A Study on the Relationships between Unsafe Driving Behaviors and Driver’s Inner Factors When Entering a Non-signalized Intersection

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Abstract—By conducting an interview survey using actual driving videos, we found that normal drivers without the right of way have incorrect awareness of the potential hazards when entering a non-signalized intersection. We also conducted a questionnaire survey in which subjects answered a sequence of their driving behaviors concerning when and how they make safety checks and operate the accelerator and brake pedals. We revealed the characteristics of unsafe driving behaviors of normal drivers through comparison with the desirable ones of skilled drivers. We extracted 12 inner factors that cause deviations from desirable driving behavior and revealed the relationships between the inner factors and four elemental driving behaviors. Finally, we discussed the possibility of applying the models to a concrete method of driver safety education.

Index Terms—Driving Behavior, Intersection, Inner Factors, Accident, Human Factors

I. INTRODUCTION

In Japan, some intersections with low traffic density don’t have traffic signals. In such intersections, the stop-line and the stop sign determine the right of way to enter the intersection. However, there have been many right-angle collisions at non-signalized intersections, and the stop-line and the stop sign do not work well for preventing collisions. Here, unsafe driving behaviors of drivers without the right of way are the main cause of the collisions. Many researchers have developed driving support systems that inform drivers without the right of way about the existence of the stop-line or a crossing car using the infrastructure of the traffic environment [1]. Some drivers don’t accept the information because there is no perfect system. On the other hand, many researchers have analyzed unsafe driving behaviors of drivers without the right of way [2]. They only tend to point out unsafe driving behavior itself and cannot reveal the causes of accidents in detail.

First of all, we should reveal unsafe driving behaviors of drivers without the right of way in detail in order to develop a driving support system that is effective in maintaining driver safety or to conduct driver safety education that improves unsafe driving behavior. In a previous study [3], we experimentally recorded driving behaviors of skilled drivers and normal drivers when entering some non-signalized intersections and revealed some unsafe driving behaviors of the normal drivers. In another previous study [4], we measured profiles of cars of drivers without the right of way when passing through some non-signalized intersections. The result of this study confirmed that many normal drivers exhibited similar behaviors to the drivers in the above study. Furthermore, we proved that drivers who exhibit such unsafe driving behaviors have the possibility of crashing into an object such as a crossing car or bicycle when it appears with dangerous timing.

The purpose of this study is to reveal causes of unsafe driving behaviors by conducting some surveys that examine awareness of drivers who exhibit unsafe driving behaviors. At first, we conduct an interview survey in which subjects watch a video of their driving behaviors recorded in the previous experiment. We ask the subjects why they didn’t stop or sufficiently slow down at the stop-line and why they didn’t make a sufficient safety check. Through this interview survey, we examine drivers’ awareness of safe driving when they exhibit unsafe driving behavior. Next, based on the result of the interview survey, we suppose that normal drivers without the right of way have incorrect awareness of safe driving. We reveal the characteristics of unsafe driving behaviors that normal drivers often exhibit through a questionnaire survey. And we extract incorrect awareness of safe driving and make models that express the relationships between a driver’s awareness and his/her unsafe driving behavior patterns. At last, we discuss a concept of applying the models to concrete driver safety education.
II. INTERVIEW SURVEY

In a previous study [3], we carried out an experiment by using a car that had certain kinds of measurement equipment. We recorded the driving behaviors of two skilled drivers and those of four normal drivers. Here, the skilled drivers had worked in a car manufacturing company and had qualifications for teaching driving skills for many years. We expected them to have correct awareness of safe driving. The normal drivers were graduate students who had driven for less than 6 years and drove often. As a result of a comparison between both driving behaviors, we found that unsafe driving behaviors particular to normal drivers were not to stop at the stop-line, not to sufficiently slow down, and not to sufficiently look from side to side to check for crossing cars. Based on data of the actual driving behaviors, we carried out a simple simulation that calculated whether the skilled drivers or the normal drivers can safely avoid an accident when a bicycle or a crossing car appears with dangerous timing. The simulation results revealed that the normal drivers who exhibited unsafe driving behaviors have a low possibility of avoiding an accident.

Based on the results of the previous study, we supposed that right-angle collisions are caused as follows. Normal drivers who often exhibit unsafe driving behaviors don’t meet with an accident if no object appears when passing through an intersection. So, most unsafe drivers are overconfident that their driving behaviors are safe. However, in consideration of the simulation results, we can suppose that the low possibility of avoiding an accident is the main cause of right-angle collisions. In order to fundamentally prevent right-angle collisions, normal drivers should improve their unsafe driving behaviors.

In addition, normal drivers may have incorrect awareness of safe driving because they exhibit the same unsafe driving behavior at the same intersection. Actual driving data recorded on the road is not enough to reveal such incorrect awareness. In order to reveal why the normal drivers exhibited unsafe driving behaviors, we conducted an interview survey that examined what normal drivers thought that they could make sufficient safety checks for pedestrians, bicycles and crossing cars while they were approaching the stop-line.

- Because they could not look over the crossing road sufficiently at the stop-line, they intended to slow down not at the stop-line but just short of entering the crossing road.
- If they maintained their cars’ intended speed in the experiment (10–20 km/h), they thought that they could make a sufficient safety check and avoid objects that suddenly appeared.

On the other hand, for the skilled drivers, we asked them why they stopped at the stop-line and how they made a safety check when passing through non-signalized intersections. As a result, concerning awareness of safe driving that determines skilled drivers’ behaviors, we obtained the following remarks.

- The skilled drivers completely stopped at the stop-line and started moving again after confirming that there was no pedestrian, bicycle, or crossing car coming toward them at that time.
- They continued slowing down while making safety checks of these objects until entering the crossing road. Especially in a low-visibility intersection, they had high awareness of bicycles and pedestrians that tended to move irregularly.
- Finally, they moved their cars to the position where they could look over the crossing road. And they accelerated only after confirming that there was no crossing car that could collide with their cars. In a low-visibility intersection, they eased the front of their cars into the crossing road and continued making a safety check until they could look over the crossing road.

B. Differences of Driving Behaviors between Skilled and Normal Drivers

Based on the results of the previous study and the interview survey, we obtained Figure 1, which expresses flows of driving behaviors of skilled drivers and normal drivers. As shown in Figure 2, especially in a low-visibility intersection, a driver cannot directly make a safety check for the existence of objects that have the possibility of crashing into his/her car (we call such objects “potential hazards”) until just short of the point where his/her car crashes into the potential hazards. Therefore, a driver cannot finish making a sufficient safety check before reaching the position like normal drivers did.

As shown in Figure 1, in processes (2), (3) and (4), the skilled drivers continued sufficiently slowing down while making safety checks of the potential hazards from the stop-line. Such behaviors of skilled drivers can reduce the possibility of accidents. However, the normal drivers finished such behaviors in the process (1) because they had little awareness of the potential hazards. In addition, as they commented in the interview survey, normal drivers had overconfidence in the slow-down speed that was sufficient for avoiding crashing into the objects. Because of this little awareness and overconfidence, the normal drivers didn’t stop or slow down at the stop-line.
could be conducted easily. However, such a method requires much time and cost. In this study, we attempted to examine unsafe driving behaviors in detail and to extract inner factors. We found that such examination helps us to reveal unsafe driving behaviors, the normal drivers necessarily have a heightened possibility of crashing into a crossing car or bicycle. We thought that such unsafe driving behaviors are caused by incorrect awareness of safe driving.

We focused on such incorrect awareness of safe driving and called it “inner factors.” Inner factors are defined as incorrect awareness of the existence or behaviors of potential hazards and incorrect awareness of the action of a driver’s car when entering a non-signalized intersection without the right of way. The awareness is essential for passing through an intersection safely and not interrupting the movement of crossing cars with the right of way, pedestrians and bicycles.

III. METHOD OF QUESTIONNAIRE SURVEY

We examined the whole flow of driving behaviors as shown in Figure 1 through recording the actual driving behaviors on the road and conducting an interview survey. We found that such examination helps us to reveal unsafe driving behaviors in detail and to extract inner factors. However, such a method requires much time and cost. In this study, we attempted to examine unsafe driving behaviors by the following questionnaire survey that could be conducted easily.

Considering the results of the interview survey, unsafe driving behaviors at a certain position must be strongly influenced by the driving behaviors before the position.

When PSFs (Performance Shaping Factors) that influence human behavior are extracted in the field of Human Factors, human error and its factors are analyzed based on a flowchart of human behaviors [5]. Similarly, in the questionnaire survey, subjects provided the details of their daily driving behaviors in time sequence. This questionnaire survey aimed at revealing what normal drivers intended in their driving and what kinds of unsafe driving behaviors they exhibited. The driving behaviors answered in the questionnaire survey cannot completely express the actual driving behaviors but can reflect drivers’ awareness when drivers determine their behaviors. So, we considered that we could reveal drivers’ intended unsafe driving behaviors and extract inner factors by analyzing the result of the questionnaire survey. This questionnaire was composed of three parts: (Part 1) questions concerning the flow of driving behaviors, (Part 2) questions concerning the subject’s awareness of stopping and slowing down, and (Part 3) questions concerning traffic regulations. Part 1: Questions concerning the flow of driving behaviors

The traffic law provides that a driver without the right of way must not interrupt the movement of a crossing car with the right of way, a pedestrian or a bicycle. However, the traffic law does not explain a concrete method of driving without the right of way except for stopping at the stop-line. Drivers should determine themselves how they make a safety check and control the speed of their cars. In order to analyze the flow of driving behaviors when entering a non-signalized intersection, it is indispensable to learn the drivers’ basic action plan, like at what point they make a safety check, where they stop, and so on.

From the viewpoint of how the subjects make a safety check and how they operated the accelerator and the brake pedal, they reported the driving behaviors in time sequence on the basis of the front of their car. Here, the road was divided into 12 sections as shown in Figure 3, and the subjects reported driving behaviors from when they perceived the existence of an intersection (section [1]) to when they passed through the opposite pedestrian crossing (section [12]). Concerning safety checks, the subjects reported where they looked, which objects they made a safety check, and how they moved their heads and

![Figure 1. Flow of driving behaviors of skilled driver and normal driver](image1)

![Figure 2. Visible area according to position of driver’s car](image2)
Drivers can see well around the intersection. And they cannot see whether cars are coming from the crossing road at all.

Drivers cannot see well around the intersection because a high wall obstructs their view. And they cannot see whether cars are coming from the crossing road at all.

Given the results of the interview survey, we considered that inner factors concerning stopping and slowing down were fundamental factors of not stopping at the stop-line and insufficient slowing down. In order to extract such inner factors, we created the following questions concerning stopping and slowing down. The subjects freely answered these questions.

- If you don’t stop at the stop-line although you understand the rule of stopping, why don’t you stop?
- If you don’t sufficiently slow down when entering an intersection, why not?
- Do you think that the position of the stop-line or the stop sign is not appropriate? If not, why not?
- What speed do you identify as the slow-down speed?

Table 1: Attributes of 24 subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Driving Experience</th>
<th>Age</th>
<th>Experience of Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>5 years</td>
<td>30s</td>
<td>Accident</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>3 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>8 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>4</td>
<td>Male</td>
<td>9 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>6 years</td>
<td>20s</td>
<td>Accident</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>1 year</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>7</td>
<td>Male</td>
<td>5 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>8</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>9</td>
<td>Male</td>
<td>5 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>10</td>
<td>Male</td>
<td>3 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>11</td>
<td>Male</td>
<td>5 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>12</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>13</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>14</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Accident</td>
</tr>
<tr>
<td>15</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>16</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>17</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>18</td>
<td>Male</td>
<td>5 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>19</td>
<td>Male</td>
<td>3 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>20</td>
<td>Male</td>
<td>9 years</td>
<td>20s</td>
<td>Accident</td>
</tr>
<tr>
<td>21</td>
<td>Female</td>
<td>9 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>22</td>
<td>Male</td>
<td>5 years</td>
<td>20s</td>
<td>Close Call</td>
</tr>
<tr>
<td>23</td>
<td>Male</td>
<td>3 years</td>
<td>20s</td>
<td>Nothing</td>
</tr>
<tr>
<td>24</td>
<td>Male</td>
<td>4 years</td>
<td>20s</td>
<td>Accident</td>
</tr>
</tbody>
</table>
IV. RESULTS AND EXAMINATION OF QUESTIONNAIRE SURVEY

A. Drivers’ Inner Factors concerning Not Stopping at Stop-line

Based on the result of questions in part 3, all of the subjects correctly understood the priority at both intersections A and B. The following analyses don’t deal with the factor that the subjects misunderstood the traffic regulations.

From the results of questions in part 2, we obtained the following incorrect awareness of stopping, slowing down and making a safety check. Nine subjects (38%) could not sufficiently make a safety check for crossing cars at the existing stop-line. The subjects had low awareness of making safety checks for pedestrians, bicycles and crossing cars. And this means that they incorrectly understood the meaning of stopping at the stop-line. Six subjects (25%) answered that they had no need to stop or understood the meaning of stopping at the stop-line. Six subjects (25%) understood the proper slow-down speed incorrectly. In more than half of the subjects understood. Here, the slow-down speed means that these subjects were overconfident in their cars’ speed when making a safety check or avoiding a crash. Table 2 shows the slow-down speed that the subjects understood. Here, the slow-down speed means the speed at which a driver can stop immediately after perceiving the object even if they didn’t maintain the slow-down speed exactly. This means that these subjects were overconfident in their cars’ speed when making a safety check or avoiding a crash. Table 2 shows the slow-down speed that the subjects understood. Here, the slow-down speed means the speed at which a driver can stop immediately after perceiving an object. Generally, proper slow-down speed is regarded as 5-10 km/h. More than half of the subjects understood the proper slow-down speed incorrectly. In consideration of the above answers, many normal drivers had inner factors.

B. Selection of Elemental Driving Behaviors

In order to examine the characteristics of unsafe driving behaviors of normal drivers based on the results of questions in part 1, we selected four elemental driving behaviors that characterize the whole flow of entering an intersection. In this study, we focused on entering an intersection and excluded objects of the opposite side. Then, we defined the objects that a driver should make a safety check for, such as pedestrians, bicycles and crossing cars. Based on the speed of the car’s speed in answers, there were many cases in which the car’s speed was the lowest in these two sections. We also focused on the finishing position where a driver makes a safety check for each object. The result of the graph of the car’s speed in answers, there were many cases in which the car’s speed was the lowest in these two sections. We also focused on the finishing position where a driver makes a safety check for each object:

- Elemental driving behavior A: Speed of driver’s car at the stop-line
- Elemental driving behavior B: Finishing position where a driver makes a safety check around the stop-line
- Elemental driving behavior C: Speed of driver’s car when a driver’s car enters the crossing road
- Elemental driving behavior D: Finishing position where a driver makes a safety check for crossing cars

Here, concerning the safety check for crossing cars, we defined two kinds of elemental driving behaviors. Concretely, around the stop-line, a driver should make a safety check for crossing cars that come toward a driver (elemental driving behavior B.) A driver should look from side to side and make a safety check for crossing cars around the edge of the crossing road (elemental driving behavior D.) Furthermore, we thought that a driver simultaneously makes safety checks for pedestrians, bicycles, and crossing cars around the stop-line and integrated these safety checks into elemental driving behavior B.

C. Analysis of Driving Behaviors

In order to analyze the characteristics of unsafe driving behaviors of normal drivers, we defined desirable driving behavior for each elemental driving behavior. For the elemental driving behaviors A and C concerning the car’s speed, we thought that a driver should stop at the stop-line and at the edge of the crossing road where the driver’s car may crash into an object. For elemental driving behaviors B and D concerning safety checks, we thought that a driver should continue making a safety check until just short of the position where a driver’s car may crash into an object. A driver without the right of way needs to continue making safety checks from the stop-line until passing through the intersection. Therefore, concerning elemental driving behavior B, we regarded the driving behavior when a driver continues making a safety check for pedestrians, bicycles, and crossing cars until the stop-line as the desirable one. Concerning making a safety check for crossing cars (elemental driving behavior D), we considered that the proper finishing position of making a safety check was different depending on the visibility of an intersection. In the high-visibility intersection, a driver can look over the crossing road at the edge of the crossing road. On the other hand, in the low-visibility intersection, a driver can look over the crossing road at the position where a part of a driver’s car enters the crossing road as the skilled drivers do. Therefore, concerning elemental driving behavior D, we defined the desirable driving behaviors depending on the visibility of the intersections as shown in Table 3. We also defined unsafe driving behaviors that deviated from the desirable one. Table 3 shows the result of questions in part 1 for four elemental driving behaviors.

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<table>
<thead>
<tr>
<th>Slow-down speed</th>
<th>Number of subjects (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 5 km/h</td>
<td>4 (17%)</td>
</tr>
<tr>
<td>5-10 km/h</td>
<td>6 (25%)</td>
</tr>
<tr>
<td>more than 10 km/h</td>
<td>14 (58%)</td>
</tr>
</tbody>
</table>
We examine why normal drivers tend to exhibit unsafe driving behaviors. We compared driving behaviors in two different intersections A and B, in which the subjects exhibited more unsafe driving behavior in intersection A than in intersection B. This result means that the subjects didn’t intentionally exhibit proper driving behavior in the high-visibility intersection A although they could understand the proper speed and the proper position where they should finish making a safety check for each object.

On the other hand, many subjects exhibited unsafe driving behaviors even if they entered the low-visibility intersection where they had difficulty in perceiving each object. Furthermore, in the sequence of subjects’ driving behaviors answered in questions in part 1, some subjects didn’t make a safety check for a particular object at all in both intersections, for example, a bicycle, a crossing car that come toward the subject’s car. This result means that the subjects could not understand the existence of each object that they should make a safety check for. Through the above examination, we found that some drivers could not understand the desirable driving behavior itself.

We also examine the stopping at the stop-line. As shown in Table 3, there were only three subjects who stopped at the stop-line in both intersections. This result means that the normal drivers had little awareness of obeying the traffic rule. However, there were more subjects who stopped at the stop-line in the low-visibility intersection B than in the high-visibility intersection A. Based on these results, we can suppose that a driver without the right of way stops or slows down when entering an intersection not only to obey the traffic rule but also to make sufficient safety checks and to avoid a crash safely. This supposition corresponds to the fact that there were more subjects who exhibited desirable driving behaviors in the low-visibility intersection than in the high-visibility intersection.

### D. Relationship between Finishing Position of a Safety Check and Car’s Speed

We examine the result of the previous section in detail. We analyze the relationships between finishing positions of making a safety check for each object and the car’s speed at the stop-line (see Figure 6) and at the edge of the crossing road (see Figure 7). Here, we deal with data in the high-visibility intersection A where the subjects tended to exhibit unsafe driving behaviors.

<table>
<thead>
<tr>
<th>Driving behavior</th>
<th>Details of driving behaviors</th>
<th>In high-visibility intersection A</th>
<th>In low-visibility intersection B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Safe or not (Percentage)</td>
<td>Safe or not (Percentage)</td>
</tr>
<tr>
<td>A-1</td>
<td>Stop at the stop-line</td>
<td>□ 3 (13%)</td>
<td>□ 11 (46%)</td>
</tr>
<tr>
<td>A-2</td>
<td>Slow down at the stop-line</td>
<td>□ 14 (58%)</td>
<td>□ 11 (46%)</td>
</tr>
<tr>
<td>A-3</td>
<td>Insufficiently slow down at the stop-line</td>
<td>□ 7 (29%)</td>
<td>□ 2 (8%)</td>
</tr>
<tr>
<td>B-1</td>
<td>Continue making a safety check until the stop-line</td>
<td>□ 9 (38%)</td>
<td>□ 16 (67%)</td>
</tr>
<tr>
<td>B-2</td>
<td>Finish making a safety check before the stop-line</td>
<td>□ 15 (65%)</td>
<td>□ 8 (33%)</td>
</tr>
<tr>
<td>B-3</td>
<td>Not make a safety check around the stop-line</td>
<td>□ 0 (0%)</td>
<td>□ 0 (0%)</td>
</tr>
<tr>
<td>C-1</td>
<td>Stop at the edge of the crossing road</td>
<td>□ 12 (50%)</td>
<td>□ 9 (38%)</td>
</tr>
<tr>
<td>C-2</td>
<td>Slow down at the edge of the crossing road</td>
<td>□ 12 (50%)</td>
<td>□ 9 (38%)</td>
</tr>
<tr>
<td>C-3</td>
<td>Insufficiently slow down at the edge of the crossing road</td>
<td>□ 10 (42%)</td>
<td>□ 4 (17%)</td>
</tr>
<tr>
<td>D-1</td>
<td>Finish making a safety check at the position where a driver can look over the crossing road</td>
<td>□ 4 (17%)</td>
<td>□ 10 (42%)</td>
</tr>
<tr>
<td>D-2</td>
<td>Finish making a safety check at the edge of the crossing road</td>
<td>□ 10 (42%)</td>
<td>□ 12 (50%)</td>
</tr>
<tr>
<td>D-3</td>
<td>Finish making a safety check before the edge of the crossing road</td>
<td>□ 10 (42%)</td>
<td>□ 2 (8%)</td>
</tr>
</tbody>
</table>

□ : Safe driving behavior  □ : Unsafe driving behavior

Figure 6. Relationship between finishing point of safety check and speed of subject’s car at stop-line

Figure 7. Relationship between finishing point of safety check and speed of subject’s car at edge of crossing road
In Figures 6 and 7, the horizontal axes express the finishing position of making a safety check concerning elemental driving behaviors B and D. If a subject exhibited driving behavior B-1, he/she had correct awareness of making a safety check at the stop-line. Similarly, if a subject exhibited driving behavior D-1 or D-2, he/she had correct awareness of making a safety check at the edge of the crossing road. The vertical axes express the car’s speed at the stop-line or at the edge of the crossing road. These are determined by the line graph of car’s speed answered in questions in part 1. Defining the slow-down speed that is sufficiently safe for entering a non-signalized intersection as 5 km/h, the gray area in these figures expresses that the subjects insufficiently slowed down.

As shown in Figures 6 and 7, the car speed of the subjects who finished making a safety check before the stop-line or at the edge of the crossing road (driving behaviors B-2, D-3) was higher than that of the subjects who continued making a safety check at the position (driving behaviors B-1, D-1 and D-2.) The subjects who finished making a safety check at the incorrect position would not feel the necessity of stopping or slowing down at the stop-line or at the edge of the crossing road. This result corresponds to the supposition that a driver without the right of way tends to stop or slow down for the purpose of making a safety check. However, two subjects stopped at the stop-line although they finished making a safety check before the stop-line. They would have high awareness of obeying the traffic rule. Similarly, some subjects sufficiently slowed down at the stop-line although they finished making a safety check before the stop-line. They would slow down for the purpose of avoiding an object when it suddenly appeared. On the other hand, some subjects didn’t stop or slow down at the stop-line or at the edge of the crossing road (driving behaviors B-1, D-1 or D-2) although they continued making a safety check at the positions. They would incorrectly understand the slow-down speed that is essential for making a safety check properly.

E. Relationship between Slow-down Speed That a Driver Understands and Car’s Speed

We examine inner factors of the subjects who incorrectly understood the slow-down speed although they made a safety check at the proper position. Here, we deal with data of the subjects who made a proper safety check at the stop-line (driving behavior B-1) or the edge of the crossing road (driving behaviors D-1 and D-2) in the high-visibility intersection A. In Figures 8 and 9, the horizontal axes express the slow-down speed that the subjects understood. The vertical axes express the car’s speed at the stop-line or at the edge of the crossing road.

As well as shown in Figures 6 and 7, the gray area in Figures 8 and 9 expresses that the subjects insufficiently slowed down. The oblique lines in the figures mean that the slow-down speed that the subjects understood corresponded to the car’s speed. Based on the above, the subjects’ awareness of the slow-down speed when making a safety check can be classified into the following five types as shown in Figure 10.

Type 1: Subjects understood the slow-down speed correctly. And they actually drove at the slow-down speed.
Type 2: Subjects understood the slow-down speed incorrectly. But they sufficiently slowed down.
Type 3: Subjects understood the slow-down speed correctly. But they were overconfident that they could make a sufficient safety check even if they didn’t maintain the slow-down speed exactly.
Type 4: Subjects intended to slow down sufficiently. But they could not do so because they understood the slow-down speed incorrectly.
Type 5: Subjects understood the slow-down speed incorrectly. And they were overconfident that they could make a sufficient safety check even if they didn’t maintain the slow-down speed exactly.

As shown in Figures 8 and 9, most of the subjects who didn’t slow down sufficiently at the stop-line or at the edge of the crossing road were classified into types 4 or 5.
Thus, for drivers who don’t slow down when making a safety check, we should make them improve their behaviors in consideration of their inner factors.

V. INNER FACTOR MODEL

A. List of Inner Factors

Through the analyses of the interview survey and the questionnaire survey, we listed the following 12 inner factors. We considered that normal drivers have less awareness of pedestrians and bicycles than that of crossing cars. They would change the speed of their cars when making a safety check according to the object. Therefore, we classified inner factors concerning a car’s speed when making a safety check into two factors (inner factors (3), (4) and inner factors (6), (7).)

Inner factor (1): A driver has little awareness of obeying the traffic rule of stopping at the stop-line.

Inner factor (2): A driver understands the slow-down speed incorrectly.

Inner factor (3): A driver thinks that he/she can make a sufficient safety check around the stop-line even if he/she doesn’t maintain the slow-down speed exactly.

Inner factor (4): A driver thinks that he/she can make a sufficient safety check at the position where his/her car enters the crossing road even if he/she doesn’t maintain the slow-down speed exactly.

Inner factor (5): A driver thinks that he/she can stop perfectly after perceiving an object even if he/she doesn’t maintain the slow-down speed exactly.

Inner factor (6): A driver thinks that he/she can make a safety check around the stop-line as sufficiently when he/she slows down as when he/she stops.

Inner factor (7): A driver thinks that he/she can make a safety check for crossing cars around the point where his/her car enters the intersection as sufficiently when he/she slows down as when he/she stops.

Inner factor (8): A driver thinks that he/she can make a sufficient safety check for pedestrians when he/she is coming to the stop-line. Otherwise, a driver has no awareness of making a safety check for pedestrians around the stop-line.

Inner factor (9): A driver thinks that he/she can make a sufficient safety check for bicycles when he/she is coming to the stop-line. Otherwise, a driver has no awareness of making a safety check for bicycles around the stop-line.

Inner factor (10): A driver thinks that he/she can make a sufficient safety check for crossing cars that come toward him/her when he/she is coming to the stop-line. Otherwise, a driver has no awareness of making a safety check for crossing cars around the stop-line.

Inner factor (11): A driver thinks that he/she can make a sufficient safety check for crossing cars when he/she is coming to the position where his/her car enters the crossing road.

Inner factor (12): A driver thinks that he/she can make a sufficient safety check for crossing cars even if he/she cannot look over the crossing road.

B. Inner Factor Models concerning Safety Check

We consider the relationships between the 12 inner factors and unsafe driving behavior patterns for each elemental driving behavior. The relationships concerning safety checks are very simple. Figures 11 and 12 show models that express the relationships between related inner factors and unsafe driving behavior patterns concerning elemental driving behaviors B and D. We called such a model an “inner factor model.”

For elemental driving behavior B, inner factors (8), (9) and (10) are related to making a safety check around the stop-line. If a driver has awareness of making a safety check for either a pedestrian, a bicycle, or a crossing car that comes toward him/her at the stop-line, he/she continues making a safety check until passing through the stop-line. If a driver has no awareness of making a safety check for all objects at the stop-line, he/she finishes making a safety check before approaching the stop-line.

Similarly, we could make an inner factor model concerning elemental driving behavior D. Inner factors (11) and (12) are related to making a safety check for crossing cars. Depending on the degree of awareness of crossing cars, a driver finishes making a safety check after entering the crossing road (driving behavior D-1,) at the edge of the crossing road (driving behavior D-2,) or before the edge of the crossing road (driving behavior D-3.)

C. Inner Factor Models concerning Car’s Speed

Figures 13 and 14 show models that express the relationships between related inner factors and unsafe driving behavior patterns concerning elemental driving behaviors A and C. In the previous section, we supposed

![Figure 11: Inner factor model for elemental driving behavior B](image1)

![Figure 12: Inner factor model for elemental driving behavior D](image2)
that a driver without the right of way stops at the stop-line for the purpose of not only obeying the traffic rule but also making a safety check and avoiding the crash safely. Based on this supposition, we created an inner factor model concerning elemental driving behavior A. Inner factors (8), (9) and (10) that are related to making a safety check around the stop-line (elemental driving behavior B) have influence on the car’s speed at the stop-line. In addition, inner factors (1), (2), (3), (5) and (6) are related to the car’s speed at the stop-line.

In the case where a driver makes a safety check for an object at the stop-line, he/she doesn’t stop at the stop-line if he/she has inner factor (6). In the case where a driver doesn’t stop at the stop-line or finished making a safety check before approaching the stop-line, he/she doesn’t sufficiently slow down if he/she has inner factor (2). In the case where a driver understands the slow-down speed correctly, he/she doesn’t sufficiently slow down if he/she has both inner factors (3) and (5). Through the above process, a driver determines his/her intended car’s speed.
for the purpose of making a safety check or avoiding a crash with the object. Lastly, a driver’s awareness of obeying the traffic rule (inner factor 1) has influence on the car’s speed at the stop-line. Similarly, we could make an inner factor model concerning elemental driving behavior C as shown in Figure 14.

D. Application of Inner Factor Models to Driver safety education

In the previous study [4], which recorded a series of car speeds of normal drivers without the right of way when entering some non-signalized intersections, there were no driver who perfectly stopped at the stop-line. And there were few drivers who sufficiently slowed down at the stop-line. Compared with this result, the proportion of subjects who reported that they stopped or slowed down at the stop-line was much higher. In the questionnaire survey, some subjects would answer safer driving behavior than their actual driving with having much awareness of the traffic rule. Because the traffic law doesn’t explain other proper driving behaviors than stopping at the stop-line, we think that the result of the questionnaire survey could almost express subjects’ daily driving behaviors. Therefore, it is expected that the questionnaire survey can reveal unsafe driving behaviors and extract inner factors.

Driving support during the actual driving cannot easily improve a driver’s daily unsafe driving behaviors because he/she thinks his/her driving behavior is safe. We should conduct driver safety education by which an unsafe driver can understand the problem with his/her driving behavior and improve his/her inner factors fundamentally. Inner factor models can express the relationships between the inner factors and unsafe driving behaviors. By using these models, we can judge what inner factors a driver has based on his/her actual driving data. Such judgment of the existence of inner factors is significant for conducting driver safety education because many drivers may misunderstand what inner factors they have. Furthermore, when we express a series of driving behaviors using four elemental driving behaviors, we can simulate the possibility of causing accidents in a dangerous situation with animation on a PC screen as shown in Figure 15. Through the simulation, we can make normal drivers understand the fundamental causes of right-angle collisions. Thus, the inner factor models will be effective to driver safety education.

VI. Conclusion

In this study, we conducted a questionnaire survey in which subjects answered a series of driving behaviors when entering non-signalized intersections without the right of way. At first, based on the skilled drivers’ behaviors and their comments, we defined four elemental driving behaviors. We focused on the method of making a safety check and controlling the car’s speed at the stop-line and the edge of the crossing road. Then, we analyzed the details of subjects’ unsafe driving behaviors and revealed that they had incorrect awareness of safe driving that caused their unsafe driving behaviors.

Concerning safety checks, many subjects didn’t continue making a safety check until the proper position. This was because they could not understand the existence or the behaviors of objects that had the possibility of crashing into their cars when entering and passing through an intersection. Concerning the car’s speed, many subjects didn’t stop or sufficiently slow down at the stop-line and around the edge of the crossing road. Such unsafe driving behaviors were caused by the subjects’ overconfidence that they could make a sufficient safety check and avoid the objects safely even if they didn’t stop or slow down. And misunderstanding of the slow-down speed had influence on such unsafe driving behaviors, too. Almost half of the subjects finished making a safety check before the stop-line or the edge of the crossing road. Then, they didn’t feel the necessity of stopping or slowing down at such a point. This incorrect awareness caused unsafe driving behaviors. Finally, we made models that expressed the relationships between inner factors and unsafe driving behaviors and discussed the possibility of applying the models to a concrete method of driver safety education.

Through the questionnaire survey in which subjects made profiles of their driving behaviors, we could reveal their intended unsafe driving behaviors and inner factors. In the future, we will use the actual driving data on the road and establish a concrete method of driver safety education that improves a driver’s inner factors fundamentally.

REFERENCES

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