PEDESRIAN'S BEHAVIORAL MODEL FOR TRAFFIC SAFETY WITH THE EFFECTS OF THE ESTABLISHING OBJECTS ON A LOCAL STREET

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Abstract: Pedestrian's traffic safety in a local street is influenced not only by passing automobiles, but also by the objects for habitant's daily life established on road such as electric light pole, post box, auto-sale machine and so on. In this study, pedestrian's behaviors to avoid the danger when person and automobile pass each other are described as to safety indices to analyze traffic safety. Using this kind concept of road safety, a model to describe pedestrian behavior is constructed, in which the behavior is responded to the level of danger by external situations compared with a threshold by internal property of pedestrian to avoid danger. It is applied to study the effects of on-street establishing objects on pedestrian traffic safety and give an outline of pedestrian behaviors in a local street for evaluating road safety degree.

1. INTRODUCTION

As a type of public space, local street in community area is directly related to habitant's daily life and accommodates many establishing objects such as electric light poles, post box, auto-sale machine and so on. It is also an effective space for traffic functions whereas is used for pedestrian walking and bicycle travelling. However, with the increase of automobiles, much car traffic penetrates this space, too. The objects established on a street become a big fault to the passage of both of pedestrian and bicycle, and car, make the safety of road space decline. Therefore, in a local street, not only passing automobiles, but also establishing objects on road has an influence on traffic safety.

This paper discusses pedestrian's traffic safety in the street according to the conditions of passing automobiles and on-street objects. In order to analyze the influence of establishing objects on pedestrian's traffic safety, electric light pole is picked up as the representative of establishing objects on road in this study.

In the past study concerning traffic safety of local area, the emphasis is mainly placed on the mutual interference between automobile and pedestrian or bicycle on the street. Relevant measures such as Woonerf Plan and community road are used to improve the safety of pedestrian and bicycle in district traffic. Road hump, chicane and so on are used to restrain automobiles traffic as hard means. On the other hand, the safety of bicycle travelling and the complicated phenomenon among automobiles and pedestrian in the crossing of road are

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analyzed, too. However, on a local street of actual situation, various establishing objects for numerous purposes exist and have a serious influence on traffic safety. Therefore, the establishing objects on street are also considered as influencing factor on pedestrian traffic safety in a local street.

The concept of pedestrian traffic safety in this study is not directly linked with traffic accidents, but pedestrian's behaviors to avoid the danger when person and automobile pass each other are described as to safety indices to analyze traffic safety. The behavior is a reflex of person's recognition to the danger surrounding him/her based on road actual environments such as on-street object conditions, traffic volume, automobile velocity, nearing degree of automobiles and pedestrian's property etc. Using this concept of traffic safety, pedestrian behaviors to keep away from the passing automobiles at different places with and without establishing objects are investigated, and relevant influencing factors are analyzed. A model to describe pedestrian behavior is constructed, in which the behavior is responded to the level of danger by external situations compared with a threshold by internal property of pedestrian to avoid danger. It is applied to study the effects of on-street establishing objects on pedestrian traffic safety and give an outline of pedestrian behaviors in a local street for evaluating safety degree of street.

2. INVESTIGATIONS ABOUT PEDESTRIAN'S BEHAVIORS ON A LOCAL STREET WITH THE ESTIBLISHING OBJECTS

To analyze whether or not establishing objects on a street have an influence on traffic safety, it is necessary to investigate the actual situation of street, traffic conditions and behaviors of pedestrian. Therefore, an electric light pole is picked up as a representative of establishing objects on street. With the help of video camera, the movement of pedestrians and automobiles were observed in November 1997. The observation lasted for one hour in the morning (7:30-8:30), in noon (12:00-13:00), in the evening (17:00-18:00), separately. The contents of investigation include pedestrian behaviors while meeting automobiles and passing each other at the place with or without the objects in the nearing on street. When pedestrian meets automobile and passes each other with automobiles, the main responsive actions to sense a situation around body can be described as lowering walking speed, more nearing the road side to walk, stopping the walk and keeping previous state to walk. In this study, the responsive actions, except keeping previous state to walk, are defined as the behaviors to avoid danger. Figure 1 shows relevant influencing factors on a local street, and moving state of pedestrian and automobiles, and relevant attributes to be considered in this study.

To exclude the influence of interference of two-way car traffic and easily observe pedestrian behavior to avoid danger while passing each other with automobile, a straight section of 4 m width in a local street with more traffic of pedestrian and automobiles is taken up for the investigation.

The place influenced by the installation of on-street objects is considered as the neighborhood and the opposite side of establishing objects (electric light pole) on road space. But, with the increase of distance where leave object, the influence degree to be undergone will decline. Therefore, the street is divided into four parts (ellipse partial in Figure 1), that is, neighborhood (POINT1) of establishing object on the same side and its opposite side (POINT2), where are directly influenced by establishing objects, and the place (POINT3) where there is not objects on the same side of electric light pole and its opposite side (POINT4), as to the spot of observation. POINT3, 4 are separated off and set from POINT1, 2 to more than 12 m. Also, to consider that the passage movement (position and speed) of pedestrian and automobile changes in different time, three time zones as stated previously to each POINT are observed separately. Whether there are differences of passage movement in each time zone can be judged through variance

analysis.

Based on this, three transversals (making the a, b, c spot respectively) which did the scale of 10-cm unit in each observing part are installed to exactly investigate pedestrian behavior when passing each other with automobile. In the same time, relevant data of influencing factors such as passing time of pedestrian and automobile, car speed, walking speed, position of human body (the distance leaving the wall of building) and car's position (the distance leaving the wall) are also found out by video camera. The interval distance between automobile and pedestrian, that is, the distance from the centerline of human body to the side of automobile can be calculated. As for the attribute of pedestrian, it is defined as the aged and non-aged.
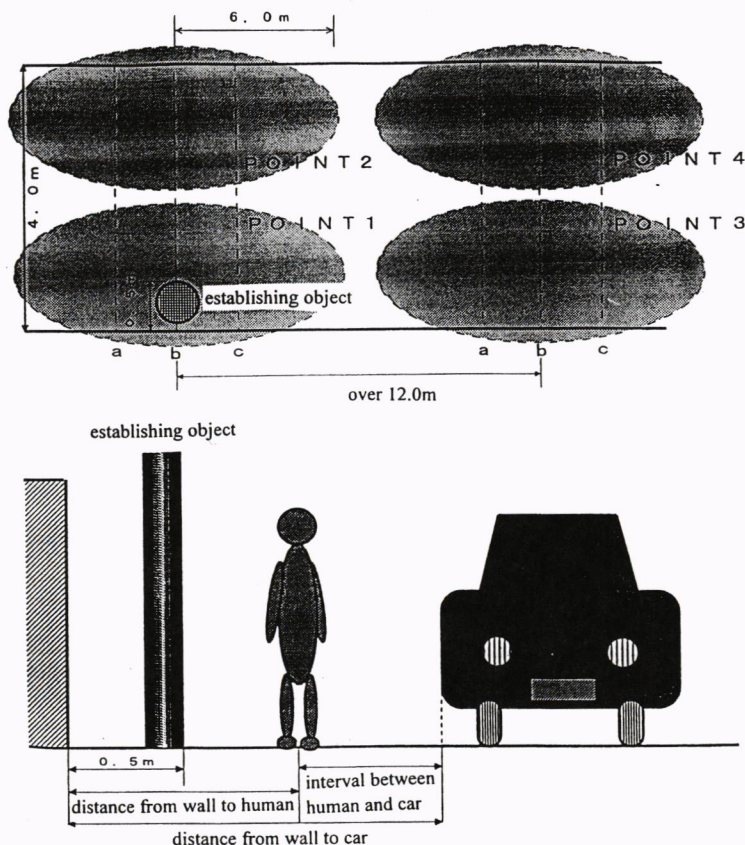

Figure 1. Situation of the Observation on Road Section

3. ANALYSIS OF RELEVANT FACTORS TO INFLUENCE PEDESTRIAN'S BEHAVIOR

The traffic of automobiles and pedestrians, the number of times that pedestrians pass each other with automobiles, the number of times of pedestrian's behavior to avoid danger when meeting automobiles observed at four observing spots in three time zones are shown as in Table 1. The total traffic of automobiles and pedestrians observed is 370 car and 195 person, respectively. There are 45 times for the passing each other of pedestrian and car, 29 times for pedestrian behaviors for avoiding danger in which mostly is more nearing the road side to walk while

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lowering speed, and only two times of stopping walk was observed. Also, the percentage of behaviors to avoid danger by the place of passing each other is 92.3% in POINT 2, 83.3% in POINT 1, 50% in POINT 3 and 28.6% in POINT4, separately.

The relevant factors directly related to pedestrian behaviors, such as position of human and car while passing each other, interval distance between human and car, walking speed of pedestrian and running speed of car while passing each other or not, will have some fluctuation according to different observing spot based on time zone. Through variance analysis as shown in Table 2, it is known that there are significant differences in these factors according to different spot. But, the differences based on different time zone are not found.

Table 1. Traffic of Automobile and Pedestrian at Each Observing Spots
in Three Time Zones

Time zone Observing	POINT1		POINT2		POINT3		POINT4	
	Automobile (vehicle)	Pedestrian (person)	Automobile (vehicle)	Pedestrian (person)	Automobile (vehicle)	Pedestrian (person)	Automobile (vehicle)	Pedestrian (person)
7:30-8:30	64	26	32	31	44	24	43	31
12:00-13:00	21	8	27	15	26	12	26	13
17:00-18:00	19	10	22	9	20	8	26	17
Total	104	44	81	45	90	45	95	61
Number of passing Each other	12		13		6		14	
Number of avoidance behavior	10		12		3		4	

Table 2. Variance Analysis Based on the Time Zone and Observing Spot

Items	Interval distance between car and pedestrian (cm)	Distance from the wall (cm)		The speed while Passing each other (m/minute)		The speed while not passing each other (m/minute)	
		pedestrian	Automobile	Pedestrian	automobile	pedestrian	Automobile
Means	84.2	69.9	107.7	79.36	296.89	87.21	383.01
Variance	32.0	82.7	46.6	201.13	5829.4	201.18	7412.4
Influence of place	○	○	○	○	○	×	○
Influence of time zone	×	×	×	×	×	×	×

Note: F-test in the level of 5%, ○: there are influence.
× : there are not influence.

Through the comparisons with pedestrian and automobile positions while passing each other or not at the street (Table 3, 4), it is found that at observing spot POINT 1,2,3, there are all the differences, but, at POINT 4, there are only differences in pedestrian positions and not in automobile positions.

Similarly from Table 5, 6, at POINT 1, 2, the walking speed of pedestrian passing each other with automobiles is different from that not passing each other, and the running speed of automobile, too. But, at POINT 3, 4, there are all not the differences.

Table 3. Position of the Car Running at the Street

Place	POINT1		POINT2		POINT3		POINT4	
Position	①	②	①	②	①	②	①	②
Means (10cm)	7.83	9.65	4.15	7.46	3.67	6.53	3.86	7.11
Variance	5.79	6.83	6.83	1.97	4.25	1.87	4.03	10.01
t-test	○		○		○		○	
F-test	×		○		○		○	

Note : ①: Distance between car and wall when passing each other with pedestrian.
② : Distance between car and wall when not passing each other with pedestrian.
○: There is the difference in 5%-test level.
× : There is not the difference in 5%-test level.

Table 4. Position of Pedestrian Walking at the Street

Place	POINT1		POINT2		POINT3		POINT4	
Position	①	②	①	②	①	②	①	②
Means (10cm)	14.08	12.31	10.62	6.53	12.83	9.25	11.07	10.87
Variance	2.81	1.66	4.42	2.15	3.37	3.3	6.84	3.54
t-test	○		○		○		×	
F-test	×		○		×		×	

Note : ①: The distance between pedestrian and wall when passing each other with car.
② : The distance between pedestrian and wall when not passing each other with car.
○: There is the difference in 5%-test level.
× : There is not the difference in 5%-test level.

Table 5. Speed of Car Running at the Street (m/ minute)

Place	POINT1		POINT2		POINT3		POINT4	
Speed	①	②	①	②	①	②	①	②
Means	285.24	382.63	267.46	358.45	347.05	400.71	312.71	391.10
Variance	2204.1	7408.8	3539	6375.5	6155.7	7070.1	9809.1	8005.1
t-test	○		○		○		×	
F-test	×		○		×		×	

Note : ○: There is the difference in 5%-test level.
× : There is not the difference in 5%-test level.

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Table 6. Speed of Pedestrian Walking at the Street (m/minute)

Place	POINT1		POINT2		POINT3		POINT4	
Speed	①	②	①	②	①	②	①	②
Means	83.94	95.17	74.83	82.84	74.03	84.66	81.92	87.57
Variance	218.35	306.43	212.32	94.25	198.45	138.15	163.64	217.95
t-test	○		○		×		×	
F-test	×		×		×		×	

Note : ○: There is the difference in 5%-test level.
       ×: There is not the difference in 5%-test level.

And also, in this study, the relationships between human position and walking speed of pedestrian, and between automobile position and running speed of automobile at each observing spot are analyzed by regression analysis. From Table 7, 8, it can be derived that when automobile passes each other with human, the coefficients of correlation between position and running speed of automobile are very low, at all observing spots. On the other hand, at POINT 1, 2, there are some correlation between walking speed of pedestrian and his position, in which, the coefficients of correlation is 0.779 and 0.884, respectively, but, at POINT 3,4, this kind of correlation is very low.

Table 7.   Relation between Position and Each Speed of Pedestrian at Observing Spot

Place	POINT1	POINT2	POINT3	POINT4
Constant	46.467 (4.672)	50.542 (4.481)	4.614 (9.114)	62.431 (7.360)
Position (10 cm)	4.784 (3.927)	5.847 (2.265)	9.114 (2.410)	5.053 (2.446)
Correlative coefficient	0.779	0.564	0.884	0.577

Note: Position is the interval distance between pedestrian and wall.
      The value of parenthesis is the t-value to describe the variation of position.

Table 8. Relation between Position and Each Speed of Automobiles at Observing Spot

Place	POINT1	POINT2	POINT3	POINT 4
Constant	493.345 (4.627)	457.86 (6.425)	675.977 (3.052)	571.808 (5.338)
Position (10 cm)	-14.777 (-1.964)	-17.936 (2.72)	-25.631 (-1.498)	-23.321 (-2.507)
Correlative coefficient	0.528	0.634	0.599	0.603

Note: Position is the interval distance between automobile and wall.
      The value of parenthesis is the t-value to describe the variation of position.

From the observed data, the accumulation distribution of interval distance between automobile and pedestrian according to each spot while their passing each other are investigated as shown in Figure 2. It is meant that the interval between car and person at POINT 1 with an electric light pole and its opposite side POINT 2, tends to become narrow compared with POINT 3, 4.

These analysis results as stated-previously show that all influencing factors directly related to pedestrian behavior are influenced by the on-street objects. And also, the attributes of pedestrian such as the aged or the non-aged shall be taken into accounts in the behaviors.
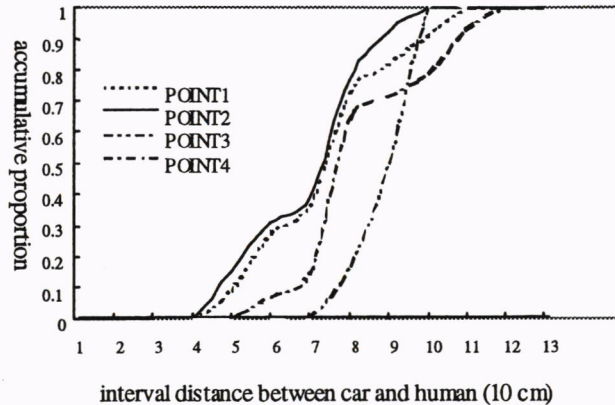

interval distance between car and human (10 cm)

Figure 2. Accumulative Distribution of the Interval Distance between Automobile and Pedestrian

4. PEDESTRIAN'S BEHAVIORAL MODEL TO AVOID DANGER WITH THE INFLUENCE BY THE ESTABLISHING OBJECTS IN A LOCAL STREET

Pedestrian behaviors are influenced by many external and internal factors when he/she passes each other with automobiles in a local street. Generally, the external factors include road conditions, running speed of car, interval distance between pedestrian and car, position of pedestrian walking in the street. The internal factors can be described as human's own conditions such as the aged or the non-aged. Pedestrians choose their behaviors to avoid the danger through comparing the external condition with the internal factors and judging the dangerous level of the surrounding nearing body.

A pedestrian who are walking on a road with some individual characteristic will measure the speed of coming car with his/her eye and consider the surrounding condition and his/her own position. In the meantime, the dangerous level nearing body will be computed in his/her brain. If the dangerous level when keeping his/her walking speed and position just as previously exceeds a certain threshold value, the pedestrian will tries to lower the dangerous level by the behavior to avoid danger. That is, whether to start an avoidance behavior is decided by comparing and distinguishing the external dangerous level with a threshold value by the internal factor of pedestrian attribute. Therefore, A model of distinguishing and judging the size between the dangerous level of external situation and threshold value of pedestrian can be used as to describe pedestrian behavior. This kind of distinction model is often used in psychophysics. A kind of disaggregate model which is used for traffic behavioral analysis can also be called as the distinction model with the use of utility difference among choice routes. Therefore, in this study, the disaggregate logit model is adopted as to describe pedestrian behaviors for the avoidance of danger.

Based on the point of view as mentioned-above, the dangerous level function by the external factors is defined as:

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$$V_1 = \sum \alpha_i w_i \qquad (i=1,2,3,4,5,6) \tag{1}$$

Where, α_i are parameters of all variables, which is estimated from the observed data. w_1, w_2, w_3 are the variables to express running speed of automobiles, interval distance between car and pedestrian and position of pedestrian respectively. Also, because the dangerous level is related to the place where pedestrian passes each other with automobile, and the probability of occurrence of pedestrian's behavior to avoid danger is directly influenced by the place passing each other based on the analysis of previous chapter, some dummy variables (w_4, w_5, w_6) are introduced to indicate the place, in which $w_4=1$, $w_5=0$ and $w_6=0$ is meant for POINT1, $w_4=0$, $w_5=1$ and $w_6=0$ for POINT 2, $w_4=0$, $w_5=0$ and $w_6=1$ for POINT 3, $w_4=0$, $w_5=0$ and $w_6=0$ for POINT 4.

Also, supposing that the threshold value of pedestrian by the internal factor is the following formula:

$$V_2 = \beta_0 + \beta_1 z \tag{2}$$

Where, β_0 β_1 is variable parameters estimated. z is dummy variables which show the attribute of pedestrian, in which $z=0$ (the aged) and 1 (the non-aged).

Based on the analysis as mentioned above, the probability that V_1 exceeds V_2 is:

$$P_1 = \exp(V_1)/(\exp(V_1) + \exp(V_2)) \tag{3}$$

Based on the data observed, these parameters of each function can be estimated. Table 9 shows each kind of parameter of pedestrian behavioral model for avoiding danger. The values in parenthesis are the t-value based on the variation of each variable. Although the number of data is not adequate, the likelihood ratio under the adjustment of the free degree is 0.483. And also the rate of goodness of hit reaches to 84.4%. So, it is derived that the reproducibility of the model is very good.

Table 9. Pedestrian Behavioral Model to Avoid Danger

Explanation variable		Parameter (t-value)
Running speed of automobile (α_1)		0.0154 (1.5966)
Interval distance between car and pedestrian (α_2)		-1.2997 (-1.6764)
Walking position of pedestrian (α_3)		-1.4980 (-2.2791)
Dummy variables of POINT		
w_4 (α_4)		7.2634 (2.4304)
w_5 (α_5)		3.6877 (2.0307)
w_6 (α_6)		1.2323 (0.8519)
Threshold Value	Constant (β_0)	-12.1882 (-1.7095)
	Attributes (β_1)	2.2028 (1.2571)
Number of samples		45
Number of alternative choice		2
Likelihood ratio adjusted		0.483
Hit rate		84.40%

5. INFLUENCE OF ON-SRTEET OBJECTS ON ROAD TRAFFIC SAFETY

In a local street of community area, pedestrian and bicycle is indispensable. In the meantime, with the increase of automobiles, when car runs on the street, the interference among car, pedestrian and bicycle will increases. The establishing objects on a street increase road danger in the interference because they make the space of road decrease.
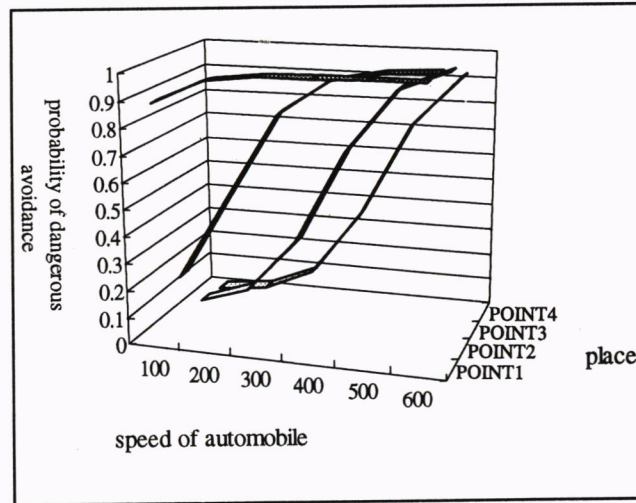

Figure 3. the Aged Pedestrian Behavior to Avoid Danger
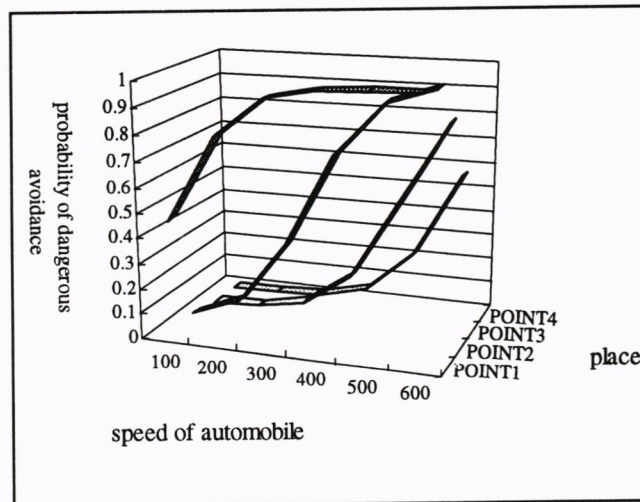

Figure 4. the Non-Aged Pedestrian Behavior to Avoid Danger

Using the behavioral model built-above, the influence of on-street objects on road safety will be investigated. In this paper, assuming that interval distance between car and pedestrian is 65 cm

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and the distance between pedestrian and wall (the walking position of pedestrian) is 70 cm. Under this kind of situations of assumption, the probability of dangerous avoidance of pedestrian in each place with or without on-street objects can be calculated with the changes of vehicle speed. From the result of computing the model, the influences of on-street objects on road safety through the index of dangerous avoidance can be derived. Figure 3 shows the situations of the aged pedestrian on the street. It is found that POINT 1,2 are very easier to cause the behaviors to avoid danger while the pedestrian passing each other with automobile.

Figure 4 shows the situations of the non-aged pedestrian on the street. And also it can be known that POINT1,2 is more dangerous than POINT3, 4 from the probability of causing the dangerous avoidance. Furthermore, it is derived that behavior of the aged pedestrian to avoid danger while passing each other with automobile is more easily caused under the same conditions, by the comparing Figure 3 with Figure 4.

In order to keep road safety within a certain degree, it is necessary to control vehicle speed and reduce automobile traffic by using some traffic regulations. Therefore, in a local street with on-street objects, we can use the index of pedestrian behavior to avoid danger as to regulate the maximum speed of automobiles.

In this study, it supposes a threshold value to the danger of traffic is supposed when pedestrian passes each other with car on a local street where the establishing objects exist. By comparing the dangerous level (V_1) which was given by the road situation to this threshold value, the influences of establishing objects on the street are discussed and the model of occurrence estimate of pedestrian behavior of dangerous avoidance is constructed. The concept of traffic safety in case of this study is not directly related to traffic accident and so on, but, make the pedestrian's behavior to avoid danger where there is a sense from the external environment a safe index. It was possible to estimate and analyze the influence of on-street objects on road safety by using the pedestrian behavioral model.

In these factors which influences pedestrian behaviors, the inclination of road and plain of pavement and so on should be considered. In this stage of the study, all factors are not still reflected only in the data of the investigation. However, it is thought that the basic influence of the on-street objects on road traffic safety can be suggested. The establishing objects on a street include not only electric light pole, but also other objects such as on-street parking car, auto-sale machine and so on. We will proceed relevant investigation and analysis to other establishing objects. In addition to pedestrian safety, bicycle safety on a local street shall be considered in the local street, too. This study has gone only for the local street of 4m width. Road width is also related to other factors of safety. Therefore, all factors shall be synthetically analyzed, and have some values to continue this kind of study in the future.

6. CONCLUSIONS

Road safety is a very important issue of automobile society. It is not only directly related to the problem of traffic accidents, but also to human daily life. This paper discusses the traffic safety from pedestrian behavior when walking on a local street, considering the influences of road condition such as on-street objects on traffic safety. The relevant research results have been concluded as follows.

(1) As an index of traffic safety, this study does not directly take up the data such as traffic accident, but uses occurrence ratio of pedestrian to avoid danger while passing each other with automobiles, considering the pedestrian's internal conditions and surrounding situation such as whether or not the on-street objects exist.

(2) A model to describe pedestrian behavior for traffic safety is constructed, using disaggregate logit model. In the pedestrian behavioral model, pedestrian behavior to avoid danger is caused by comparing the threshold value of human to the dangerous level of surrounding situation on a street. The surrounding situations are decided by many influencing factors such as running speed of car, interval distance between human and car, human position walking on a street, and the place where human passes each other with automobile and so on. The threshold value is derived from the internal factor (attribute) of pedestrian. So, the model can also be called as a process of the distinction of dangerous level.

(3) From pedestrian behavioral model, This study investigated the influence of establishing objects on road traffic safety. And also, based on the occurrence ratio of pedestrian behavior to avoid danger, the regulation speed of car on the street with the on-street objects was discussed.

As the 2nd step of this study in the future, we will consider the evaluation of road safety and the accident percentage on the road where establishing objects exists.

REFERENCES

1) Traffic Engineering Society (1983), **Traffic Engineering Handbook**, Gihouto, Tokyo.
2) Tanaka Yosiku (1977), **Psychological Measurement Method**, the 2nd edition, the University of Tokyo.
3) Traffic Engineering Society (1996), **Community Zone Forming Manual--the Area Traffic Guidance**, Tokyo.
4) EZRA HAUER (1997), **Observational Before-After Studies in Road Safety**, First edition, PERGAMON, New York.
5) Arano Koumitsu, *etl* (1986), The analysis of speed restraint effect using the fault at the road of pedestrian and car coexistence, **Journal of Traffic Engineering**, Vol.21, No.6.
6) Sano Kokuhiko (1982), Car speed and rule factor of a local route, **Journal of Traffic Engineering**, Vol.17, No.5.
7) Mark Poch and Fred Mannering (1996), Negative Binominal Analysis of Intersection Accident Frequencies, **Journal of Transportation Engineering**, ASCE, Vol.122, No.2, pp. 105-113.