EFFECTS OF DRIVERS' AGE, FLOW RATE AND SOME OTHER ROAD ENVIRONMENT RELATED FACTORS ON TRAFFIC ACCIDENTS AT FOUR-LEGGED SIGNALIZED INTERSECTIONS

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abstract: Traffic accidents have kept on increasing for quite a few years in Japan. Moreover, injury accident amount reached a new peak of 761,789 in 1995. Of all the accidents, intersection accidents accounted for 58.7%. Effective countermeasures against intersection accidents are urgently needed. Our recognition of the occurrence of intersection accidents, however, is still far from clear. Based on the data of 112 four-legged signalized intersections in Tokyo and the results of related previous studies, the effects of drivers' age, traffic flow rate, intersection shape, surrounding land use pattern and intersection size on intersection accidents are presented in this paper.

1. INTRODUCTION

1.1 Backgrounds

In Japan, although many countermeasures against traffic accidents have been employed, the increasing trend of traffic accidents is still continuing. From Figure 1, we can see that while fatalities fluctuating around 10 thousands a year, traffic injuries keep on increasing since 1990. In 1995, the injury amount of traffic accidents is 55.5% higher than that in 1977. Moreover, the record of injury accident amount, 720,880 in 1969, was reset by 761,789 in 1995. About 58.7% of total accidents, or 44.7% of fatal accidents occurred in or near intersections in 1995.

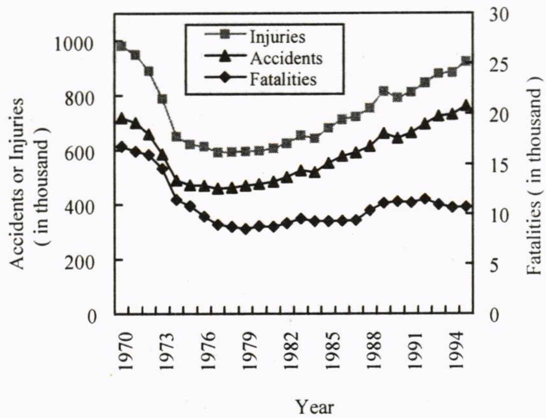

Figure 1: Trends of accidents, fatalities and injuries in Japan
Data source: ITARDA (1996)

To stop the increase of traffic accidents is an urgent task in Japan. One of the key procedures in approaching the target is to find an effective countermeasure against intersection accidents. As clearly identifiable accident black spots and road sections have been reduced through conventional measures in Japan, the increasing trend of accidents indicates that conventional countermeasures can not efficiently reduce certain types of accidents (PWRI, 1996). We need some new measures against the accidents. Our limited knowledge, however, has seriously hindered the improvements of intersection safety. No study can be well accepted as a generalized theory to guide the practice so far, although many researchers have kept on striving for a fairly long time. Moreover, previous studies failed to achieve a consistency on many basic issues despite of their fitness in specific areas. For example, although signal installation is widely regarded as an effective measure, previous studies on safety effects of signal installation have obtained opposite conclusions (Persaud, 1987).

This implies that for the purpose of deriving a commonly acceptable conclusion on traffic accident occurrence, basic analyses and statistical works are still needed. As traffic accidents are normally a comprehensive result of human, vehicle and road environment related factors, any changes of the above factors might cause the variation of accident rate. Kontaratos (1974) studied the effects of accident causal factors and concluded that human related factors are the most important. In Figure 2, human related factors accounted for 93.1% of the total, while road environment and vehicle related factors made up only 39.4% and 13.8% respectively. This indicates that to study the effects of human and road environment related factors might be more efficient at present.

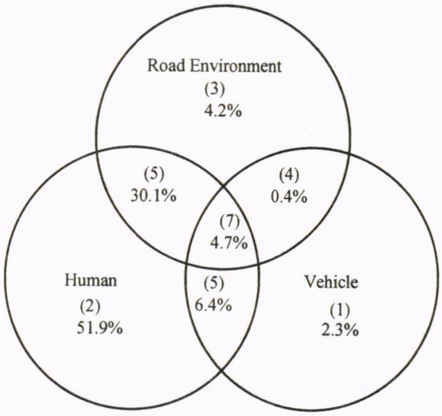

Figure 2: Accident causal factors and their accounts
Data source: Kontaratos (1974)

When talking about human factors, age is always an indispensable key (Kimura *et al*, 1995 and Matsushima 1987). In this study, drivers' age is regarded as a dominant factor of their behaviors, and the mental and physical changes with age are analyzed. Similar to the function of age in human factors, traffic volume plays the most important role among road environment factors. Based on the data of 112 intersections in Tokyo, the effect of total entering traffic flow rate on accidents are statistically studied. Besides, the effects of surrounding land use pattern and intersection size are also qualitatively introduced.

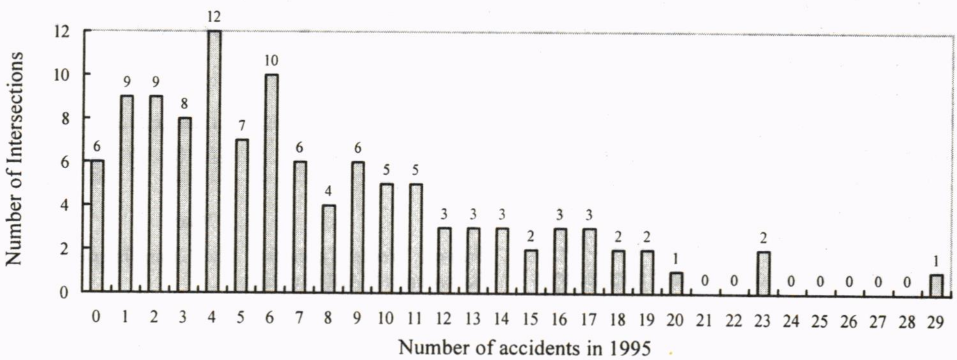

Figure 3: Accident numbers of the selected intersections

1.2 Data and the Selected Intersections

Amano *et al* (1982) have proved that the number of legs of an intersection is related to its accident rate. The purpose of this study, however, is to find the effects of drivers' age, traffic flow rate, surrounding land use pattern, and intersection size on accident rates. Thus all the samples selected are four-legged signalized intersections, which is the most common type. In total, 112 four-legged signalized intersections with different crossing angle, size, and surrounding land use pattern are randomly selected in Tokyo for this study. Data of accident number, intersection layout, surrounding land use and traffic flow rate of the selected intersections in 1995 were collected. The distribution of accident number and the ratio of each accident type are listed in Figures 3 and 4 respectively based on the data of the selected intersections. From Figure 4, we can see that angle accidents during turning movement and rear end accidents are the dominant accident types at four-legged signalized intersections in Tokyo.

2. THE MECHANISM OF ACCIDENT OCCURRENCE

Before we start to analyze the effects of causal factors, it might be very helpful to make clear the mechanism of accident occurrence at first. As shown in Figure 5, traffic situation at intersection areas are very complex - automobile flows, motorcycle flows (including mopeds), bicycle flows and pedestrian flows of different directions conflict frequently there. This makes the intersection accidents diversified in form and complex in causation.

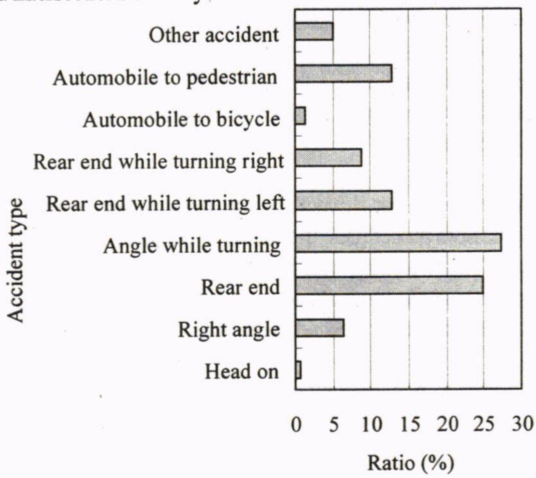

Figure 4: Accident occurrence of each type

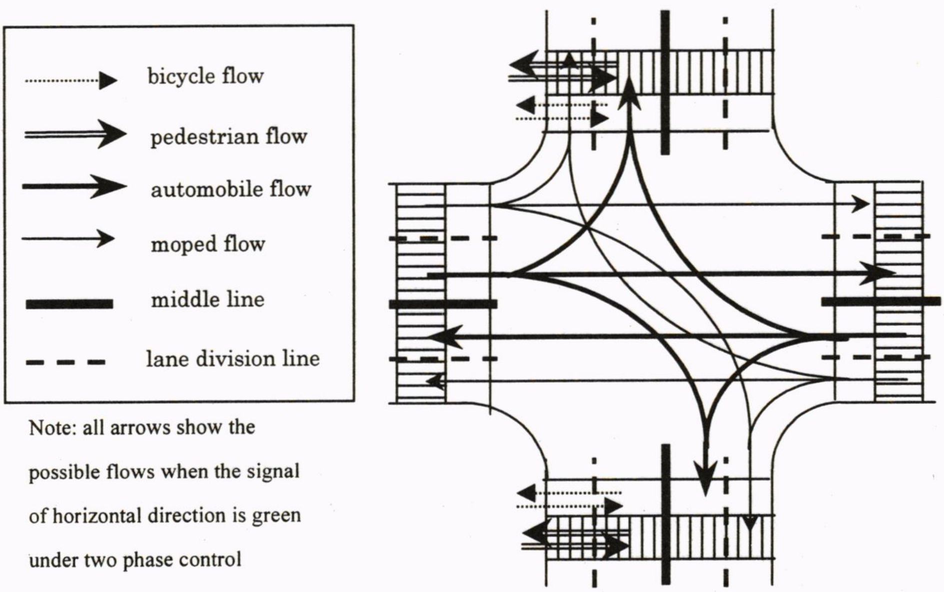

Figure 5: Diagraming traffic flows in a typical intersection in Tokyo

Hauer *et al* (1988) divided vehicle to vehicle accidents of four-legged intersections into 15 types according to maneuvers of the two vehicles before the collision. This kind of classification is undoubtedly more accurate and easier to describe, since each kind of accidents has its own features. Fridstrom *et al* (1996) pointed that random causal factors ("noise", "disturbance") had a decisive effect on accident occurrence at a micro level. Despite of the specifics of different accident types, the occurrence of accidents is considered to be based on two premises in this study, one is the hazardous behavior of the driver, and the other is the emergence of disturbance. A disturbance here means a factor which can lead a hazardous behavior to an accident. To give a common definition on the term 'hazardous behavior', however, is very difficult, as the concept of 'hazardous' itself changes with the situation. As an example, here we consider the case of a typical pattern of rear end accidents - both of the two involved vehicles belong to the same through traffic flow at a four-legged signalized intersection. A hazardous behavior here means that the gap of two consecutive vehicles are too short for the following driver to make a proper response when the leading vehicle brakes. A disturbance here can be anything possible to cause the leading vehicle to brake, such as a red signal, conflicting vehicle, illegally crossing pedestrian and etc. To illustrate the concept, a flow chart of this accident type is given in Figure 6, in which affecting factors of each procedure are listed in a shadowed box.

We can see that drivers' performance, when passing through an intersection, is constituted by three successive procedures: the first is to perceive the change of traffic environment; the second is to make a decision for dealing with the change; and the third is to carry out the maneuver. Thus drivers' abilities of perceiving, thinking and acting are the most important factors affecting accident occurrence, and all those abilities are closely related to drivers' age as will be demonstrated in this study.

Another important point of intersection safety is how frequent the disturbances will emerge. Maybe you have the experience that in a prosperous commercial area, there are quite a few signal disregarding pedestrians , or in the evening, when traffic density is low, some drivers are found to run a red signal. All those examples are implying some relationship between disturbances and their influencing factors. To reduce the frequency of disturbances is also a very important measure for improving intersection safety. Traffic volume, surrounding land use and intersection size are considered having remarkable effects on the frequency of disturbances.

Although here we only explained the occurrence mechanism of rear end accident of through traffic, the same method can be also applied to the analysis of other accident types as well.

3. THE EFFECTS OF DRIVERS' AGE

As aforementioned, the change of human related factors might cause the corresponding variation of accident rate. Age is a predominant factor of a driver's perceiving, thinking and acting abilities. The change of components of each age group will inevitably influence the occurrence of accidents.

A persuasive example is the increase of accident amount along with the growth of elderly population. Evidences can be found by checking the breakdown structure of traffic fatalities of each age group in Figure 7. If we define elderly people here as those who are over 65 years old, we can see that although total fatality number is fairly stable around 10 thousand a year, the ratio of elderly fatalities keeps on increasing. Meanwhile fatality ratios of other age groups are fluctuating or decreasing. This phenomenon can be explained by the transition of population structure as shown in Figure 8 (S.B., 1985). From 1950 to 1995, the ratio of elderly people in the total population had increased by 2.8 times, from 5% to 14%. In the coming future, the ratio will be further extended to about 24% in 2020. Correspondingly, the proportion of elderly drivers will extend to 20% of the total in 2040 (Kimura *et al*, 1995). This indicates that a further increase of traffic accidents might be inevitable if no effective countermeasure can be found in the near future.

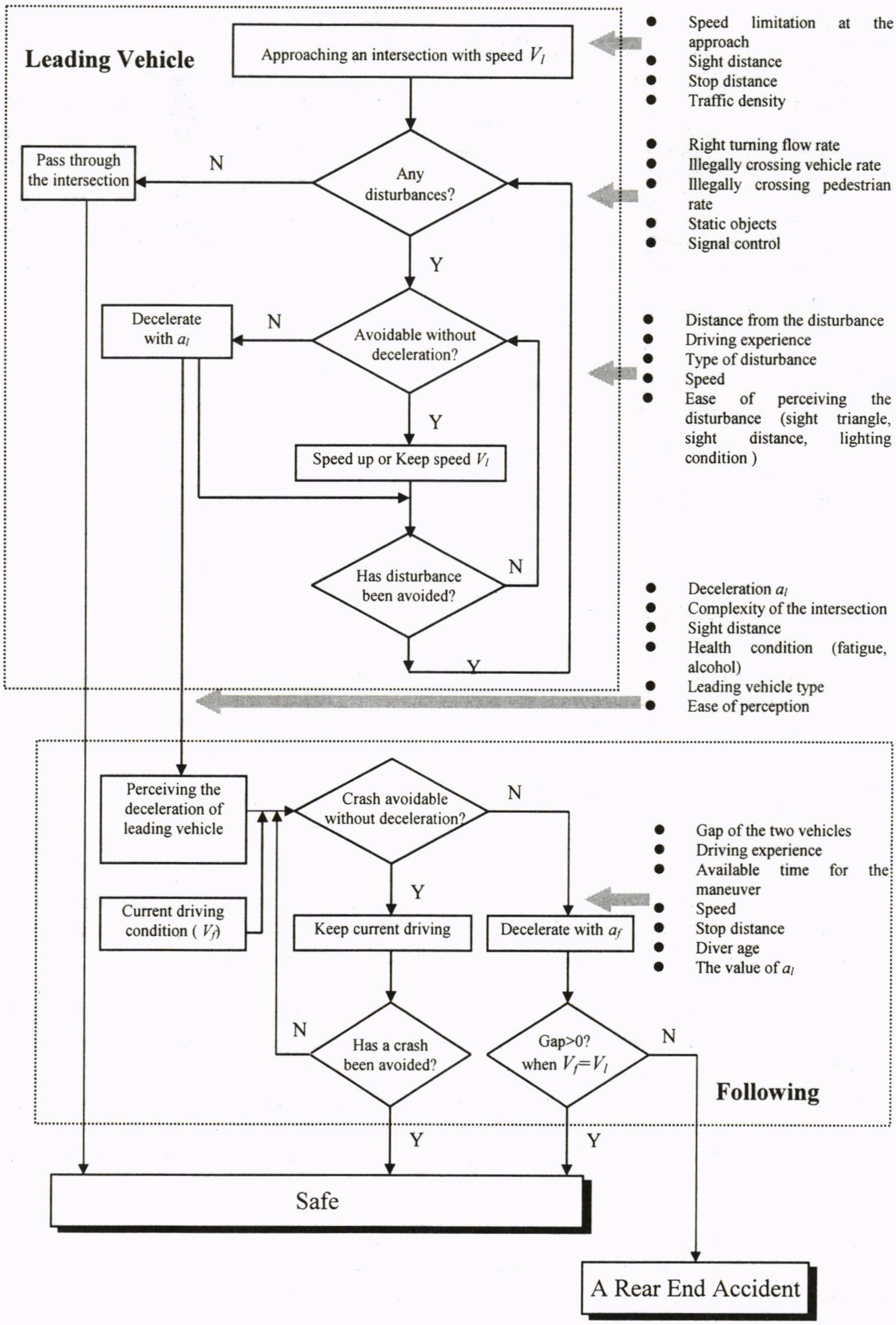

Figure 6: Flow chart of though traffic rear end accidents

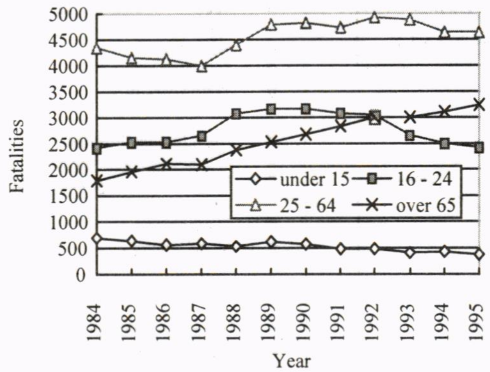

Figure 7: Transition of traffic fatalities in Japan
Data source: ITARDA (1996)

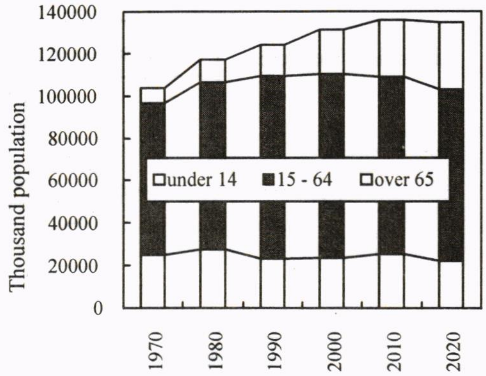

Figure 8: Population trend in Japan
Data source: S.B. (1985)

3.1 Declination of Mental and Physical Abilities with Aging

It is well known that human's abilities of both mental and physical change with age. Ishibashi (1983) analyzed the change of human abilities with age and pointed out that the declines of mental and athletic capacities are remarkable for elderly people as shown in Figure 9. In detail, the following four capacity decreases are considered affecting accident risk directly.

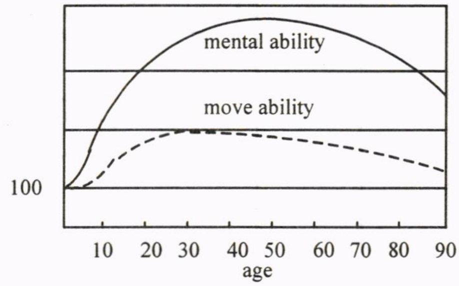

Figure 9: Mental and physical abilities as a function of age
Source: Ishibashi (1983)

(1) Visual ability. As shown in Figure 10 (Seo *et al*, 1996), sight is decreasing hastily with the increasing of age after 45. The capacity of discerning moving objects, which is very important for driving, decreases faster than that of static objects, and only about 50% of the capacity is left when a person enters his/her elderly age. Besides, human's vision field also decreases with aging. Furthermore, an elderly driver generally takes a longer time to adapt the change of luminance.

(2) Auditory ability. The negative effects of hearing ability decline on traffic safety have been proved by many studies. Audible volume range of each pitch for different aged people are shown in Figure 11 (CBS, 1996). We can see that elderly people are especially poor in hearing voice of high pitch. Unfortunately, the sound of engine and horn is just located in the range significantly affected by age. This makes the elderly driver difficult to perceive the driving speed by engine voice and the approaching of other vehicles. In an experiment (CBS, 1996), a tested young driver could detect the coming vehicle 25 meters away by engine voice while an elderly driver only 12 meters away.

(3) Information processing ability. Miura (1992) studied the effect of driving environment on drivers' behavior and found that with the increasing complexity of driving environment, response eccentricity (size of functional field of view) decreases and reaction time increases. This means that the expansion of information for processing will significantly enlarge drivers' perception reaction time. The additional time, however, is not uniformly distributed among drivers of different age groups. Bell *et al* (1992) studied the reaction time under selective conditions and found that the additional time of elderly

people accelerated with the increase of experiment complexity.

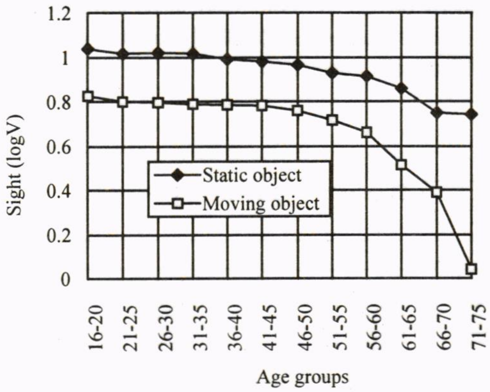

Figure 10: Sight ability of different aged persons
Source: Seo *et al* (1996)

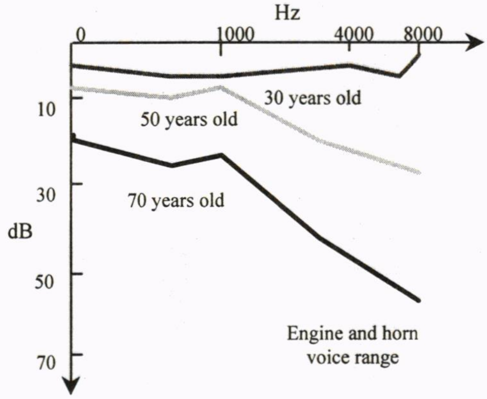

Figure 11: The declination of auditory ability with aging
Source: CBS (1996)

(4) Reaction ability. Needless to say, the ability of reaction is very important in driving and has been studied since several decades ago. Wright *et al*(1978), studied the relationship between brake reaction time and age by experiment, and the result is shown in Figure 12. Tokuda (1994) also found that elderly drivers have higher error rate in reaction.

All the above changes of mental and physical capacities will inevitably affect the drivers' accident risks, especially at intersections.

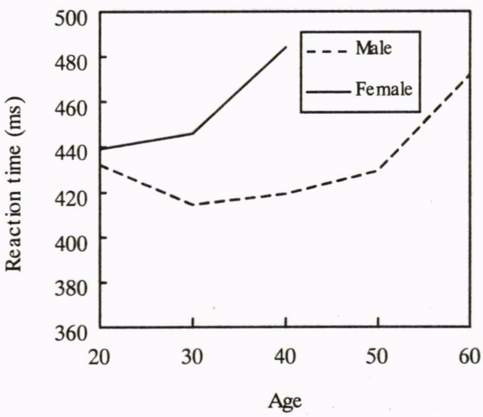

Figure 12: Brake reaction time as a function of age
Source: Wright *et al* (1978)

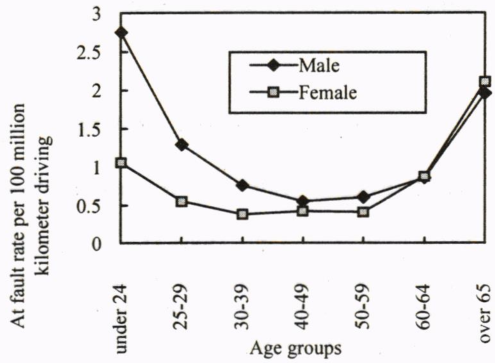

Figure 13: At fault driver rate in fatal accidents
Source: Fujita (1996)

3.2 The Effect of Age on Intersection Accident Risks

Driving is an integrated procedure of perceiving environment condition, deciding corresponding maneuver, and implementing it. As mentioned before, drivers of different age groups have different abilities of sight, hearing, information process and reaction. Thus accident risk of different age groups will be different. In case of the elderly drivers, despite the fact that elderly drivers normally have abundant driving experiences, the mental and physical ability declines due to aging still make them very poor in perceiving information and implementing driving maneuvers. In other words, they are likely to perceive dangers later, react slower and less exact. Therefore elderly drivers are more likely to be involved in accidents, especially under complex traffic conditions, such as intersections (CBS, 1996). The at fault driver rates by age groups of fatal accidents are shown in Figure 13 (Fujita, 1996).

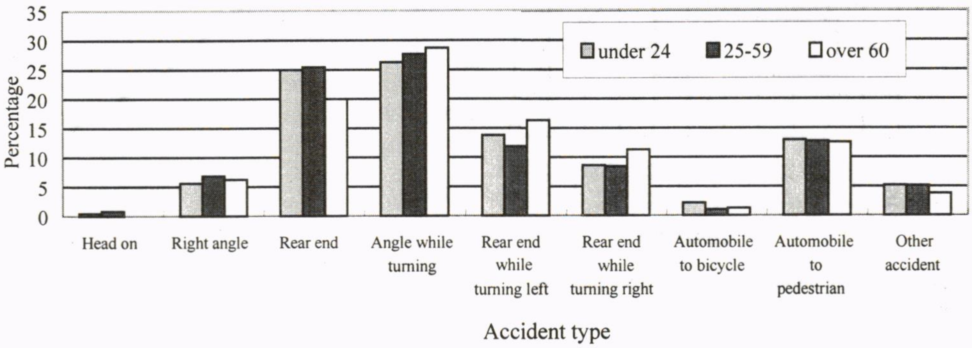

Figure 14: Accident involvement distribution by age of driver at fault for specific accident types in Tokyo

Figure 14 is the age distribution of at fault drivers by accident types based on the data of the 112 four-legged signalized intersections in Tokyo. It shows that drivers of over 60 years old experienced the highest percentage among all age groups for accidents that involved turning movements, such as right angle while turning and rear end while turning. Similar result was also found in the US (Stamatiadis *et al*, 1991). Moreover, due to the declined physical condition, elderly people's tolerance in crashes are normally poor. Once they are involved into any accidents, the severity is normally higher than road users of other age groups. Fujita (1996) found that death rate of elderly drivers is 2 or 3 times higher than 25 to 64 years old drivers.

4. THE EFFECTS OF SOME ROAD ENVIRONMENT RELATED FACTORS

4.1 The Effect of Traffic Flow Rate and Intersection Shape

Many studies (e.g. Affum, 1995, Hauer *et al* 1988) predicted the occurrence of accidents according to the related traffic flows. As traffic flow rate is not the only factor affecting accidents, it will be quite important to exclude the interference of other factors as much as possible when studying the effect of flow rate. In this study, by comparing the temporally changing traffic volume and its corresponding accident amount, we can ultimately exclude the effects of other factors. The statistical analysis of traffic flow rate and accident amount by time in Denenchofu area in Tokyo found that traffic accident number is proportional to $x^{1.4}$, where x is the total entering traffic flow rate. As the correlation coefficient is as high as 0.90, we can say that total entering traffic flow rate has significant effect on total accidents. You can easily get an intuition by examining Figure 15, in which the change of traffic volume with time coincides with the change of accident amount very well.

The correlation tests of total accidents in 1995 and the yearly averaged entering traffic flow rate for all the selected intersections in this study is shown in Figure 16. For all the 112 intersections, total accident amount is found proportional to the total entering traffic flow raised to the power of 1.25 when correlation coefficient is equal to 0.50. For the purpose of testing the effect of intersection shape, samples are divided into two groups, i.e. regular and irregular, according to the crossing angle of the legs. If the crossing angle of an intersection is between 75° to 105°, it is regarded as a regular one, otherwise an irregular intersection. There are 81 regular intersections and 31 irregular intersections within the selected samples. There is a significant difference between accident risk of regular and irregular intersection samples as the value of *t* statistics equal to 2.48. Formulae

$$y_r = 0.0932x^{1.25} \quad (1)$$

and

$$y_{ir} = 0.1204x^{1.25} \quad (2)$$

are the regressed relationship between traffic flow rate (x) and accidents (y) for regular and irregular intersections respectively. From Figure 16, we can see that accident risk of irregular intersections is about 30% higher than regular intersections.

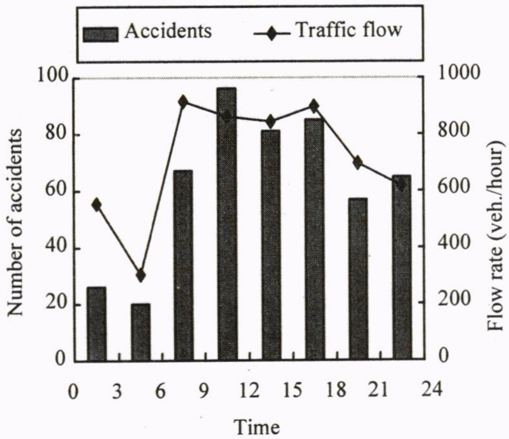

Figure 15: The relationship of accident amount and hourly traffic flow in Denenchofu area

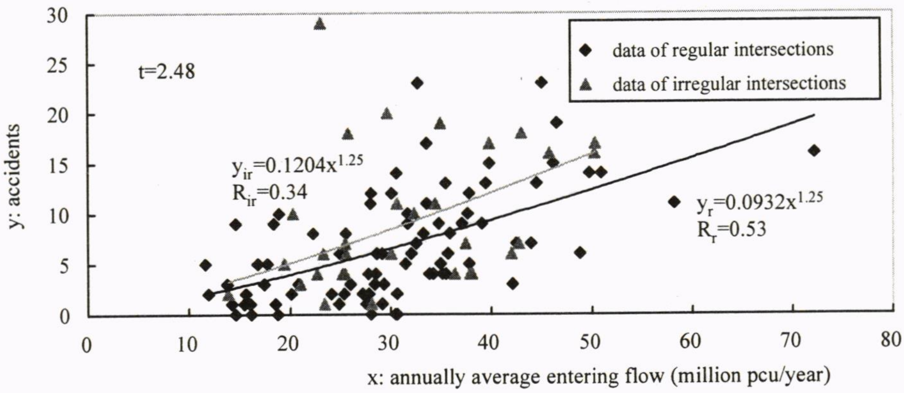

Figure 16: The relationship of accidents and traffic flow rate

4.2 The Effect of Surrounding Land Use

As mentioned before, the occurrence of accidents is closely related to the frequency of disturbances. Surrounding land use of an intersection is definitely a key factor affecting human activities within or near the intersection. In this study, the locations of intersections are divided into 5 patterns according to the land use properties surrounding them. From pattern 1 to pattern 5, the frequency of human activities increases. The statistics for testing the effects of land use pattern on accident frequency, $F(4, 107)=21.4$, shows that the effects are very significant. The definition of each land use types are listed in Table 1.

Table 1: Description of land use type classification

Pattern 1	areas of isolated residential houses and factories;
Pattern 2	residential areas of concentrated multistory residential houses;
Pattern 3	public residential areas and general office districts;
Pattern 4	concentrated office areas or near a railway station;
Pattern 5	the most prosperous commercial areas or the area with two or more railway stations concentrated.

The summary statistics of the intersections located at each land use type is given in Table 2. Although we can not completely exclude the interference of other factors in the analysis, the result listed can somewhat reflect the increasing trend of accident risk from land use pattern 1 to pattern 5. Moreover, the observed accidents and the normalized accidents, which are calculated by formulae (1) and (2) for regular and irregular intersections respectively, are compared in Figure 17. The normalized values are higher than the observed in land use pattern 1 and 2, almost equal in pattern 3 and lower in pattern 4 and 5. This can be easily explained by the frequency of disturbances. As disturbance frequency increases with human activities from land use pattern 1 to 5, accident risk also increases simultaneously.

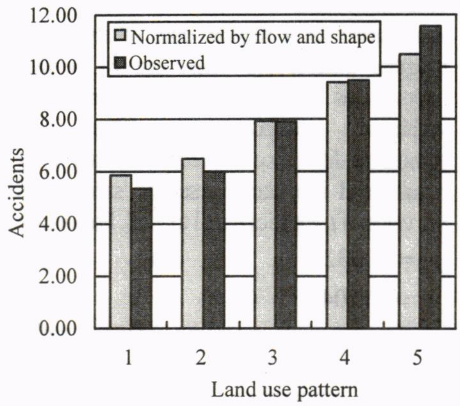

Figure 17: The effect of land use pattern

Table 2: Accident Summary Statistics of Each Land Use Pattern

Parameters	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5
No. of intersections	23	28	29	23	9
Total accidents	123	168	229	218	104
Mean	5.35	6.00	7.90	9.48	11.56
Median	3	4	6	9	7
Standard deviation	5.32	5.40	6.15	4.66	8.49
Minimum	0	0	1	1	4
Maximum	20	19	23	16	29
Accident rate (accidents per million entering vehicles)	0.19	0.20	0.25	0.26	0.27

4.3 The Effect of Intersection Size

The geometric size of a four-legged intersection is generally proportional to the lane numbers of the crossing approaches. By referencing Figure 4, it is not difficult to imagine that one additional lane will increase several conflict points rather than one. Of course, by multiple phase signal control, we can remarkably reduce the conflicts. The problem is that to increase signal control phases might reduce the capacity of the intersection. Also, the increase of signal control cycle, will probably increase the rate of signal disregard as well. So we need to balance between safety and capacity. Unfortunately, no theory has been achieved to guide the practice. The design of signal control gives much more prior to the capacity than safety. Thus our empirical judgment is that the larger an intersection is, the more dangerous it might be.

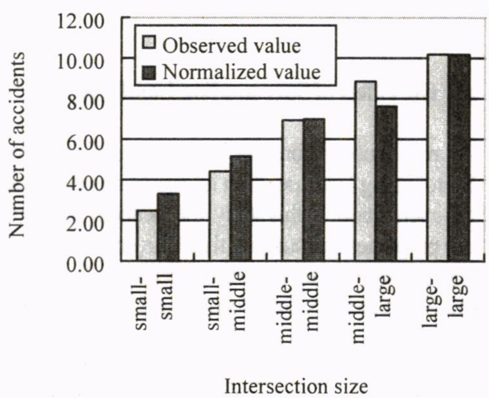

Figure 18: The effect of intersection size on accident occurrence

The statistics summarized in Table 3 are based on the data of 81 regular shaped intersections. In general, both the accident number per intersection and accident rate per million entering vehicles increase with intersection size. This supports our intuition that larger intersection should have more accidents. However, it is worth noticing that large-large intersection accident rate is lower than that of middle-large intersections. Disturbance frequency may still be the reason for that exception. Imata (1990) found that signal disregard rate of pedestrian is reverse proportional to traffic volume and the crossing road width. This indicates that, the disturbance frequency might not be absolutely higher in large sized intersections due to the behaviors such as signal disregards. Besides, traffic regulations at large intersections, such as right turning forbidden, also contribute to the low frequency of disturbance. Therefore we need to consider the absolute effect of various kinds of disturbances when comparing accident risk among different sized intersections. Again we compared accidents between observed value and normalized value by formula (1) for each sized intersection in Figure 18. It is showing that while small-small and small-middle intersections are overestimated, middle-large and large-large intersections are underestimated by formula (1).

Table 3: Traffic Accident Rates of Different Sized Intersections

Intersection size[1]	Number of intersection	Total accidents	Accidents per intersection	Average entering flow (million vehicles/year)	Accident rate (per million vehicles)
small-small[2]	15	37	2.47	17.3131	0.1425
small-middle	16	71	4.44	24.6200	0.1802
middle-middle	13	90	6.92	31.6182	0.2190
middle-large	19	168	8.84	33.9098	0.2608
large-large	18	183	10.17	42.4231	0.2396

Note:
1. here small means the width of one intersection side is less than 13 meters; middle means between 13 and 21 meters and large means larger than 21.
2. 'small-small' shows that both of the two sides of an intersection is small, while 'small-large' indicates that one side is large and the other side is small.

5. CONCLUSIONS AND SUMMARIES

In this study, we have analyzed the mechanism of intersection accident occurrence and concluded that hazardous driving and the existing of disturbances are two indispensable premises for most of the accidents. When making a safety improvement plan, it might be better to consider the following two sides: the first is how to reduce hazardous driving by both subjective and objective means; and the second is how to reduce the frequency of disturbances to an acceptable level by traffic control and management.

Human related factors are the most important in traffic accidents. Due to the complex situation in intersection area, elderly drivers have exposed a higher accident rate, especially for some complicated maneuvers. By comparing the abilities of sight, hearing, information process and reaction, we have found that the variation of the abilities with aging is quite obvious. This might be able to explain why drivers of different age groups have different accident risks.

Traffic volume, intersection shape, size and surrounding land use are three important road environment related factors affecting intersection accidents. Based on the data of 112 randomly selected intersections in Tokyo, a statistical analysis is implemented in this study. The effects of traffic volume, intersection shape, size and surrounding land use on accident occurrence are basically obtained. Traffic accident amount of the 112 selected intersections have been found proportional to the total entering flow rate raised to the power of 1.25. Intersections with irregular shape are 30% more dangerous than those with regular shape. The fact that intersection accident rate increases from land use pattern 1 to pattern 5, indicates that the frequency of human activity is also a significant causal factor. The effect of intersection size on accident risk is found related to the widths of both the two crossing roads. As some disturbances, e.g. conflict points of vehicles, increase with lane number while some other disturbances, e.g. illegally crossing pedestrians, decrease with it, the exposed effect of intersection size depends on the absolute value of disturbance frequency. In this study, accident risk of the sample intersections roughly increases with their size.

For the purpose of making a better safety improvement plan, it is necessary to study the effects of accident causal factors in a more detailed manner. The basis for a successful further study will be the qualified data. As the existing statistics are too aggregate for the study, it might be very significant if some new statistical manner for this specific aim is considered and implemented immediately.

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The 2nd Conferencs of the Eastern Asia Society for Transportation Studies
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