ANALYSIS OF BEHAVIORS AND INTERACTIONS OF PEDESTRIANS, BICYCLES AND CARS IN NARROW URBAN STREETS

Young-in KWON	Shigeru MORICHI	Tetsuo YAI
Doctoral Student	Professor	Associate Professor
Dept. of Civil Eng.	Dept. of Civil Eng.	Dept. of Civil Eng.
Tokyo Institute of Tech.	University of Tokyo	Tokyo Institute of Tech.
Fax : 81-3-3726-2201	Fax : 81-3-5689-7290	Fax : 81-3-3726-2201

abstract : This study focuses on the phenomena analysis of behaviors and interactions of pedestrians, bicycles, and cars in narrow urban streets. The main purpose is to find out the moving behavior of traffic modes and interaction phenomena between traffic modes. For the analysis of moving behavior of traffic modes, path of traffic modes around obstacles, sidewalk-using behavior of pedestrians, car speeds with different street and traffic environment were analyzed. For the interaction phenomena between traffic modes, possibility of conflict avoidance between traffic mode was analyzed.

1. INTRODUCTION

Urban streets were used and occupied mainly by pedestrians before the advent of cars at the end of the nineteenth century. With the progress of vehicle technology and motorization in the beginning and middle of the twentieth century in Europe and America, the occupation of street spaces are gradually replaced by cars which give rapidity and comfort for people's movement. It happened after the middle of the twentieth century in Japan and recently at other East Asian countries those are late for the motorization.

The master plan of urban transport is mainly for car transport for several decades since the first comprehensive transport study performed in the middle of 1950's for urban transport plan in Detroit, United States. The car centered transportation plans are continued for several decades until the people realized the importance of pedestrian transportation as for the components of the comprehensive urban transportation system. Its importance was also stressed with the rise of issues over environment and energy problems as well as better quality of living in the city centers.

The street environment in the East Asian countries is much different with that of Western countries from the viewpoint of historical background. The width of street is narrow and the sidewalk is not a common facility even in Japan. The share of narrow streets which is less than 5.5 meters in width is 86.5% in the total road of Japan and 95.9% of them is less than 13.0 meters in width. There is a strong need to find out the moving behavior of traffic modes and interaction between traffic modes for the planning process of these road environments.

2. LITERATURE REVIEW

There are few papers on the behaviors and interactions of pedestrians, bicycles, and cars in the mixed traffic conditions, but several papers on this subject were published from the viewpoint of only pedestrian traffic flow analysis. This field of researches could be categorized as ① pedestrian behavior at macro level of planning such as route choice considering street and traffic environment and ② pedestrian behavior and interactions at micro level of planning such as walking position, conflict and avoid behavior between pedestrians only or with other obstacles such as column of a building.

For the modeling of pedestrian flow, Naka (1978) surveyed and analyzed the pedestrian flow at a concourse of a railway station categorizing the pedestrian flow into two kinds that is crossing flow which considers the flow of pedestrians as one stream and complicated flow which considers individual pedestrian behavior separately. The analysis focused on the behavior to avoid conflict and was applied to computer simulation. Mouri and Tsukaguchi (1980) surveyed the walking position of pedestrian considering the traffic volume of both pedestrian and car suggesting the standards of installation priority of sidewalks in residential areas.

Tatebe and Nakajima (1990) found out the characteristics of avoidance behavior of pedestrians against a column under free walking conditions based on three factors of distance by experimental survey : distance to keep personal space, distance caused by the pedestrian's forward movement, and distance exerted by the forecast of movement of an obstacle. Also, Tsujimoto et al. (1992) did experimental research for the analysis of pedestrian movement quantitatively by using the technique of digital image processing focusing on the finding of the beginning point of avoiding behavior and distance between a pedestrian and a standing obstacle.

Oomura et al. (1994) observed the walking behavior of pedestrians at the concourse of JR Tokyo station analyzing the pedestrian movement considering the conflicts between pedestrians and columns. The measured factors are generation rate of pedestrians, perception distance between pedestrians and column, which was used for the graphic simulation of the pedestrian movement in the concourse of railway station. Iida and Kitamura (1995) surveyed and simulated the pedestrian behavior at the inside of rest areas of express highway to find out the relationships between pedestrians, cars and layout of physical objects by developing a model which represents pedestrian movement as a function of the amount of available information in addition to the principles of avoidance of collision and distance minimization. The result was presented through graphic display simulation to visualize the effect of design components.

3. DATA COLLECTION AND ANALYSIS VIEWPOINT

Data collections for the analysis were performed in the year of 1996 and 1997 at twenty-five streets around several private railway stations, which are located in the southeast of the Tokyo Metropolitan area. The widths of streets ranges from around 5 to 10 meters including sidewalk. Some of the streets are with separated sidewalk. Separation between pedestrians and cars are in form of mount-up, bollard, and guardrail, colored or lined only.

The 8mm video recordings were performed for the survey about 30 minutes for each street sections for both weekday morning and weekend day times to consider the work trip as well as leisure trip and shopping trip. Video footage for recording could be possible as shown in Picture-1 & 2, but some of them are positioned at street side level. Video recording were analyzed with 1/30 seconds of comma basis which could consider the movement of pedestrians, bicycles, and cars in slow motion for analysis. Table-1 shows general descriptions of the streets selected and surveyed for this study.

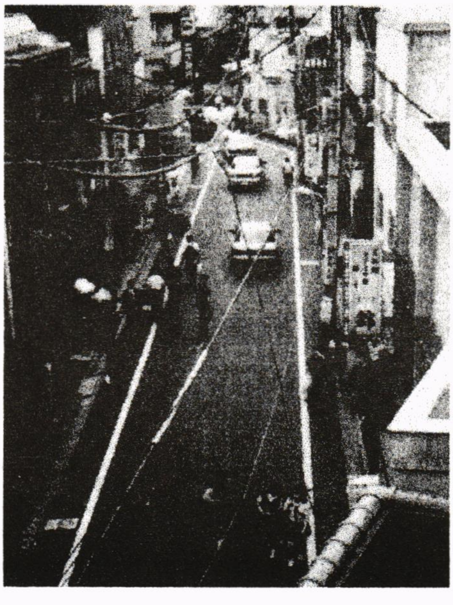
It could be assumed that traffic modes such as pedestrians, bicycles, and cars are generated varying with land use and different street section depending on its environments of streets. The basic movement characteristics of traffic modes are the function of their attributes and traffic environment, respectively. For example, the walking speeds of pedestrians are different with the age, purpose of walking, pedestrian density, etc.

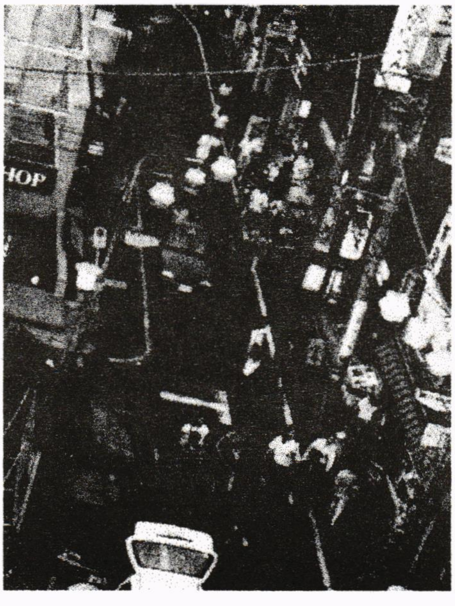
The movements of traffic modes are influenced by stopped or moving obstacles within the influential distance. The stopped obstacle could be street furniture or a parked car and moving obstacles might be other traffic modes. This paper examines the phenomena concerned with this movement of different traffic modes where the conflict easily occurs. By the analysis of the phenomena, it is possible to find out parameters to simulate the movement of traffic flow in the narrow streets.

Table-1 General description of the streets surveyed for analysis

No.	Places of Streets	Sidewalk Types	Width of Street*	Pedestrian**	Bicycle**	Car**
1	Kitasenzoku	Guard-rail	5.6m(1.6m)	468 Peds/h.	12 Bis/h.	250 Vehs/h.
2	Oookayama	Mount-up	4.1m(1.1m)	216 Peds/h.	60 Bis/h.	330 Vehs/h.
3	Midorigaoka 1	Lined	5.0m(1.3m)	240 Peds/h.	48 Bis/h.	282 Vehs/h.
4	Midorigaoka 2	Lined	4.5m(2.5m)	230 Peds/h.	220 Bis/h.	110 Vehs/h.
5	Midorigaoka 3	Mount-up	5.9m(2.3m)	600 Peds/h.	72 Bis/h.	222 Vehs/h.
6	Jiyugaoka 1	Bollard	5.6m(1.9m)	552 Peds/h.	24 Bis/h.	132 Vehs/h.
7	Jiyugaoka 2	Lined	3.1m(2.6m)	2,496 Peds/h.	288 Bis/h.	84 Vehs/h.
8	Jiyugaoka 3	Colored	3.1m(3.3m)	1,296 Peds/h.	192 Bis/h.	204 Vehs/h.
9	Toritsudaigaku 1	Lined	5.3m(2.9m)	1,644 Peds/h.	564 Bis/h.	30 Vehs/h.
10	Toritsudaigaku 2	Guard-rail	3.5m(1.8m)	480 Peds/h.	96 Bis/h.	248 Vehs/h.
11	Kuhonbutsu	Bollard	6.2m(3.4m)	144 Peds/h.	48 Bis/h.	216 Vehs/h.
12	Oyamadai	Guard-rail	6.4m(1.4m)	48 Peds/h.	36 Bis/h.	456 Vehs/h.
13	Todoroki	Mount-up	6.2m(3.5m)	948 Peds/h.	132 Bis/h.	54 Vehs/h.
14	Futakodamagawa 1	Guard-rail	6.5m(1.2m)	220 Peds/h.	132 Bis/h.	296 Vehs/h.
15	Futakodamagawa 2	Bollard	6.0m(3.4m)	288 Peds/h.	108 Bis/h.	156 Vehs/h.
16	Miyamaedaira	Mount-up	3.0 m(1.3m)	720 Peds/h.	120 Bis/h.	840 Vehs/h.
17	Musashisinzyo	Bollard	4.0 m(3.6m)	60 Peds/h.	180 Bis/h.	180 Vehs/h.
18	Musashigosugi	Bollard	6.7 m(2.6m)	180 Peds/h.	180 Bis/h.	180 Vehs/h.
19	Kamata 1	Colored	3.0 m(2.0m)	120 Peds/h.	180 Bis/h.	60 Vehs/h.
20	Kamata 2	Colored	4.5 m(3.0m)	120 Peds/h.	60 Bis/h.	180 Vehs/h.
21	Simokitazawa	Lined	2.5 m(2.1m)	3240 Peds/h.	120 Bis/h.	0 Vehs/h.
22	Umegaoka	Lined	3.5 m(1.0m)	720 Peds/h.	240 Bis/h.	60 Vehs/h.
23	Oomorigaigan	Lined	5.0 m(2.8m)	60 Peds/h.	60 Bis/h.	120 Vehs/h.
24	Oomori	Lined	3.0 m(3.0m)	120 Peds/h.	120 Bis/h.	60 Vehs/h.
25	Tachigaikawa	Lined	3.5 m(2.6m)	240 Peds/h.	120 Bis/h.	60 Vehs/h.

* Represents the width of street section for cars and figures inside of the parenthesis are width of sidewalk.
** Represents weekday peak hour traffic flow rate of pedestrian, bicycle and car flow.





Picture-1 & 2 View of surveyed narrow streets in Tokyo

4. MOVING BEHAVIOR OF TRAFFIC MODES

The traffic modes in narrow streets move considering the interaction with other traffic modes. The behavior of these traffic modes can be classified into two groups. The first one is moving behavior of different traffic modes and the second one is interaction phenomena between traffic modes. This section will treat the former and the following section will include the latter.

4.1 Path of Traffic Modes around Obstacles

The different traffic modes in narrow streets are apt to conflict stationary obstacles such as street furniture, parked bicycles or cars. In this case, 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-1. In Figure-1, 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 calculated by averaging the 6 surveyed streets located around Midorigaoka, Jiyugaoka, and Kamata urban railway stations. It should be mentioned that the traffic condition of these streets is not so much congested and the traffic modes could choose their moving route without the effect of other traffic modes.

Table-2 shows survey results for the influence distance of stationary obstacles on pedestrians, bicycles, and cars. The mean values of α and β for pedestrians are 4.6 m and 4.9 m, and γ for pedestrians is 0.34 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). Overall tendency of the parameter is biggest in the case of cars, the next bicycles comparing with that of pedestrians.

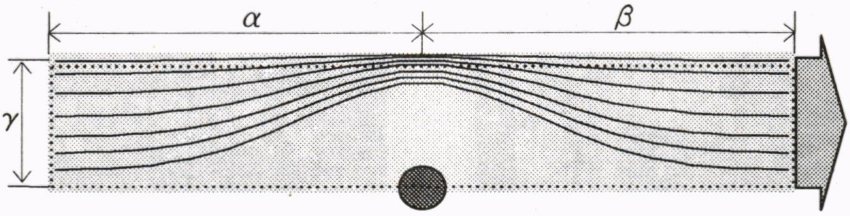


Figure-1 The influence of obstacles to the path of traffic modes

Table-2 The survey results for α, β, and γ

Parameters	Pedestrians	Bicycles	Cars
α	4.6m (283)*	5.8m (127)	9.4m (210)
β	4.9m (122)	6.2m (149)	11.0m (155)
γ	0.34m (189)	0.61m (103)	0.76m (138)

* Number of measured samples.

4.2 Sidewalk Using Behavior of Pedestrians

It may be assumed that pedestrians prefer to walk along streets where it is safe and comfortable to walk. Considering this, the sidewalk and street use behavior of pedestrians were observed for different street environments and different traffic flow conditions. While the decision by pedestrians to either use the sidewalk or the street is more stochastic than deterministic, 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. Table-3 shows the result of quantification analysis for the estimation of the share of pedestrian walking on sidewalk. Explanatory variables of pedestrian behavior for walking position are considered as follows:

- Street environment : sidewalk type, type of sidewalk separation, street location, car lane and sidewalk width
- Traffic condition : car traffic operation, pedestrian, car, and bicycle volume per width, and average car speed
- Others : survey time (AM, PM)

The analysis results show that the share of pedestrian walking on sidewalk varies with different condition of the street environment, traffic, and so on. According to the result of quantification analysis as in Table-3, pedestrians tend to pass sidewalk in the morning time, at both side sidewalk, other types of sidewalk rather than line separation of sidewalk, and two way car traffic. Also, the share of sidewalk passing pedestrians increase with wider car lane, wider pedestrian lane, less pedestrian traffic and more car and bicycle traffic. Figure-2 compares the actually surveyed values and the estimated values of 25 streets for the share of pedestrian walking on sidewalk.

Table-3 Analysis of share of pedestrian walking on sidewalk

Item		Number of Samples	Score	Range	Partial Corr. Coef.
Survey Time	1. AM	17	0.039	0.066	0.342
	2. PM	24	-0.027		
Sidewalk Type	1. One side	12	-0.164	0.233	0.104
	2. Both side	29	0.068		
Type of Sidewalk Separation	1. Line	16	-0.143	0.412	0.305
	2. Color	6	0.269		
	3. Mount-up	6	0.068		
	4. Bollard	8	0.031		
	5. Guardrail	5	0.004		
Street Location	1. Residentail	11	-0.008	0.386	0.212
	2. Resi. & Comm.	12	0.022		
	3. Commercial	11	0.124		
	4. Office	6	-0.261		
Traffic Operstion	1. One way	17	-0.018	0.031	0.071
	2. Two way	24	0.013		
Car Lane Width		41	0.101		0.180
Pedestrian Lane Width		41	-0.033		0.380
Pedestrian Volume per Width		41	-0.003		0.531
Car & Bicycle Volume per Lane		41	0.010		0.368
Average Car Speed		41	-0.002		0.045
Multiple Corr. Coefficient. r = 0.784		Constant = 0.2996			

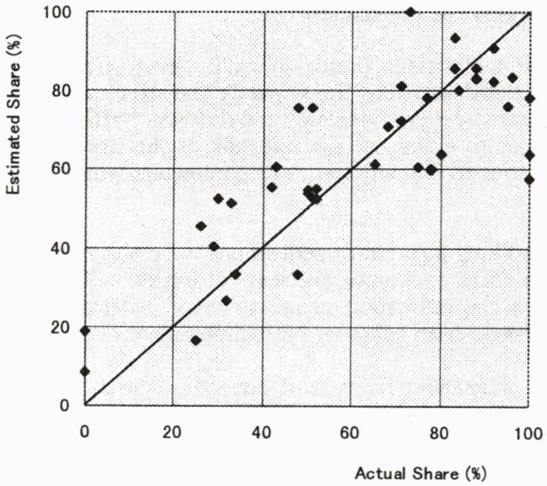


Figure-2 Actual and estimated pedestrian walking share on sidewalk

4.3 Car Speed with Different Street and Traffic Environment

The speed of a car passing a narrow urban street depends on street environment, traffic condition, and so on similar to the sidewalk using behavior of pedestrians. But, unlike pedestrian walking position, the car tends to move considering more on safety and speed. Table-4 show the analysis of quantification on the running speed of car at 25 streets and Figure-3 show the estimated and surveyed value of speed of car.

Table-4 Vehicle speed by street and traffic condition

Item		Number of Samples	Score	Range	Partial Corr. Coef.
Survey Time	1. AM	17	1.153	1.969	0.465
	2. PM	24	-0.816		
Sidewalk Type	1. One side	12	-0.639	0.903	0.629
	2. Both side	29	0.264		
Type of Sidewalk Separation	1. Line	16	2.020	7.331	0.378
	2. Color	6	-3.350		
	3. Mount-up	6	-1.352		
	4. Bollard	8	2.504		
	5. Guardrail	5	-4.827		
Street Location	1. Residentail	11	5.672	14.022	0.144
	2. Resi. & Comm.	12	0.365		
	3. Commercial	11	-8.350		
	4. Office	6	4.119		
Traffic Operation	1. One way	17	4.965	8.481	0.099
	2. Two way	24	-3.516		
Car Lane Width		41	4.547		0.186
Pedestrian Lane Width		41	-3.344		0.055
Pedestrian Volume per Width		41	-0.043		0.392
Car & Bicycle Volume per Lane		41	-0.137		0.560
Multiple Corr. Coefficient. r = 0.804		Constant = 14.883			

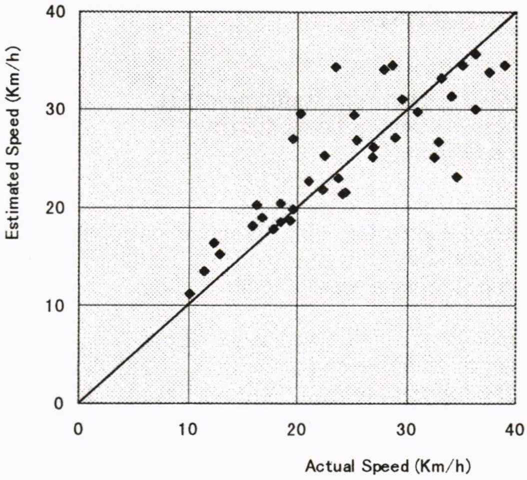


Figure-4 Actual and estimated car speed at narrow urban street

5. INTERACTION PHENOMENA BETWEEN TRAFFIC MODES

The interactions between traffic modes in narrow streets are existing when the other traffic modes are located within the influential distances, which is different among traffic modes. The parameters and models of interactions among traffic modes are complicated compared to the car traffic flows on the road which was already modeled and formulated as traffic flow theory several decades ago. Figure-5 shows the concept of interaction between traffic modes with the function of longitudinal and lateral distance and relative speed.

The influential distance could be defined as the distance where one mode of traffic take an action to change its moving route or speed with the purpose of preventing conflict and keep safe and comfort states against other traffic modes. To find out this distance, observation was performed with repeated slow motion of video that could show the traffic flows in one thirty seconds comma basis.

With this concept, the probability of route change or speed reduction to prevent conflict between traffic modes could be formulated as follows.

Probability of Conflict $= 1 / \{1 + \exp(-B_n)\}$ ....(1)

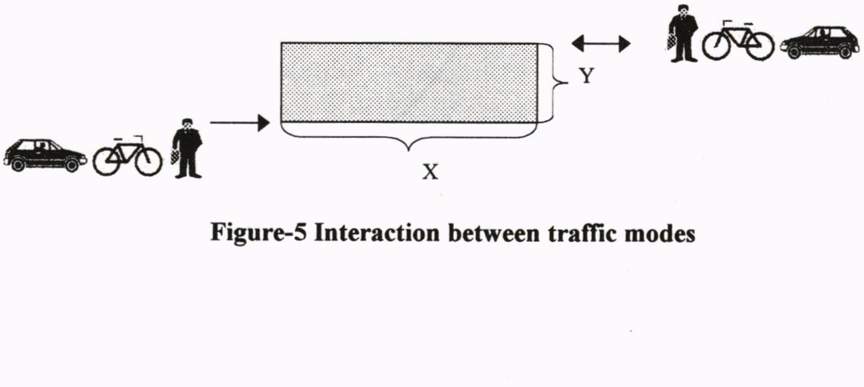


Figure-5 Interaction between traffic modes

$$B_n = C_{n0} + C_{n1}(X/S_R) + C_{n2}(Y/S_R) \quad \text{..........(2)}$$

where, C_{ni} is coefficient
X is longitudinal distance between traffic modes (m)
Y is lateral distance between traffic modes (m)
S_R is relative speed (Km/h)

Table-5 shows the results of estimation with the model calculated by maximum likelihood method. The overall results show that the model is feasible for the survey area for the formulation of interaction phenomena between traffic modes.

Figure-6 shows the probability of conflict avoidance of pedestrians following pedestrians in terms of longitudinal distance X and lateral distance Y. The figure shows that pedestrians do not change their moving route more than 5 meters, ahead. In case of Y equals to 0 and X equals to 3 meters, the probability of conflict avoidance is around 40 percents.

Figure-7 shows the probability of conflict avoidance of bicycles following pedestrians in terms of longitudinal distance X and later distance Y. The figure show that bicycle do not change their moving route more than 18 meters, ahead. In case of Y equals to 0 and X equals to 6 meters, the probability of conflict avoidance is around 41 percents.

Table-5 Influential subjects and objects between pedestrians and other modes

Conflict Type	C_0	C_{n1}	C_{n2}	Samples	Likehood Ratio	Hit Ratio(%)
Ped to Ped	2.232(8.9)*	-0.758(-6.2)	-9.719(-14.3)	1,010	0.34	82.6
Ped by Ped	6.057(6.0)	-0.849(-6.8)	-4.214(-5.9)	277	0.35	80.1
Ped to Bic	0.686(5.6)	-0.685(-4.6)	-9.376(-12.9)	1,725	0.20	74.8
Ped by Bic	2.037(5.4)	-0.785(-6.9)	-5.884(-3.5)	415	0.34	79.7
Ped to Car	1.502(10.5)	-0.465(-4.9)	-9.719(-17.6)	1,651	0.42	79.8
Ped by Car	1.902(9.8)	-0.216(-9.8)	-13.437(-12.5)	1,010	0.43	82.6

* Denotes t-value.

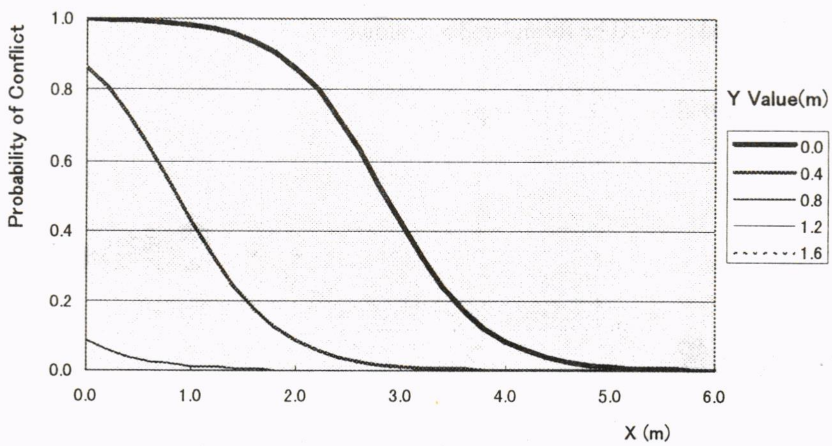


Figure-6 Possibility of conflict avoidance of pedestrians following pedestrians

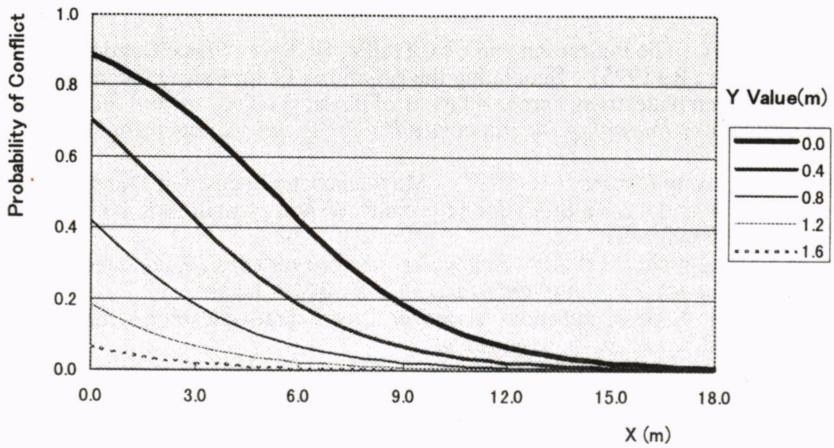


Figure-7 Possibility of conflict avoidance of bicycles following pedestrians

6. CONCLUSION AND FURTHER RESEARCH

In this paper, the behavior and interactions of different traffic modes are observed and analyzed to determine several parameters explaining the traffic phenomena at narrow urban streets. The main findings are the influential distance from standing obstacles to the moving traffic modes, pedestrian walking position, car speed, and the interactions among traffic modes in mixed traffic conditions.

Through the literature review, it was found that the existing research in this field is performed mostly for the traffic flow of pedestrians for the avoidance behavior against obstacles or behavior of pedestrians considering the environment only. Therefore, this paper added the pedestrian behavior and its conflict phenomena against bicycles and cars including different traffic and street environment conditions.

The newly found parameters could partly explain the complicated traffic flows happening in mixed traffic conditions. The paper can be used as a fundamental study for the establishment of improvement guidelines for better walking environment of urban streets such as pedestrian paradise or one way streets. Further survey and analysis is to be continued for the various street environments and traffic conditions for the application to the c computer simulation technology. For example, this paper did not consider congested traffic condition because the surveyed data is mostly for not congested streets.

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