EXAMINING THE FACTORS RESPONSIBLE FOR THE REAR-END COLLISION AT THE MERGING SECTION OF THE GRADE SEPARATED CROSSING

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Abstract: The traffic accident is still a serious problem in Japan. In this study, the rear-end collision at the merging section is focused as a typical case of traffic accident occurrence at black spots with grade separated crossing. At this section, rear-end collision between the first and second vehicles in the queue happens frequently because second driver can also see the main stream. It could be thought that the difficulty of merging into the main stream makes the driver to mismatch the decision of merge. To fully understand the mechanism of this kind of traffic accident, this paper employs the Variation Tree Method. This method allows for identifying appropriate countermeasures that make a specific intersection safe from the view of road and roadside condition. From the video observation, factors for the improvement in road design were clarified

Key Words: traffic accident, grade separated crossing, rear-end collision

1. INTRODUCTION

The trend of fatal accident is declining now in Japan. However the number of traffic accident is increasing year by year. There were almost 930,000 traffic accidents that occurred in 2000, and this figure surpasses the highest record in the past. According to the 1997 estimate of Japanese Ministry of Management and Coordination Agency the annual cost of traffic accidents (human loss for death and injury, property loss) are almost 4 trillion-yen. Therefore it is easy to understand that the problem of traffic accident is still serious.

To solve these problems, Japanese National Police Agency and Ministry of Construction selected the 3,196 black spots from the national arterial roads in 1997. And many organizations related with traffic safety installed various countermeasures such as making the additional lane for right-turn vehicles, light up the intersection, minimize the size of intersection and so on, into these black spots. However, these countermeasures were installed without analyzing the cause of traffic accident and evaluating the effect of these. Therefore, the effectiveness of these countermeasures is not so high, and it is not good procedure to install these countermeasures into the other intersection. It is important to

analyze the cause of traffic accident at the black spots and make the standard of road design and countermeasures in each intersection.

Furthermore, only 20,000 traffic accidents occurred at these black spots. This means that it is important to analyze the cause of traffic accident and to take the countermeasures that come from the analysis at the black spots. Because total number of traffic accidents occurred at the black spots (20,000) is too small compared to the total number of traffic accident (930,000).

The aim of this study is to analyze the cause of traffic accidents at the black spots.

2. STUDY AREA

The GIS (Geographic Information System) for traffic accident analysis, that was developed for the traffic accident analysis in the Aoba Ward, Yokohama City in 1991 and have the 12 years traffic accident data, was utilized to select the study area. In this study, accident type was used to select the black spot, because it could be thought that it is easy to understand the reason why these places are black spot from the viewpoint of road design or traffic condition. Accident type would show the circumstance of traffic accident occurrence. It is easy to result the factor associated with the road design compared to the other categories such as day, weather and so on. For example, it can be considered that extent of the sight might be the factor if this place is the black spot for crossing collision. As there are various kinds of traffic accidents at black spots such as rear-end collision, head-on collision, and so on, black spots can be classified by accident types. In this study rear-end collision at the merging section of the grade separate crossing was selected because at this place share of rear-end collision is high and also there are many traffic accidents (10 accidents per one year).

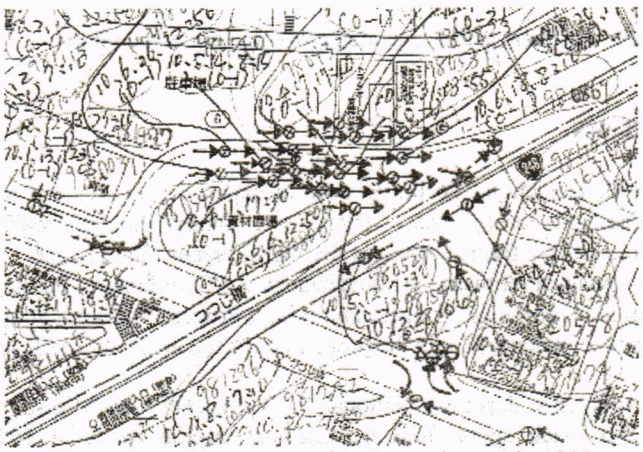

Figure-1 Accident occurred at the study area in 1998

Figure-1 shows the traffic accident pattern that was occurred in 1998 at this study area. It is easy to understand that there are many rear-end collision at the branch lane and few traffic accidents occurred at the main lane. It could be thought that there exists some problem for the traffic circumstance. Site investigation was done to understand the reasons of these

characteristics. Many factors related with traffic accident were founded from the site investigation at this area.

Figure-2 Overview of study area

Lack of the lane for acceleration

To construct a merging section, it is required to make the lane for the acceleration of the vehicle that merge into the main stream to catch up the speed of the vehicle that runs in the main stream. However, there is no lane for acceleration at this area because this road was constructed as a renewal by-pass route of the existing lane. Acquiring land for this lane was very difficult, primarily due to holding of the land by multiple owners. Due to this, the length of acceleration lane was shorten than the desired one. Therefore driver who wants to merge into the main stream should take a longer headway to merge compared to the case with the acceleration lane because it takes longer time to speed up. This longer headway will generate the variety of the decision to merge creating a highly accident-prone situation.

Location of stop-line

When a driver who wants to merge into the main stream comes to the merging section, driver firstly stop at the stop-line. In this place, the location of stop-line is a little far from the main stream, and this makes driver to go forward until the place where merging vehicle will not disturb the vehicle running in the main stream. This is not good way of merging into the main stream because driver sometime stops two times and this will make another driver behind the queue misunderstood that forward vehicle had started to merge at the first start. By the way, it could be thought that police is eager to put the stop-line apart from the main stream because of the lack of acceleration lane. Driver tend to keep a longer view toward the main stream because of the difficulty of merging while it is possible for the driver in the branch lane to check the main stream from the stop-line.

Combined area for merging and diverging

This section has merging and diverging area, nevertheless it is usual to separate the merging and the diverging sections when grade separated crossing is decided to be constructed. Area separated with the merging and the diverging section is safer compared to the combined one. The reason of this is that the driver who want to merge into the main stream could concentrate for merging, and the driver runs in the main stream feel comfortable not to happen the merge and diverge at the same time. As this merging and diverging lane is made together, it is able to get the long view and this brings the driver in the second vehicle in the queue could check

the main stream. This makes other reason for the rear-end collision that comes from the difference of the decision for entering to the main stream.

Gas station near by this section

There is a gas station near by this section, and many vehicles enter the gas station. As the way of showing the winker is different in each vehicle running in the main stream, it is hard for the driver who stops at the branch lane to distinguish the winker (winker for diverging or going out to the gas station). This uncertainty influences toward the second driver in the queue. Some first driver in the queue will start to merge if the first driver checks the winker of the vehicle running in the main stream and misunderstand this sign as to show the decision for diverging. And also, some second driver in the queue will start when he realizes that the first vehicle starts to merge. In this case, it will be more danger if the driver running in the main stream shows the winker for entering the gas station.

Angle between the main lane and branch lane

To compare with the similar section, an interesting characteristic is found that the vehicle sometimes merges into the main stream without stopping in the branch lane. Almost all vehicles stop at the branch lane if this branch lane crosses to the main lane vertically. It could be thought that merging without stopping in the branch lane might be hard for the vehicle coming from the branch lane because driver should change the direction in 90 degree and this makes driver difficult to merge without stopping at the branch lane. Same result was obtained by comparing with the section where the angle of both lanes is smaller than this section. In this section, it is hard for the driver who wants to merge to see the main stream because of the angle, and this makes the driver to stop at the branch lane. From these characteristics of the traffic flow at the merging section, there might be some factors related to the angle of both lanes.

3. MECHANISM OF REAR-END COLLISION AT THIS SECTION

Many factors related to the rear-end collision at this section were considered from the site investigation. In this chapter, mechanism of the paths of rear-end collision at the merging section of grade separated crossing was made utilizing traffic accident data. In this traffic accident data, it is able to understand the date and weather of traffic occurrence, age, sex and the speed that driver feel danger of accident related person, accident type, crash point and so on. Among these indices, speed, crash point, and accident type were used to understand the patterns of traffic accident occurrence in this study. In the GIS for traffic accident analysis, there are traffic accident data of 12 years from 1988 to 1999, and totally 109 traffic accidents had occurred at this section. Figure-3 shows the share of the number of traffic accidents in each accident type. It is easy to understand that the share of rear-end collision is higher compared to the accident occurred in the Aoba Ward (whole area). Therefore, it could be thought that there is some reason causing the rear-end collision there from the viewpoint of road design.

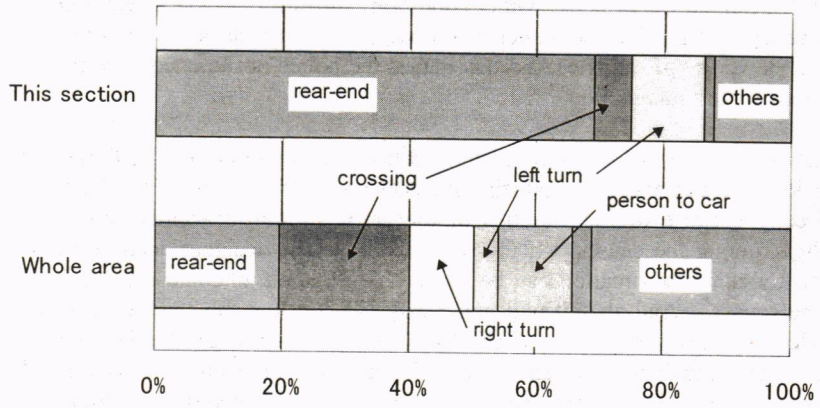

Figure-3 Comparison of traffic accident by accident type

Utilizing the data in the accident report such as driver's action at that time and the speed that driver realize the danger, it is possible to summarize the accident pattern, that is more detail than accident type, into 10 patterns (Table-1).

Table-1 Classification of traffic accident at this section

accident	location		Pattern	number of accidents
rear-end collision	merging section		Rear-end collision to the vehicle in increasing the speed	35
			Rear-end collision to the vehicle in decreasing the speed	27
	main lane	tail of traffic jam	Rear-end collision to the vehicle that locates tail of the traffic jam	11
		diverging section	Rear-end collision to the vehicle that decrease their speed by the diverging vehicle	
			Rear-end collision to the vehicle toward the diverging vehicle	
		merging section	Rear-end collision to the vehicle that decrease their speed by the merging vehicle	
			Rear-end collision to the vehicle toward the merging vehicle	6
left-turn collision	main lane	diverging section	Left-turn collision between the motorcycle	7
lane change	main lane		Accident in the lane change	4
others				19

From this table it can be seen that the share of the number of rear-end collision is high and almost rear-end collision occurred at the branch lane. This result might be a something interesting. The driver of the vehicle who drives in the main stream might have higher stress when he runs through this section, because the traffic condition is not stable from the existence of the diverging and merging vehicle. However there are few accidents at the main

lane. This means, it might be the better condition. If traffic accident occurred at the main flow, the severity of it might be higher compared to the accident occurred at the branch lane from some viewpoint of safety. And this makes the police not to encourage the installment of countermeasure at this section.

To understand the cause of traffic accident in detail, it is important to clarify the sequence of traffic accident occurrence. In analyzing the cause of traffic accident, it is hard to show the factor directly because of the varieties of the cause of traffic accident and the complex relationships among the causes. If the sequence of traffic accident occurrence is clarified, the apparently complex situation can be reduced to a simple one and making it possible to identify the causes. And also, it will make easier to consider the countermeasures for each cause. However, to make the sequence of it, there is a need to get the detailed information about the traffic accident occurrence. In this case, the procedure of imaging the traffic accident occurrence using the limited information was held, because it is impossible to get this information

Table-2 Sequences of the traffic accident occurrence

No	sequence of the traffic accident occurrence
1-1	Rear-end collision that the driver in the second vehicle misunderstand the action of the forward vehicle
1-2	Rear-end collision while the second vehicle moves forward
2-1	Rear-end collision that the driver in the second vehicle would not stop
2-2	Rear-end collision of creep phenomenon
2-3	Rear-end collision that the driver in the second vehicle could not find the forward vehicle
3-1	Rear-end collision to the vehicle that locates tail of the traffic jam
3-2	Rear-end collision to the vehicle that decrease their speed by the diverging vehicle
3-3	Rear-end collision to the vehicle toward the diverging vehicle
3-4	Rear-end collision to the vehicle that decrease their speed by the merging vehicle
3-5	Rear-end collision to the vehicle toward the merging vehicle
4-1	Left-turn collision that the vehicle run in the main lane involves the motorcycle
4-2	Left-turn collision that the motorcycle rushed to the vehicle turning to the left

Table-2 shows the sequences of traffic accident occurrence at this section. The sequence of traffic accident occurrence was divided into 12 cases. This table illustrates the case of traffic accident occurrence in each accident type. It is expected that this procedure significantly improves the assessment of the cause of traffic accident. Furthermore, to understand the cause related to the road design in detail, Variation Tree was made by making the paths to show the relationship between the factors. Variation Tree could clarify the sequence of traffic accident occurrence from the expression of path diagram. This method was used mainly in the system management engineering to clarify the system's fault such as the accident at the nuclear plant. This method would have advantage to clarify the sequence in the man-machine system because there are only few persons related to the accident and these persons have same decision system in controlling the system. Therefore there exists some difficulty in order to use this method to the situation of traffic accident. It is important to consider the relationship between the persons related to the traffic accident. Thus, there will

be many Variation Tree to show the one sequence of the traffic accident. Police would know the sequence of traffic accident in detail because they had investigated the sequence of traffic accident for the judgement at the traffic court. However it is unable to get this information because this is not recorded in the accident report as the numerical data. Therefore it is required to image the sequence of traffic accident occurrence utilizing the limited information from the sheet of the accident report. Figure-4 shows the one pattern of rear-end collision that occurred at the branch lane.

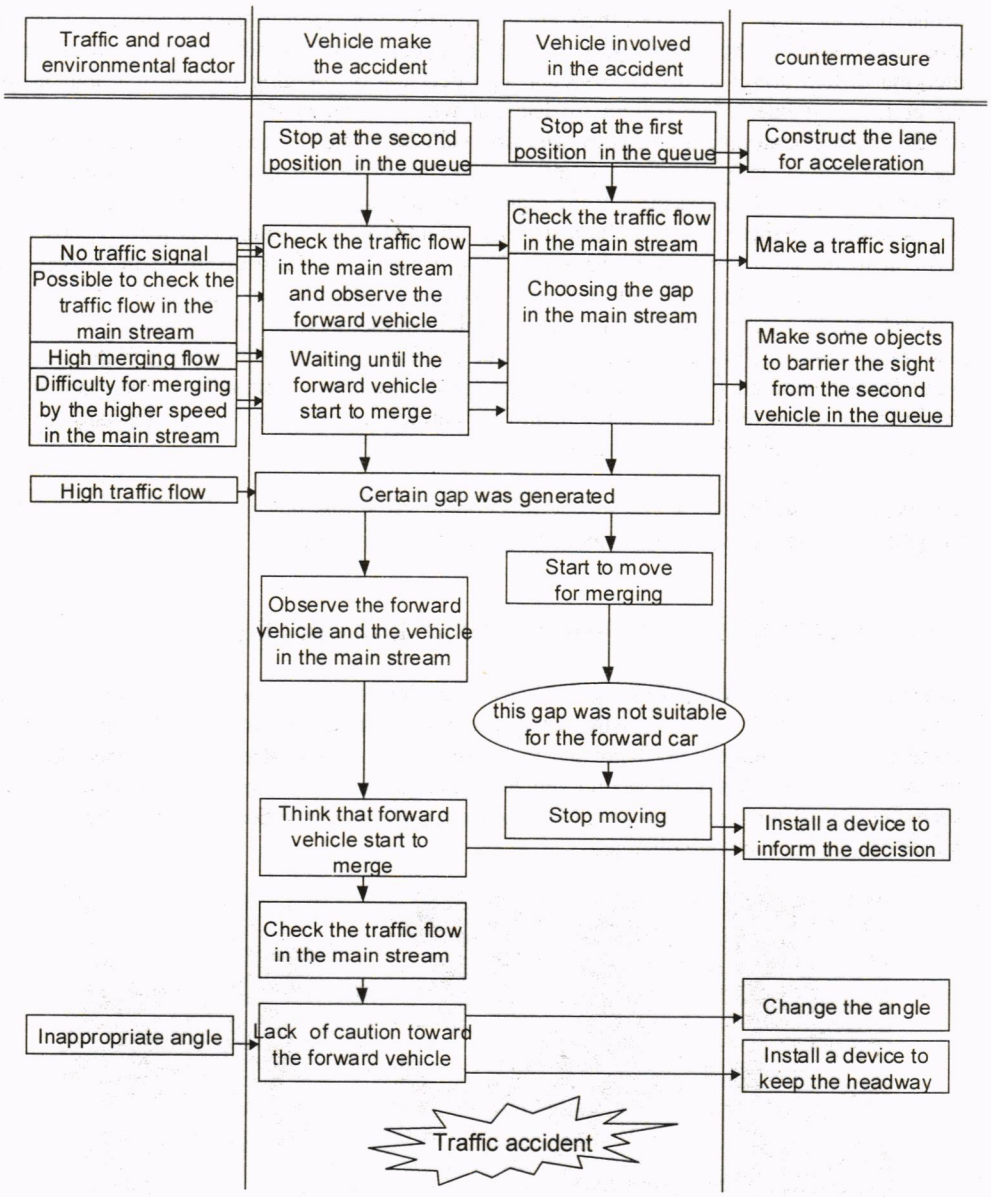

Figure-4 Variation Tree of rear-end collision at this section

In this figure each component such as vehicles and countermeasures were displayed by the axis of the time. Two columns were used to show the action of each vehicle related to the traffic accident. Traffic and environmental factor was written at the left side and countermeasures for the action of vehicles were written at the right side. By summarizing the pattern of traffic accident, it is easier to understand the cause of traffic accident in detail.

This figure, it depicts that there are mainly three factors responsible for the rear-end collision. First is a traffic condition. If the headway in the main stream is stable and long, it will be easier for the driver in the branch lane to merge into the main stream because of the clear decision of merging. However, there are many traffic flow both in the main lane and branch lane in this section, there is a high possibility to occur a subtle headway that the decision of merging differs driver to driver. Second is a decision of merging for the first and second driver in the queue. The pattern of decision will be divided into 4 patterns. It is most danger when decision of the driver in the first vehicle is "stop" and decision of the driver in the second vehicle is "go" in these 4 patterns. At this place, the driver in the branch lane will catch a various headway because of the high traffic flow in the main stream. And also, there is a possibility to merge into the main stream without having enough headway, because it is difficult to merge into the main stream. These varieties of the decision of the driver will increase the hazard for rear-end collision. Third is a decrease of the caution toward the forward vehicle of the driver in the second vehicle in the queue. At this place the angle of both main and branch lane is small. Thus, the angle of the sight of the driver in the queue is quite large compared to the intersection that both road cross vertically. Therefore if the driver in the queue tend to check the main flow carefully, caution toward the forward car will decrease and this brings higher danger.

To evaluate these factors, video survey was conducted at this place. And factors related to the rear-end collision will be clarified through the traffic analysis.

4. EVALUATE THE FACTOR FOR THE REAR-END COLLISION

Video survey was conducted on November 6th in 2000 over this area. Two video cameras were used to get the characteristics of traffic flow and the behavior of the driver. One camera is set to catch the headway and travel speed in the main stream. And the other one was set to catch the action of second vehicle in the queue. From this video observation, the adequate gap of front car, the timing of the winker, position of the decision, and other relevant pieces of information were obtained.

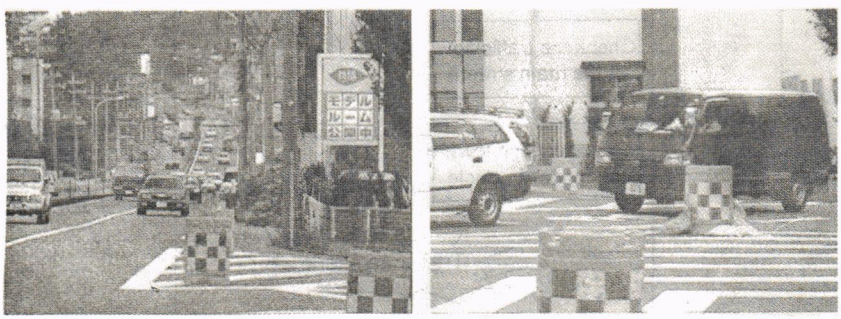

Figure-5 View from the video camera

Figure-6 shows the comparison of the driver's gender between the traffic accident and traffic flow. From this figure the percentage of combination, that the gender of the driver in the first vehicle is female and the driver in the second vehicle is male, is higher compared to the percentage of the opposite case, that the gender of the driver in the first vehicle is male and the driver in the second vehicle is female, while the percentage of the combination of male driver in the both first and second vehicle is almost same. It can be fairly inferred that variance of the headway decided by the female is larger than that decided by the male, and the headway decided by the female for merging is also tend to long compared to the headway decided by the male. These characteristics show the difference of decision for merging, creating a dangerous situation for the rear-end collision, because the driver of the second vehicle in the queue could not understand the gender of the driver in the forward vehicle. This figure shows the variance of decision for merge influences toward the rear-end collision. It could also be thought that similar situation will be existed for the patterns that elderly driver or novice driver stops at the front in the queue. However there is a sign to show the driver for both elderly person and novice driver, and they put the seal to show their status (elderly or novice). This will increase the safe because the driver in the second vehicle in the queue could understand the driver status of the forward vehicle.

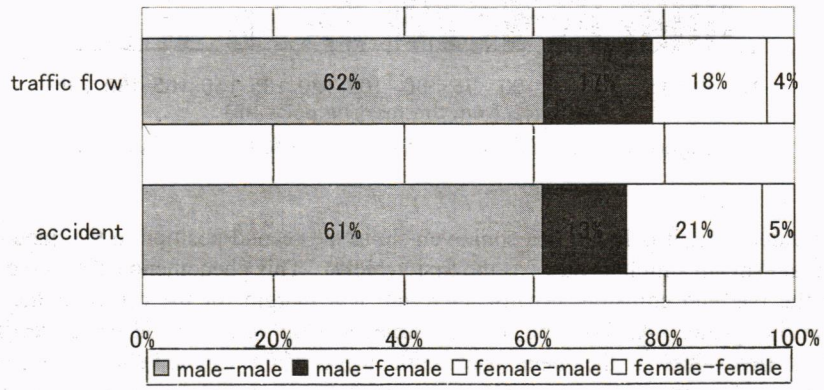

Figure-6 Comparison of the driver's gender between the traffic accident and traffic flow

To understand the influence of the gas station located near by this section, the position that the driver start to show the winker was measured from the video data. Figure-7 shows the position that the driver start to show the winker in each for diverging and going out to the gas station, and also the position that the vehicle in the queue start to merge when the vehicle in the main stream starts to diverge. From this figure, it is found that there are some overlap area of the winker appearance for both diverging and going out to the gas station, and there is some vehicle merge into the main stream around this overlapped area. This shows the danger for merging. If the driver in the first vehicle in the queue that start to merge feel impossible at that time for merging and the driver in the second vehicle feel that the front vehicle will merge into the main stream, the ratio of hazard will increase, because the situation that the driver in the first vehicle will stop for merging will tend to happen.

From this figure, it is possible to calculate the ratio of overlapped area. And multiplying the ratio of merging for the driver in the queue, it is able to show the hazard for the rear-end collision caused by the gas station beside the merging area.

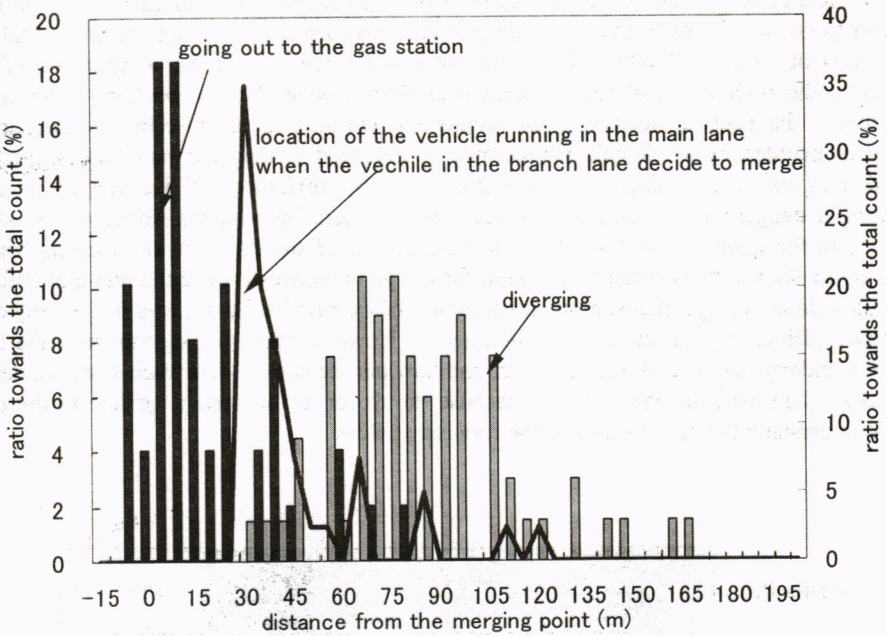

Figure-7 Position that the driver start to show the winker

From the video data, it is found that some vehicle in the second position in the queue merge into the main stream simultaneously as the first vehicle. This phenomenon shows the danger case for the rear-end collision, because there are few margin for the driver of the second vehicle in the queue. At this time, it takes times to stop when second driver realizes the break of the first vehicle in the queue, because the driver of the second vehicle is accelerating for merging. Therefore it is important to understand the current characteristic of merging for both first and second vehicle in the queue. Figure-8 shows the relationship between the gap, that is calculated by the headway and the speed of each vehicle in the main stream in time, and the percentage of merge into the main stream in each first and second vehicle in the queue. From this figure, it is found that there is a person not to merge, nevertheless there is a long gap, and the line, that shows the merge of the second vehicle, shifts to the right because of the needs for the longer gap in merging. This line will be shifted to the right and left by the characteristic of the driver such as female driver, novice driver or elderly driver. By comparing with these lines, hazard for the merging simultaneously will be clarified. And also, it is possible to evaluate the hazard for all merging section by comparing among the other merging section. Furthermore, the degree of hazard can be computed by multiplying the percentage of "stop" for the first vehicle and the percentage of "go" for the second vehicle.

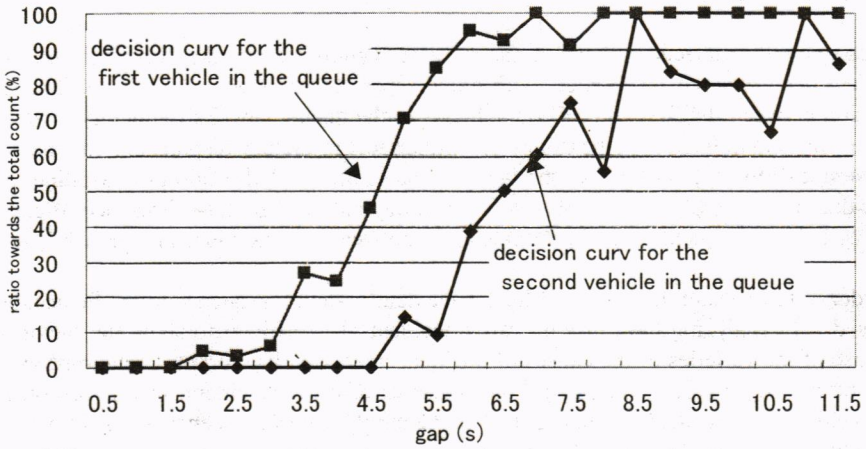

Figure-8 Decision curve for the first and second vehicle in the queue

There was an interesting case that one light truck parked in the zebra zone at this time in recording the video. This vehicle would decrease the sight for the vehicle in the branch lane. It could be thought that this would make safer situation that the first vehicle would decide for merging in the position closer to the main lane and that the second vehicle would not start together with the first vehicle because its sight distance gets decreased. Figure-9 shows the position of the decision for the vehicles to merge into the main stream in the case of ordinary situation and under the situation with a the light truck parking in the zebra zone. It is easy to understand that the position corresponding to merging decision shifts toward the main lane and the variance of position was decrease. Therefore it could be thought that this case is safer condition for the rear-end collision. However, this situation decreases the capacity of the merging vehicle, and it is important to take the relationship between these into account.

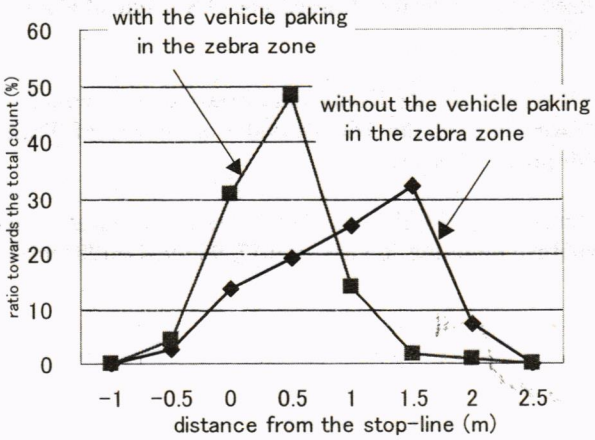

Figure-9 Position of the decision for the vehicle to merge

5. CONCLUSION

In this study, the rear-end collision at the merging section is focused as a typical case of traffic accident occurrence at black spots with grade separated crossing. At this section, rear-end collision between the first and second vehicles in the queue happens frequently. As a result of site investigation, it was possible to summarize the factors responsible for the rear-end collision, as follows; (1) Lack of the lane for acceleration, (2) Location of stop-line far away from the mail lane, (3) Combined area for merging and diverging, (4) Presence of gas station near by this section, and (5) Inappropriate angle between the main lane and branch lane.

In order to understand the causes of traffic accident in detail, sequence of traffic accident was focused. In analyzing the cause of traffic accident, it is difficult to show the factor directly because of the varieties of the causes of traffic accident and the complex relationships among the causes. By carefully tracing out the sequence of traffic accident, factors responsible for the accident can be made visible out of a seemingly complex scenario. And also, it will make easier to consider the viable countermeasures for each cause. These sequences were summarized by the Variation Tree. It is found that Variation Tree makes it easier to consider the cause and countermeasure. From the Variation Tree, it is concluded that the causes are (1) High traffic flow at this section, (2) Non-uniform merging-decision criteria used by the first and second vehicle in the queue, and (3) Lack of caution of the driver on the part of second vehicle in the queue toward the forward vehicle.

To evaluate these factors, video observation was conducted. From the traffic analysis through the video data, it was possible to observe key points, such as (1) difference of decision in merging, (2) location of winker shown by the diverging or going out to the gas station, (3) problem in merging together with first and second vehicle in the queue, (4) increase of safety level by decreasing the sight distance.

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