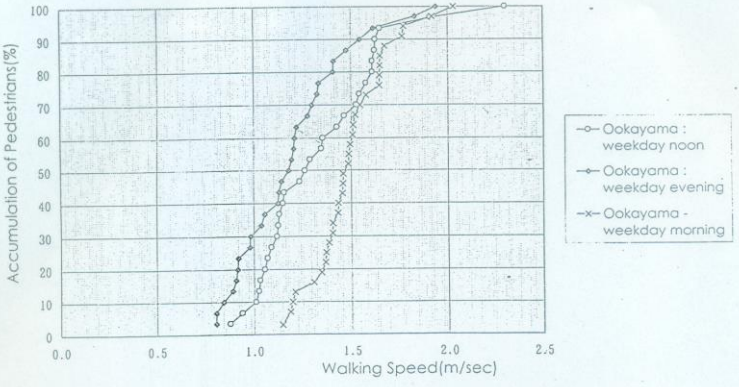

Figure 3. Accumulation of walking speed by the time of the day

Figure-3 show the accumulation curve of walking speed by the time of the day. As of survey results, the walking speed of pedestrians in the morning is most high which is followed by the speed of pedestrians of the noon and evening. Usually, the average walking speed and its distribution is decide by the constitute of pedestrians. The trip purpose of most pedestrians in the morning is working and school, and they are suppose to be at office before their working hours and walking in single not in the group commonly.

4.2 Interaction between Pedestrians and Vehicles

Pedestrians and vehicles are interactive for the mixed traffic conditions, each of them are likely to avoid conflicts for safety. Tsukaguchi(1987) suggest a relationship between the vehicle speed and safe stopping distance which can be expressed as a formula as follow;

$$S_s = 0.8V_h = 0.222\ V_s \quad \cdots\cdots (1)$$

where, S_s is safe stopping distance in meter, V_h is speed in kilometer per hour, and V_s is speed in kilometer per minute.

In this paper, a influential distance(S_i) is defined as a measured distance between a vehicle and a pedestrian where they take some actions to avoid conflict each other. A influential distances is measured figures between pedestrians and vehicles by the judgment of recorded video with different situations such as direction of pedestrians and vehicles, position of pedestrians and vehicles, and the view point of pedestrians and vehicles.

Figure-4 show side keep distance which is mainly decided be vehicles and means the side distance between vehicles and pedestrians according to the speed of vehicles. The regression of survey result show that it is proportional to the speed of vehicles. The results on these surveys including safe stopping distance which is similar to the influential distance of vehicles.

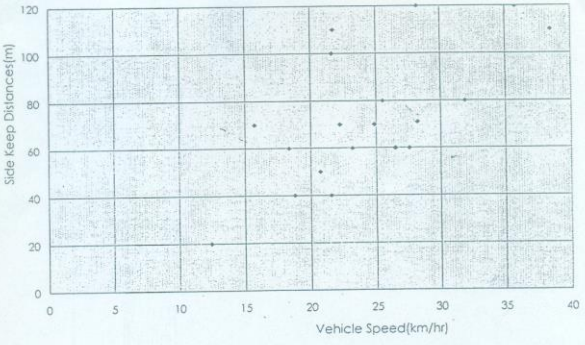

Figure 4. Side keep distances between pedestrians and vehicles

4.3 Behavior Changes of Pedestrians and Vehicles with Road and Traffic Conditions

Pedestrian and vehicles are effecting each other in their behavior. Pedestrians are trying to walk more freely without the hinder of vehicles and vehicles are tending to run faster with less pedestrian. These behavior changes were observed and summarized results are plotted in Figure-5.

In Figure-5, the effects of sideways type to pedestrian walkway route are analyzed by the walking position of pedestrian at different places. The results show that the more pedestrian walk on sidewalk with the exception of Ookayama street where the separation of vehicles and pedestrians are separated by mounted sidewalk.

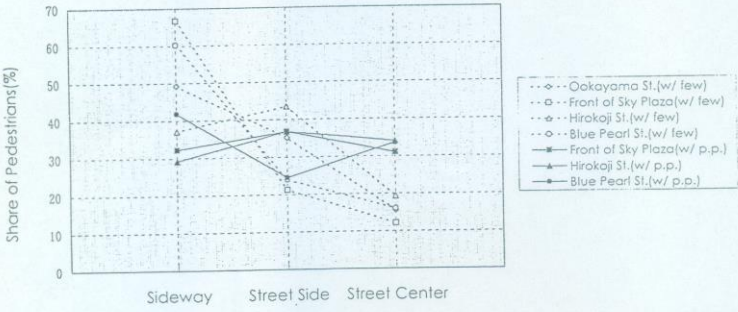

Figure. 5 Pedestrian walking position according to traffic condition

4.4 Time and Space Concept for Occupancy Indices

Tsukaguchi and Mouri(1987) defined time occupancies index(Q_{ti}) and space occupancies index(Q_{si}) of residential area for pedestrians, bicycles and vehicles by the concept of occupancy with respect to the time and space, respectively.

$$Q_{si} = (1/l \cdot d)\sum_{j=1}^{n} A_{ij} \qquad (2)$$

$$Q_{ti} = (1/t)\sum_{j=1}^{n} t_{ij} = (1/t)\sum_{j=1}^{n} (l/v_{ij}) \qquad (3)$$

where, i is traffic mode(pedestrian, vehicle, and bicycle), 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 were very meaningful to consider the suitable spatial assignment of street. Now, the new index of time-space occupancy($Q_{t\text{-}si}$) are defined considering the time and space at the same time because it is better to be integrated same time.

$$Q_{t\text{-}si} = (1/l \cdot d \cdot t) \sum_{j=1}^{n} (A_{ij})(t_{ij}) \qquad (4)$$

Time-space occupancy($Q_{t\text{-}si}$) is index considering both time occupancy and space occupancy at the same time. The result of calculation for this index for the parts of surveyed street are plotted on Figure-6 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 m^2 per pedestrian which is suggested by Tsukaguchi(1987).

It can be explained that the share of number, 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 the most surveyed streets, the share of vehicle is less than 20%, but most of them are occupy some around 40-60% in terms of space occupancy. It is clear that all of these four indices should be considered for the planning, construction, and operation of the pedestrian spaces at the mixed traffic street.

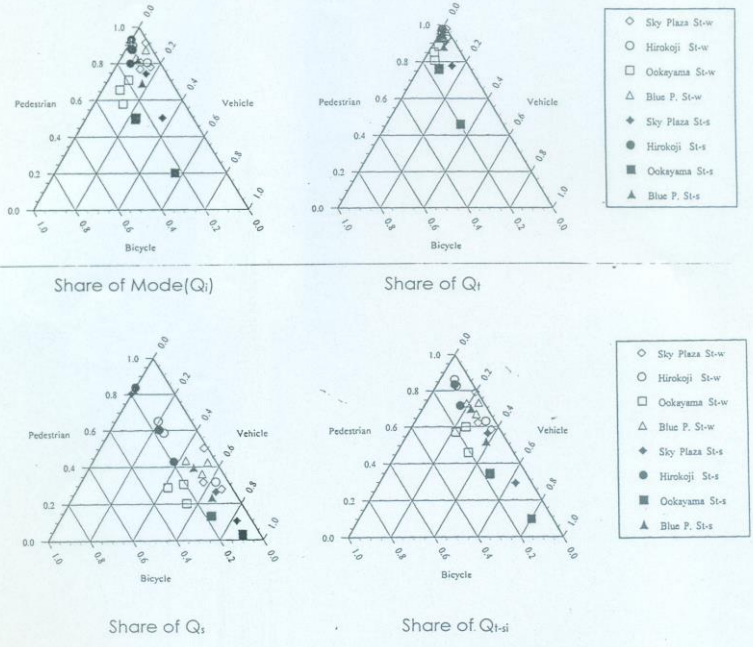

Figure-6 Share of occupancy indices for pedestrian, vehicle, and bicycle

5. SERVICE LEVEL FOR MIXED TRAFFIC OF PEDESTRIANS AND VEHICLES

US HCM adopted methodology for the LOS criteria of sidewalk and queuing area which is useful to evaluate and improvement of pedestrian space. Recently, some researches on the level of service for sideways is enlarging its methodology of measurement with new concept. Kisty, C.J.(1994), Dixon, L.B.(1996), and Sarkar, S.(1996) is trying to define more comprehensive meaning of LOS which consider more factors with new procedures.

Now, this paper try to define the level of service for the mixed traffic condition of narrow street. The basic concept are used the one of US HCM but amended for mixed traffic which consider both pedestrians and vehicle traffic. For this purpose, the concept of time-space occupancy index was used to define the criteria of index and flow rate of vehicles and pedestrians were used as well.

Table-5 shows the general concept for standards of level of service of pedestrians for the sidewalk. With this criteria, the standards of mixed traffic condition's level of service for pedestrians are suggested on Table-6. The factors for the level of service criteria were the walkway types, the flows of vehicles, bicycles, and pedestrians. The suggested figures in the Table-6 are based on the repeated observation of the recorded video with the author's judgment for the trip of work and school. The service level for the other trip such as shopping, event, or leisure should amended based on the suggested figures.

Table 5. Descriptive standards of LOS for the pedestrian

LOS	Brief Description of the Level of Service Judgment
A	Pedestrians basically move in desired paths without altering their movements in response to other pedestrians.
B	Sufficient area is provided to allow pedestrians to freely select walking speeds, to bypass other pedestrians, and to avoid crossing conflicts.
C	Sufficient space is available to select normal walking speeds, and to bypass other pedestrians in primarily unidirectional streams.
D	Individual freedom to select individual walking speed and to bypass other pedestrians is restricted.
E	Virtually all pedestrians would have their normal walking speed restricted, requiring frequent adjustment of gait.
F	All pedestrians' walking speeds are severely restricted, and forward progress is made only by "shuffling".

Reference : TRB(1985), Highway Capacity Manual

Table 6. Standards of LOS for the mixed traffic condition(work/school trip)

LOS	Walkway 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	Distinguished pavement	$1 < Q_v \leq 2$	$2 < Q_b \leq 4$	$51 < Q_p \leq 71$
D	Distinguished 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	$7 < Q_v$	$12 < Q_b$	$100 < Q_p$

6. CONCLUSIONS

This paper focused on the mixed traffic of pedestrians and vehicles to formulate the guidelines for evaluation and improvement of existing situations. There are lots of

researches on the field of pedestrian traffic flow in different countries with various traffic conditions, but few researches deal with the mixed traffic of pedestrians and vehicles' conditions. As explained at the beginning of this paper, the mixed traffic in narrow street is very important to the most of Asian countries where the pedestrian spaces were not secured in spite of rapid motorization with economic growth of the cities and countries.

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

The further research of this study would be needed for the generalization of the concept of level of service. Also, there should be more survey for different street types, traffic and weather 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.

ACKNOWLEDGMENTS

The author is thankful to the several owners of buildings located at survey area where the video recording could be possible three times a day both on weekdays and weekends.

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