ABSTRACT

In the subject research, we have studied a mechanism to provide effective attention-attracting information by analyzing the occurrence factors of Rear-End collisions on Tokyo’s Metropolitan Expressway. Focusing on the fact that the traffic accidents that frequently occur at the location surveyed significantly decreased when the adjacent new route was placed in service, we have demonstrated the factors causing the accidents through an analyses of the accidents before and after the service of the new route along with changes in traffic condition caused by the service. We have also studied the timing, media, and contents of the information to be provided corresponding to these factors.

KEYWORDS: Rear-End Collision, Factor Analysis, Provision of Information

INTRODUCTION

The Tokyo Metropolitan Expressway is an urban expressway with total length of approximately
300 kilometers covering Tokyo, the capital of Japan, and the adjacent area. Approximately 10,000 traffic accidents occur on this Metropolitan Expressway each year, of which Rear-End collisions account for about 50%. Congestion warning information boards, LED information boards (Figure 1) and other signs have been introduced to prevent Rear-End collisions, but have not yet achieved a significant decrease in the number of accidents.

In recent years, information on traffic congestion has been provided to onboard equipment using the ITS Spot Service via DSRC (Figure 1).

The reasons for the lack of any significant decrease in the number of accidents, despite these preventive measures, seem to include the facts that the factors behind the accidents remain unclear and because the information is not provided precisely when the accident risk peaks.

In this study, we researched a mechanism to provide effective and prominent information by analyzing the factors behind Rear-End collisions on the Metropolitan Expressway through a case study of an accident-prone Roppongi section of the inbound lane on Route 3 Shibuya Line.

Outline of the Points Analyzed

Figure 1 Examples of Rear-End accident prevention measures on the Metropolitan Expressway

Figure 2 shows the inbound lane alignment of the Roppongi section of the Route 3 Shibuya Line selected as a target of the study and its status of accident occurrence. The subject spot is located in the section before the fork of Tanimachi Junction, connecting the Shibuya Line with the Inner Circular Route and with a sag (-5% => +2%) just before the fork.

The status of accident occurrence shows that Rear-End accidents are concentrated between the 0.5 and 0.9 km posts near the sag, which was rated the worst point in terms of Rear-End collision occurrence on the Tokyo Metropolitan Expressway in 2009.

Figure 2 Alignment of the inbound lane of Roppongi section of Route 3 Shibuya Line (top) and status of accident occurrence there in 2009 (bottom)
The Process of Study

Figure 3 shows the process of the study.

At the beginning of this study, we formulated hypotheses concerning the accident-occurrence mechanism based on the state of accident occurrence derived from statistical accident data and images when accidents occurred.

In the next step, we attempted to verify the hypotheses by analyzing the traffic conditions before and after the commencement of service of the Central Circular Route Shinjuku Line; noting the fact that the total traffic accidents in the subject area decreased after the Shinjuku Line service went into operation. We examined the final verification of the hypotheses and identified the accident-occurrence factors to study countermeasures corresponding to the same respectively.

Finally, we analyzed circumstances in which the risk of occurrence of Rear-End collisions (hereinafter referred to as “Rear-End collision occurrence risk”) increased and studied a technique to provide prominent information on the same.

1. Formulation of hypotheses concerning the mechanism of accident occurrence
   * Formulation of hypotheses based on accident statistical data and images when accidents occurred

2. Verification of hypotheses
   * Verification of hypotheses by comparing traffic conditions before and after the Central Circular Route Shinjuku Line opened between Lines 3 and 4, noting the decline in the number of traffic accidents after the Shinjuku Line opened.

3. Study of countermeasures corresponding to respective factors

4. Study of technique to provide information corresponding to the risk of rear-end collisions
   * Analysis of circumstances in which the rear-end collision risk (risk of occurrence of rear-end collisions) is high and study of a technique to provide effective and prominent information corresponding to the risk

---

Formulation of Hypothesis concerning Accident-Occurrence Mechanism

Figure 4 shows the hypothesis of an accident-occurrence mechanism formulated based on the accident statistical data and the images when accidents occurred.

First of all, the traffic density in the first lane increases to the state of a critical flow. Subsequently, a vehicle making a sudden changeover to the first lane causes a decelerating wave forcing some other vehicles to stop at the bottom of the sag. Under these traffic conditions, drivers delay applying their brakes due to their failure to pay sufficient care to events immediately ahead of them and require a braking distance longer than what had perceived as necessary to stop their vehicles, due to the downward incline. These are the factors which we assumed to be behind the Rear-End collisions. Accordingly, we decided to verify the following four points in this study: high density traffic forming, sudden lane changeovers, differences in vehicle Velocities between traffic lanes and insufficient care paid to objects immediately ahead.
Analysis of Accident-Occurrence Status before and after the Service of the Central Circular Route Shinjuku Line (Between Lines 3 and 4)

The Central Circular Route Shinjuku Line (between Lines 3 and 4) constitutes part of the ring road and has been in service since March 2010. Figure 5 shows the status of occurrence of accidents before and after the Central Circular Route Shinjuku Line (between Lines 3 and 4) went into service. Previously, accidents were concentrated near the inflection point of the Roppongi downgrade between the 0.5 and 0.7 km posts, most of which were Rear-End collisions in the first lane. On the other hand, the total number of Rear-End collisions in the first lane decreased drastically after the Shinjuku Line went into service, as we see from Figure 5. Based on the above observations, we decided, for an analysis of the accident-occurrence factors, to try to analyze the traffic condition constituting the accident occurrence factors by comprehending the status of the occurrence of Rear-End collisions and the changes in the traffic conditions before and after the Shinjuku Line went into service, noting the fact that the total traffic accidents in the subject area decreased after this point.

Figure 5 Status of Occurrence of Accidents before and after the Shinjuku Line went into service
Verification of Hypotheses

Occurrence of State of High Density

Figure 6 shows a QV correlation diagram of random five-day periods before and after the Shinjuku Line went into service, without accidents plotted and including the volume and traffic Velocity at the time the 24 accidents occurred before the Shinjuku Line opened.

From the figure, we see that accidents were caused mainly when the traffic was relatively dense with a volume of 25 to 30 vehicles per minute (a flow rate of 1,500 to 1,800 units per hour) and a Velocity of 30 to 50 kilometers per hour immediately before the accidents occurred, namely in the area generally referred to as a critical flow.

To quantitatively determine the relationship between the changes in QV, before and after the Shinjuku Line went into service, and the state of traffic immediately before the accidents occurred, we calculated the difference in QV frequency and superposed it on the state of traffic immediately before the accidents occurred, the result of which is shown in Figure 7.

The figure shows that the frequency in the critical area decreased drastically after the Shinjuku Line went into service, which correlates with the area of the state of traffic immediately before the accidents occurred. In other words, it suggests that the decrease of the critical flow after the Shinjuku Line opened is one of the factors behind the reduced number of accidents.

![Figure 6 QV Correlation in the first lane (Random 5 day period)](image)

![Figure 7 Difference in QV Frequency (Before and after the service)](image)

Occurrence of Sudden Lane Changeovers

Using video images, we calculated the number of lane changeovers made and decreasing waves caused during random 30 minute periods before and after the Shinjuku Line went into service when one of the traffic lanes was in a state of high density and compared them for analysis. Here, we assumed that the decelerating waves were caused when the braking lamps of the following vehicles went on after the lane changeovers. The number of lane changeovers calculated is as shown in Figure 8, which shows that both the number of lane changeovers as well as the number of decelerating waves caused decreased after the Shinjuku Line went into service.
Differences in Velocity between Traffic Lanes

Figure 9 shows the status of congestion by traffic lane before and after the Shinjuku Line went into service.

From the figure, we see that the second lane was clogged with vehicles up to the Inner Circular Route (Clockwise) during the peak morning and early evening hours before the Shinjuku Line went into service.

Figure 9 State of Congestion by Lane before and after the Shinjuku Line opened
into service. The first lane was also clogged up to the Inner Circular Route (Counterclockwise) during the peak morning hours. During the daytime off-peak hours, on the other hand, the traffic velocity in the second lane exceeded 60km/h, while that in the first lane remained below 40km/h, i.e. vehicle velocity differed between the two lanes. After the Shinjuku Line went into service, the congestion in the second lane up to the Inner Circular Route (Clockwise) worsened while the traffic congestion up to the Inner Circular Route (Counterclockwise) improved. During the peak morning and early evening hours, the traffic velocity in the second lane declined to below 20km/h while that of the first lane improved to above 40km/h, representing a reverse in the velocity of traffic lanes before and after the Shinjuku Line went into service.

In view of the fact, however, that a difference in traffic velocity remained between the two traffic lanes, it is inferred that the accidents occurred not only due to the difference in velocity between the traffic lanes but also following the formation of high density traffic.

**Drivers paying less attention to events ahead of them**

A review of vehicle velocity in the first lane, before the Shinjuku Line went into service, confirmed a decline in velocity at the sag followed by a recovery in the subsequent section. This indicates the possibility that drivers ran their vehicles assuming smooth traffic based on judgment of the traffic condition (far) ahead and were thus unaware of the congestion at the bottom of the sag (Figure 10). The tendency of the drivers to look at the traffic condition ahead was also confirmed by their line of sight in the eye mark recorders (Figure 11).

The information board placed at the bottom of the sag is located about 2.5 meters higher than in ordinary locations. The eye lines of the drivers gazing at the information regarding congestion displayed on the board are directed higher than in normal cases and may possibly result in insufficient driver care to events immediately in front of them (Figure 12). Furthermore, the traffic velocity in the first lane was slower, as shown in the preceding paragraph, and driver’s attention on events immediately in front of them may become insufficient when they try to switch to the second lane.
Study of Countermeasures corresponding to Accident-Occurrence Factors

The accident-occurrence factors are summarized as follows, based on the accident occurrence mechanism verified in the preceding section:

1. A state of high density (a critical flow) and different traffic velocities between the traffic lanes
2. Sudden lane changeovers
3. Drivers paying less attention to events in front of them
4. Actual braking distance different from that perceived necessary by drivers required to stop their vehicles due to the incline of 5%

Based on the above, the following three countermeasures are conceivable: Placement or relocation of the existing information boards in or to lower locations; Restraint of lane changeovers utilizing a section line or information sign; Provision of prominent information effective in preventing Rear-End collisions (Figure 13)

At this stage, we are confronted by the issue of determining the circumstances in which the prominent information may be provided more effectively.

Accordingly, in this study, we analyzed situations where the Rear-End collision occurrence risk (the risk of occurrence of Rear-End collisions) was high and also studied a technique to provide prominent information corresponding to the respective risks of Rear-End collisions, the results of which will be summarized in the next section.
with the traffic condition before and after its occurrence. From the figure, it is confirmed that immediately before the accident occurred, the difference in traffic Velocity between the lanes was considerable and the first lane was densely congested. Accordingly, it is inferred that the traffic Velocity in the respective lanes became mutually imbalanced due to the clogging up to the Inner Circular Route and that the accident occurred under circumstances where the distance between the cars in the first lane was short.

Figure 14 Traffic Condition when the Accident Occurred (April 22, 2009)

In the next step, we compared the conditions at the time of accidents with those during a random one week accident-free period to analyze the characteristics of traffic conditions when accidents occur frequently.

An outline of the data analyzed is shown in Table 1 while the comparative results of the differences of traffic Velocity between the traffic lanes and distribution of the frequency of occupancy are shown in Figure 15.

The figure shows that the difference of Velocity existing when accidents occurred was, when compared with the random week, slightly higher in the range of -20 ~ -10km/h. On the other hand, the occupancy during the random week was frequently in the 10~20% range while that when accidents occurred was frequently in the 20~30% range, showing a difference between times when accidents occurred and ordinary conditions. Based on the above, it is inferred that the difference of traffic Velocity between the lanes as well as the state of occupancy in the first lane governed the level of risk of Rear-End accidents.

Table 1 Analyzed Variables

<table>
<thead>
<tr>
<th>Item</th>
<th>Analyzed Data</th>
<th>Analyzed Spot</th>
</tr>
</thead>
<tbody>
<tr>
<td>When accidents occur</td>
<td>Average value during periods 5~10 minutes before accidents occurred (24 samples)</td>
<td>Point downstream of the accident (0.41 kilometer post)</td>
</tr>
<tr>
<td>Random week</td>
<td>7:00<del>19:00, January 15</del>21, 2009 Data during one minute (5,040 samples)</td>
<td></td>
</tr>
</tbody>
</table>
Based on the above results, we distilled the occupancy and difference in traffic velocity as factors highly related to accidents and cross-tabulated the data at the time accidents occurred and during the random week.

Figure 16 shows the probability of accident occurrence at the time of accidents classified by traffic condition. The portions of the figure framed in red show that accidents are highly likely to occur under traffic conditions with a difference in Velocity of -15 ~ -10 km/h and occupancy of 20 ~ 30%, which comprise 46% of the total number of accidents. They suggest that the risk of occurrence of accidents increases under traffic conditions where the lane Velocity of the accident is lower and its occupancy is higher than those of lanes where no accident occurs.

Figure 17 shows the probability of occurrence during the random week classified by traffic condition. During the random week, accidents were concentrated under conditions with the difference in Velocity of -15 ~ 5 km/h and occupancy of 10 ~ 20%, whereby the probability of occurrence under traffic conditions with an accident risk, as referred to above, accounted for only 4.9% of total accidents.

These results show that the probability of accidents under conditions where the accident risk is considered high is usually low. In other words, the traffic condition with a difference in Velocity of -15 ~ -10 km/h and occupancy of 20 ~ 30% is considered to be a state with a high risk of Rear-End collision.
Relationship between the accident risk occurrence and the time of provision of information

While the provision of stationary information such as “Watch out for Rear-End collisions” provided at all times can attract attention to all accidents, it is surmised that this information will become less effective as drivers get used to it.

Accordingly, in this study, we decided to examine a technique to provide the information only under conditions of high risk so that the attention of the drivers could be attracted effectively. In this paragraph, we will summarize the result of our analysis of the relationship between the accident risk occurrence and the time when the information is provided.

In cases, for example, where the prominent information was provided under traffic conditions with a difference of Velocity of -15 ~ -10 km/h and an occupancy of 20~30%, the information will cover 45.8% (11 cases) of the total of 24 accidents. In other words, the prominent information would achieve an accident detection rate of 45.8% when provided under the above conditions.

In the case of the random week, the prominent information provided under similar traffic conditions accounted for just 4.9% of total accidents. The time of the provision of the information per accident, as calculated from the above data, will be as follows: 150 days (24 accidents occurring within a 5-month period) x 12 hours x 60 minutes x 4.9% ÷ 11 accidents = 481 minutes. The average time of provision of the information per day calculated under the same condition will be as follows: 12 hours x 60 minutes x 4.9% = 35 minutes. When the information is considered provided for individual periods of one minute, the provision of 481 times in 5 months, namely for approximately 35 minutes per day, would enable the provision of the information to approximately half (45.8%) of the accidents.

The results of these calculations summarized for the respective accident detection rates framed in Figure 16 are as shown in Table 2. The relationship between the accident detection rate and the time of information provision per accident shows that 700 minutes will be required to detect about 75% of total accidents, 1,500 minutes to detect about 90% and 3,500 minutes to detect 100%, naturally meaning that an increase in the accident detection rate will result in an increase in the time of information provision per accident. In other words, this relationship shows a tradeoff between a high accident risk with the shortest possible time of information provision and vice versa.
Table 2 Risk of Occurrence of Rear-End Collision and Time of Provision of Information

<table>
<thead>
<tr>
<th>Range</th>
<th>Accident detection rate (No. of accidents)</th>
<th>Time of information provision per accident</th>
<th>Average time of information provision per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 16 Frame in red</td>
<td>45.8% (11)</td>
<td>481 minutes</td>
<td>35 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in blue</td>
<td>75.0% (18)</td>
<td>687 minutes</td>
<td>82 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in yellow</td>
<td>87.5% (21)</td>
<td>1,533 minutes</td>
<td>215 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in green</td>
<td>100.0% (24)</td>
<td>3,572 minutes</td>
<td>572 minutes</td>
</tr>
</tbody>
</table>

Comparison with Judgment of Velocity (Below 40km/h)

In this paragraph, we made a comparison of the accident detection rate and the time of information provision in instances where the information was provided corresponding to the respective ranges of accident risk as proposed in the preceding paragraph and those where information was provided using Judgment of Velocity. Judgment of Velocity is considered to provide information when the sectional velocity in its vicinity goes below 40km/h.

The result of the comparison is as shown in Table 3, from which it is understood that the information provided based on judgment that the scope of accident risk, as shown in the frames in red and blue, increases in terms of the accident detection rate and is shorter in terms of provision time than the information provided using Judgment of Velocity.

Table 3 Comparison of information provided based on risks of Rear-End collision and by using the Judgment of Velocity

<table>
<thead>
<tr>
<th>Range</th>
<th>Accident detection rate (No. of accidents)</th>
<th>Time of information provision per accident</th>
<th>Average time of information provision per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 16 Frame in red</td>
<td>45.8% (11)</td>
<td>481 minutes</td>
<td>35 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in blue</td>
<td>75.0% (18)</td>
<td>687 minutes</td>
<td>82 minutes</td>
</tr>
<tr>
<td>Judgment of Velocity (Below 40km/h)</td>
<td>33.3% (8)</td>
<td>3,083 minutes</td>
<td>164 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in yellow</td>
<td>87.5% (21)</td>
<td>1,533 minutes</td>
<td>215 minutes</td>
</tr>
<tr>
<td>Fig. 16 Frame in green</td>
<td>100.0% (24)</td>
<td>3,572 minutes</td>
<td>572 minutes</td>
</tr>
</tbody>
</table>

Study of Methods to provide Attention-Attracting Information

Based on the result of the studies performed in the preceding sections, we study here a step-by-step mechanism for the contents of the information to be provided.

The above image is as shown in Figure 18, from which it is considered effective to classify the information provision into three ranks of A through C. No information will be provided on Rank C
as it involves only a low accident risk. In Rank B, the information will be provided as previously, as
the rank tends to cover congested conditions with an accident detection rate of about 90% and
occupancy exceeding 20%. In Rank A, with an expected accident detection rate of approximately
50%, a period of only 30 minutes per day when the accident risk is extremely high will be targeted
and an information board equipped with a revolving or flashing light to show a high degree of
danger and displaying the message “Great Danger of Rear-End Collisions!” will be used. However,
the contents and timing of the messages to be displayed as well as their impact on drivers must be
further studied in future.

While the information board as mentioned above is considered effective as a medium to provide
the information, the verified result of the effects of the ITS Spot Service\(^2\) revealed that the
information provided to onboard equipment through said service is effective in improving the
degree of driver’s focus in front and maintaining a longer interval from the vehicle ahead.
Accordingly, the use of this system is also considered effective.

**Conclusion: Subjects to be studied in future**

In this paper, we studied a technique effective in providing prominent information by analyzing
the factors behind Rear-End collisions on the Tokyo Metropolitan Expressway.

The results of the analysis revealed that the factors behind Rear-End collisions comprise
differences in traffic Velocity between the traffic lanes in the state of high density (a critical flow),
sudden lane changeovers, drivers paying insufficient attention to events in front, and a braking
distance different from that perceived as necessary by drivers to stop their vehicles, due to an
downward incline of 5%.

Against the above phenomena, the following three measures are conceivable: placement and
relocation of existing information boards to lower spots, limiting lane changeovers using section
lines and information signs, and the provision of prominent information against Rear-End
collisions.

Furthermore, comparison of the traffic conditions at the time accidents occurred with those during accident-free periods revealed that the risk of Rear-End collisions increased under conditions with a difference in Velocity of -15 ~ -10km/h between the traffic lanes (lower in the first lane) and occupancy of 20~30%. At the end of the paper, we proposed the provision of prominent information corresponding to the risks of Rear-End collisions so that the information will be provided effectively.

Our challenge in future will be further study of the technique to provide prominent information, including the contents of the message to be displayed and the media to be employed to provide the same, as well as applying the results of this study to other spots.

References