VR ANALYSIS OF MULTI-VEHICLE ACCIDENTS IN UNDERGROUND URBAN EXPRESSWAY

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Abstract: Underground urban expressways which have great potential to settle many existing transportation-related problems may pose unknown risks regarding traffic safety. Vehicle accident in tunnel can more seriously damage road infrastructure and human life than outside roads because of its closed space especially in deep underground road. Therefore, it is important to consider the safety countermeasure for preventing not only a single-vehicle accident but also multi-vehicle accidents which are more damaging. We conducted a unique driving experiment with virtual reality (VR) where the multiple subjects can drive simultaneously in the same roadway space. With this experiment, we collected the microscopic driving data of multi-vehicle accidents that originated in a single-vehicle accident. The results of data analysis reveal some important factors causing the occurrence of multi-vehicle accidents.

Key Words: Multi-vehicle accident, driving simulator, underground urban expressway

1. INTRODUCTION

Underground urban expressways have great potential to settle many existing transportation-related problems such as traffic congestion in high density areas and the division of neighborhoods due to an elevated roadway. However, they may also pose unknown risks regarding traffic safety. Therefore, it is important to evaluate traffic safety prior to implementation. Our studies on the deterioration of driver’s awareness level caused by the monotonous visual stimulus inside tunnel using motion-based driving simulator MOVIC-T4, showed the deterioration of driver’s awareness level could occur while driving in the underground expressway for around 5-10 minutes (Hirata, T. et al). With these results, this paper proceeds with the analysis of multi-vehicle accidents in underground urban expressways. Vehicle accident in tunnel can more seriously damage road infrastructure and human life than outside roads because of its closed space especially in deep underground road. Therefore, it is important to consider the safety countermeasure for preventing not only a single-vehicle accident but also multi-vehicle accidents which are more damaging.

There are few researches that analyze microscopic behaviors of multi-vehicle accidents.
Many researches targeted the rear-end collisions of two vehicles and the analysis was conducted by using existing statistics (e.g. Hiramatsu, M. et al, (2000), Mohamed, A. and Hassan, A. (2004)). Some researches analyzed the characteristics of multi-vehicles accidents, but the analyses were still based on the existing statistics (Inoue, H. et al. (2001), John, N. I. et al (1999)) or observation data such as video recorded data (Gary, A. D. and Tait, S. (2006)). Raymond, J. K. et al (2005) conducted a field driving experiment to obtain a microscopic driving behavior such as response to an incident alert but it did not deal with causes of multi-vehicle accidents.

With these research backgrounds, the main objective of this research is to collect the detailed driving behaviors during multi-vehicles accidents by using virtual reality (VR) system and to conduct a fundamental analysis of the multi-vehicles accident in underground urban expressway. We conducted a unique driving experiment with virtual reality (VR) where the multiple subjects can drive simultaneously in the same roadway space. With this experiment, we collected the microscopic driving data of multi-vehicle accidents originated in a single-vehicle accident. By using this driving data, the analysis of the factors which affect the occurrence of multi-vehicle accidents is conducted.

2. AN OVERVIEW OF THE DRIVING SIMULATION SYSTEM: MOVIC-T4

Figure 1 shows the appearance of MOVIC-T4. Head Mounted Display (HMD) is used for visual system. Coupled with the head tracking sensor, the effective field-of-view can reach 360 degrees. The acceleration cueing can be duplicated by a two-degree-of-freedom motion-base. In this simulation system, around 60 surrounding vehicles can be generated. These vehicles are set to run automatically, with initial attributes such as starting position, desired running speed, desired distance headway, criterion of judgment in changing lanes, and vehicle type. Using these attributes, an algorithm for vehicles to change lanes was developed. Recorded data of the subject’s control vehicle included the driving path, speed, acceleration and braking, steering, and distance headway to the vehicle ahead. The driving path and speed for surrounding vehicles was also recorded. More detailed information regarding the development and validation of MOVIC-T4 is discussed in the paper written by the same author (Hirata, et al (2005, 2006)).

In this study, the analysis of multi-vehicle accident in tunnel, which utilizes the interactive driving behavior data between multiple drivers, is conducted. In order to obtain such kinds of data, we created a driving simulation system where multiple subjects can drive simultaneously in the same roadway space by connecting two MOVIC-T4s.

Figure 1 The Appearance of MOVIC-T4 and driving experiment for multiple subjects
3. INVESTIGATION OF THE MULTI-VEHICLE ACCIDENTS STATISTICS AND THE DRIVING SCENARIO IN OUR EXPERIMENTS

We investigated the characteristics of multi-vehicle accidents in expressways in Japan in order to determine the traffic scenario in the simulator experiments. Observations were gathered from newspaper published from 2003 to 2005. We collected a total of 467 samples of multi-vehicle accident. We define ‘multi-vehicle accident’ as the accident which involves three or more vehicles. As shown in Figure 2, the number of involved vehicles is usually 3 to 5 vehicles and multi-vehicle accident involving more than 10 vehicles is most of the time caused by bad weather conditions (heavy rain, dense fog and mist). Figure 3 shows the distribution of the causes of multi-vehicle accident. The share of accident caused by single-vehicle crash is the highest. Moreover, it is found that large-sized vehicles often get involved in multi-vehicle accident.

![Figure 2 Number of involved vehicles in multi-vehicle accident](image1)

![Figure 3 Causes of multi-vehicle accident](image2)

Based on the investigation of actual multi-vehicle accident, we focused on the simulated multi-vehicle accident caused by the single-vehicle crash in this study. The detailed single-vehicle crash behavior duplicated in the driving experiment in this study is shown in Figure 4. There are many types of single-vehicle crash. The assumed single-vehicle accident in this study is considered to be one of the simplest types of single-vehicle accident. We conducted interviewed traffic accident investigators in some relevant organizations in order to confirm that our assumed accident scenario commonly occurred. The result of interview generally supported our assumption. The virtual roadway has 15 kilometers in length, three lanes, one
merging section and one diverging section. Each lane width is 3.25m. The accident was generated at 10km point from the start point. Accidental car running at the speed of 90km/h in right-hand lane started to come close to the right side wall. After running 75m from the point of starting lateral movement, the accidental car came into collision with the wall, and then stopped at the deceleration of 0.7G with its hazard flasher lightening.

![Figure 4 Accident point and single-vehicle crash behavior in the experiment](image)

4. EXPERIMENTAL SETTINGS

As mentioned above, this study developed unique VR system that enabled us to conduct the driving experiment where the multiple subjects can drive simultaneously in the same roadway space. With this experiment, we could obtain more realistic interactive driving behavior data between multiple drivers which can help us understand the mechanism of multi-vehicle accident more precisely.

Participants in this experiment included 113 students and 99 elderly drivers.

There were three experimental driving conditions, Experiment A, B and C. In Experiment A, two subjects drove simultaneously in the same roadway. The first subject (S1) followed the computer-programmed large-sized car (AI-car) running automatically and the other subject (S2) followed the first subject S1. At the middle point of the roadway, AI-car suddenly made a single-vehicle accident based on the assumed behavior explained before (see Figure.4). The following two subject drivers must consequently react to this sudden accidental situation. Only this experiment was conducted twice for the same pair of subjects by reversing the driving order of S1 and S2.

In Experiment B, two subjects drove simultaneously in the same roadway similar to that in Experiment A. The difference is that S1 did not follow a certain vehicle and was required to drive at the speed of around 90km/h. At the middle point of the roadway (same point as Experiment A), there was an accidental car (large-sized vehicle) stopping (or this car can be interpreted as an end of traffic queue. This experiment was conducted for comparison with multi-vehicle accident caused by single-vehicle accident.

In Experiment C, two subjects drove freely without any requirement. The driving data in this experiment was used to check the driving characteristics of each subject, but is not used in the analysis conducted in this paper.
Each pair of the subjects did a driving experiment 4 times randomly. Regarding the effect of repetition of experiment A, we assumed the randomized order of the experiments could eliminate the effect. However, we checked the difference of distance headway between two trials. The result shows no significant difference between the two, so we treated the two experimental data independently. There still be possibly the other effects of the repetition, but we ignored them in this fundamental research.

5. RESULTS AND DISCUSSIONS

The share of the number of each accident type that occurred in Experiment A and B are shown in Table 1 and Table 2 respectively. Results show that the accident probability was much higher in Experiment A than in Experiment B. The probability of multi-vehicle accident was around 55% in Experiment A and around 20% in Experiment B. This difference is expected as the time for identifying the accident ahead was generally longer in Experiment B. Consequently, the multi-vehicle accident can occur more easily in Experiment A where the driver following the single-vehicle accident car did not have enough time to avoid collision. In terms of driver attribute (student or elderly), there was no clear difference in the accident probability among the different combination of two subject’s attribute.

<table>
<thead>
<tr>
<th>AI-car S1 S2</th>
<th>Student</th>
<th>Student</th>
<th>elderly</th>
<th>elderly</th>
<th>Student</th>
<th>elderly</th>
<th>elderly</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Total number of sample</td>
<td>32</td>
<td>36</td>
<td>40</td>
<td>35</td>
<td>143</td>
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<td></td>
<td></td>
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<tr>
<td>Total number of accident sample</td>
<td>25/32 (76.1%)</td>
<td>31/36 (86.1%)</td>
<td>34/40 (85.0%)</td>
<td>24/35 (68.6%)</td>
<td>114/143 (79.7%)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Number of multi-vehicle accident sample</td>
<td>16/32 (50.0%)</td>
<td>24/36 (66.7%)</td>
<td>20/40 (50.0%)</td>
<td>18/35 (51.4%)</td>
<td>78/143 (54.5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-Vehicle Accident (involving more than 3 vehicle)</td>
<td>collision → collision</td>
<td>13/32 (40.6%)</td>
<td>20/36 (55.6%)</td>
<td>17/40 (42.5%)</td>
<td>16/35 (45.7%)</td>
<td>66/143 (46.2%)</td>
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</tr>
<tr>
<td></td>
<td>not collision → collision</td>
<td>3/32 (9.4%)</td>
<td>4/36 (11.1%)</td>
<td>3/40 (7.5%)</td>
<td>2/35 (5.7%)</td>
<td>12/143 (8.4%)</td>
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<tr>
<td>Single rear-end collision (involving 2 vehicle)</td>
<td>collision → not collision</td>
<td>0/32 (0.0%)</td>
<td>2/36 (5.6%)</td>
<td>0/40 (0.0%)</td>
<td>1/35 (2.9%)</td>
<td>3/143 (2.1%)</td>
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<tr>
<td></td>
<td>not collision → collision</td>
<td>9/32 (28.1%)</td>
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<td>5/35 (14.3%)</td>
<td>33/143 (23.1%)</td>
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<tr>
<td>No Accident</td>
<td>collision → not collision</td>
<td>7/32 (21.9%)</td>
<td>5/36 (13.9%)</td>
<td>6/40 (15.0%)</td>
<td>11/35 (31.4%)</td>
<td>29/143 (20.1%)</td>
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Table 1 The share of accident type in Experiment A

<table>
<thead>
<tr>
<th>AI-car S1 S2</th>
<th>Student</th>
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<th>elderly</th>
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<th>Student</th>
<th>elderly</th>
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</tr>
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<td>17/40 (42.5%)</td>
<td>16/35 (45.7%)</td>
<td>66/143 (46.2%)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>not collision → collision</td>
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<td>4/36 (11.1%)</td>
<td>3/40 (7.5%)</td>
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<td></td>
</tr>
<tr>
<td></td>
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<td>9/32 (28.1%)</td>
<td>5/36 (13.9%)</td>
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</table>

Table 2 The share of accident type in Experiment B
Generally, the distance headway is one of the most important factors when analyzing the rear-end collision. Figure 5 shows the average headway distance of S1 and S2 driver in each accident type. Here, distance headway is measured when the subject started braking. It is clearly seen that the longer distance headway can prevent the collision with fore vehicle and consequently the combination of distance headway of S1 and S2 can explain each accident type.

Figure 6 is the scatter plot of distance headway and reaction time of S1 in Experiment A. The color of each plot represents collision or not-collision. It is indicated that longer distance headway and faster reaction time can lead to collision avoidance. For S1, it can be mostly explained with these two indices whether he/she made a collision or not.

Figure 7 is the same plot for S2. Unlike the case for S1 (Figure 6), it cannot be clearly explained with these two indices whether he/she made a collision or not. This is because the deceleration of S1 was not constant while the deceleration of AI-car was constant for all experiments. The deceleration of S1 was important factor for analyzing the collision of S2.
with S1 while it could not be the significant factor for the collision of S1 with AI-car. The simultaneous multi-subjects driving experiment conducted in this study enables us to obtain this kind of interactive and informative driving data.

In order to quantify the effects of several factors on the accident probability, we apply the logistic regression model (1). Dependent variable is whether the collision occurred or not. And we estimated the parameters in the model with several explanatory variables such as distance headway, reaction time, deceleration of fore vehicle, subject attribute and so on.

\[
\Pr(Y_i = 1) = \frac{1}{1 + \exp(-V_i)}, \quad V_i = \alpha + \sum_k \beta_k x_{k,i}
\]

\[Y = 1: \text{collision, 0: not collision}\]
\[\alpha: \text{constant, } \beta_k: \text{parameter for } x_k, \ x_k: \text{explanatory variable } k\]  

Estimated result for collision probability of S2 is shown in Table.3. It is confirmed from this model that the deceleration of fore vehicle (S1) significantly affected the collision probability. In this study, we just analyze the collision probability with the simple regression model. For understanding the detail mechanism of multi-vehicle accident more, we must consider the other factors such as the effect of rear vehicle (S2) behavior on fore vehicle (S1) behavior and non-linear effect of each determinant. In the future study, we will clarify the mechanism of multi-vehicle accident and countermeasures for its prevention through developing the model which can explain more detail driving behaviors inducing the multi-vehicle accident.

![Figure 6 Scatter plot of distance headway and reaction time of S1](attachment:image.png)
Figure 7 Scatter plot of distance headway and reaction time of S2

Table 3 Parameter estimation result for logistic regression (collision probability of S2 with S1)

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Parameter value</th>
<th>t-value</th>
</tr>
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<tbody>
<tr>
<td>Distance headway (m)</td>
<td>-0.13 (-4.23)</td>
<td></td>
</tr>
<tr>
<td>Reaction time (s)</td>
<td>1.45 (3.09)</td>
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</tr>
<tr>
<td>Deceleration of fore vehicle (m/s²)</td>
<td>-0.29 (-3.26)</td>
<td></td>
</tr>
<tr>
<td>Vehicle speed (km/h)</td>
<td>0.13 (2.84)</td>
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</tr>
<tr>
<td>constant</td>
<td>-9.73 (-2.39)</td>
<td></td>
</tr>
<tr>
<td>R-square</td>
<td>0.68</td>
<td></td>
</tr>
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</table>

6. SUMMARY AND THE FUTURE STUDY

This study focused on the multi-vehicle accident in underground urban expressways. In order to obtain the interactive driving behavior data between multiple subjects, a unique driving simulation system where the multiple subjects can drive simultaneously in the same VR roadway was developed. In the driving experiment, we duplicated the single-vehicle accident as a trigger of multi-vehicle accident which is a major cause of multi-vehicle accident. From this experiment, we obtained large number of interactive driving behavioral data when multi-vehicle accident occurred. And we conducted a fundamental analysis regarding the probability of multi-vehicle accident and the important determinants of rear-end collision. From the results of experiments, it is indicated that the multi-vehicles accident can much easily occurred when a preceding vehicle makes a single-vehicle accident (the possibility of multi-vehicle accident was over 50 percent) than when traffic congestion occurs ahead. And model analysis showed that longer distance headway and faster reaction time can lead to collision avoidance and the behaviors of preceding vehicle significantly affect the succeeding vehicle’s collision probability. For the future study, we will develop the model which can explain more detail driving behaviors considering interactions among three successive vehicles. And we will clarify the mechanism of multi-vehicle accident and countermeasures for its prevention with the developed model.
REFERENCES


