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Analysis of Low-speed Rear-end Collisions using Near-miss Incident Database

Mitsunobu Fujita
The Jiken Center Co., Ltd.

678-28 Futamata, Ichikawa-shi, Chiba, 272-0001, Japan (E-mail: mitsunobu.fujita@jikencenter.co.jp)

ABSTRACT: Statistical data on traffic accidents in Japan suggests the existence of different factors/processes in low-speed rear-end collisions than in relatively high speed ones. Analyzing the numerous data sets recorded by drive recorders and stored in a database of near-miss incidents yields several findings on the characteristics of low-speed rear-end collisions and near-miss incidents. This study analyzes the database with respect to "Classification of Factors", "Relative Approach Speed", "Overlap Percentage" and "Circumstances".

KEY WORDS: Drive Recorder, Rear-end Collision, Low Speed, Near-miss Incident

1. Introduction

Each year, a large number of people are injured in traffic accidents in Japan, even though the number of accidents has recently been gradually declining. According to Japanese police statistics [(1)], 725,773 accidents occurred in 2010 and 896,208 people were injured. Car-to-car rear-end collisions comprise the highest percentage of all accidents (32.4%).

Figure 1 shows the distribution of car speeds in car-to-car rear-end collisions (including car-to-motorcycle events) derived from the database of the Institute for Traffic Accident Research and Data Analysis (ITARDA). The speed shown is the speed just before braking, based on data obtained from police questionnaires. It shows the same pattern as that found for all traffic accidents, with low-speed collisions accounting for the majority of all cases. However, plotting the data also produces a histogram with two distinct peaks.

The presence of these two peaks has led us to propose the hypothesis that there might be different factors or processes involved in low speed rear-end collisions than in relatively high speed ones in Japan.

The aim of this study is to clarify the characteristics of low-speed rear-end collisions. The analysis is based on the "Near-miss Incident Database (NIDB)". The findings of this study are expected to contribute to the development and application of active safety technologies.

2. Near-miss Incident Database

2.1. An outline of NIDB [(2)]

The NIDB is owned by the Society of Automotive Engineers of Japan (JSAE), and consists of data obtained from drive recorders. JSAE started the data collection process for the NIDB in 2005. As of April 2010, 125 drive recorder units have been installed on taxis in Tokyo and Shizuoka (urban and suburban areas).

The drive recorders (DR) used by the NIDB comprise a video camera, an accelerometer, a GPS module and several input terminals, so they can record forward-facing video and changes in

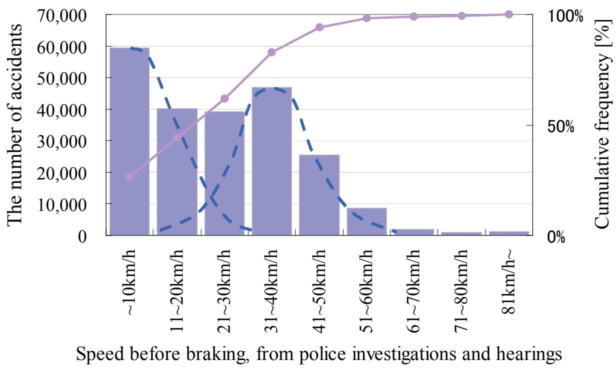


Fig.1 The speed distribution of car-to-car and car-to-motorcycle rear-end collisions in Japan in 2009, derived from the database of the ITARDA

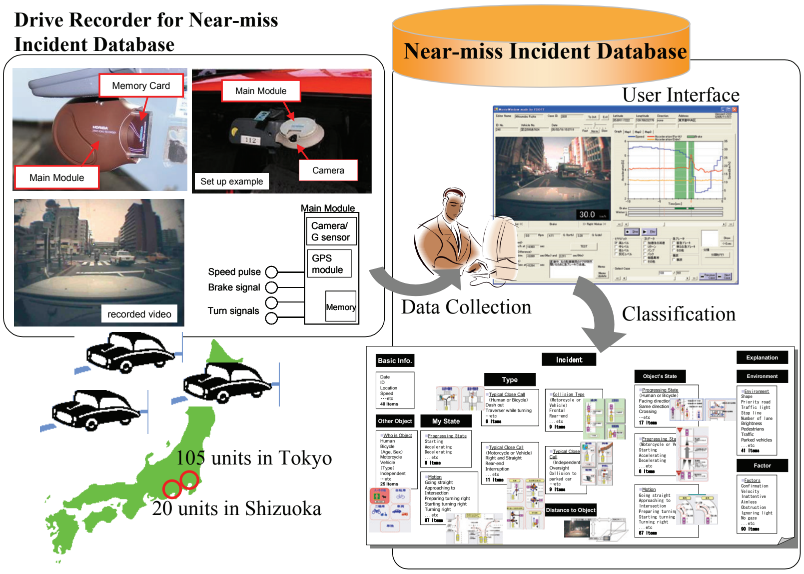


Fig.2 Outline of the total system supplying the Near-miss Incident Database, including drive recorders

running speed, acceleration, brake signals, turn indicators and location. Once longitudinal acceleration/deceleration exceeds a certain level, the sensor triggers the start of recording. The system can record 15 seconds of data each time it is triggered (from 10 seconds before to 5 seconds after the trigger). This often enables the system to record the whole sequence of events associated with accidents (collisions) or near-miss incidents (imminent collision situations). All recorded data are registered in the NIDB and classified on the basis of a range of criteria, including the collision type, the status of the car in which the drive recorder is mounted (DRCAR), the status of the other car involved in the incident (OTCAR), and the level of danger. Only one database operator in the JSAE conducts this classification work for almost all the data, so the classification is expected to show better accuracy and internal consistency than it would if more operators were involved. Figure 2 shows an outline of the total system, composed of the NIDB and DRs. As of April 2010, more than 42,000 data sets for near-miss incidents and more than 250 data sets for accidents have been registered. The present study is based on this volume of data.

In Japan, many organizations, including universities and national research institutes, have recently conducted research using various kinds of drive recorders for a variety of purposes [3-5]; and in many cases, they have browsed the NIDB and utilized it in their own research. Many significant findings based on this database have already been reported [6-10].

2.2. The outline of studied data

As noted above, a database operator in the JSAE has already classified all the near-miss incident data contained in the NIDB into one of three levels of danger - high, middle, and low.

Low-speed rear-end near-miss incidents with a high danger level were extracted and used in this study. Here, “low speed” means moving at 20 km/h or less just before braking, a category that includes 173 data sets. 158 of these are car-to-car and 15 sets are car-to-motorcycle. This study deals with both car-to-car and car-to-motorcycle cases in a single group, because of their similar speed ranges, their similar circumstances (the 15 sets of car-to-motorcycle in the NIDB seem to include no situations unique to car-to-motorcycle rear-end collisions), and our expectation that the more data sets are analyzed, the more findings will be obtained.

In addition, data on low-speed rear-end collisions were also extracted. Here, “low speed” means 20 km/h or less just before collision. Sixteen such accidents were extracted. All cases are car-to-car accidents.

Altogether, this study deals with the 189 data sets for low-speed near-miss incidents and low-speed accidents.

2.3. Obtaining distances from the recorded image

The NIDB has another unique function, which can determine the relative positions of the car involved. This function utilizes forward-facing video and enables us to measure the change in the relative position of the OTCAR soon to be rear-ended (or almost) by the DRCAR. The drive recorder, however, has only a monocular video camera, so it cannot record the scene stereoscopically. To solve this problem, it is assumed that the road is completely flat and level, which makes it possible to measure changes in the vehicles’ relative positions.

Figure 3 shows the procedure schematically. When the distortion of the lens installed in the DR is known, along with its mounted position and angle in the DRCAR, the position on the ground corresponding to each pixel in a video image can be calculated. The mounted height of the DR, an essential piece of data on its mounted position, can be equalized in all the DRCARs by mounting them at the same position. However, other variables such as pitch/yaw angles can vary from situation to situation because of the adjustable structure of a DR. In the NIDB, such unknown configurations can be calculated from the positions of the fender mirrors in the video image. Most taxis have fender mirrors (not door mirrors) in Japan, and the positions of the fender mirrors of each DRCAR are, of course, known, so the information required for this calculation is available.

Changes in the relative positions of OTCARs and DRCARs are recorded using the abovementioned function. In this study, the center of the rear end of an OTCAR is used to represent the position of the OTCAR.

The data obtained on the abovementioned premises cannot be expected to be highly accurate, because the logic is based on the assumption of flat and level ground, and the procedure involves complicated calculations. On the other hand, we think that this function is quite important as quantitative trends can be clarified to some degree by analyzing such a large amount of data.

3. Classification of Factors

3.1. Methodology

All the recorded video data relating to the extracted near-miss incidents and accidents were viewed to determine the factors

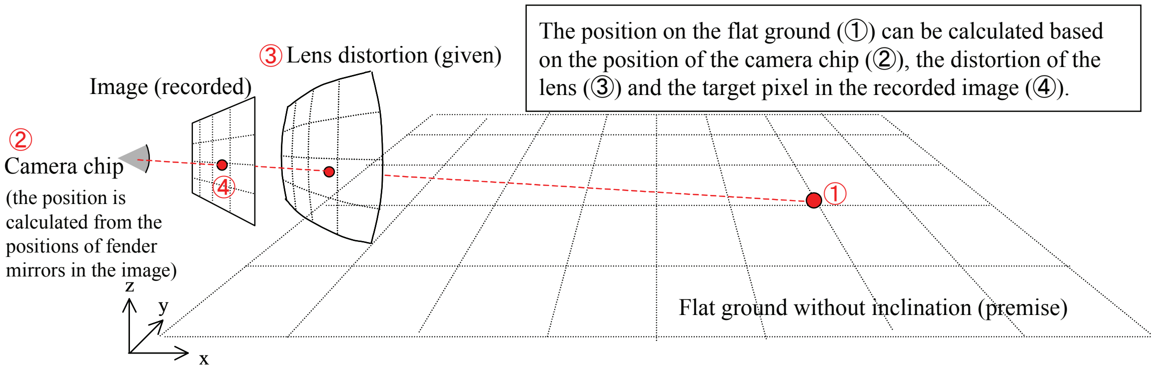


Fig.3 Determining the OTCAR’s relative position (assuming flat and level ground)

involved and the reasons these incidents and accidents occurred.

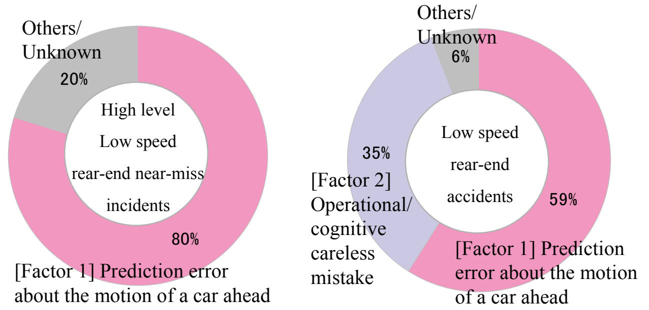
A DR can record only quite limited information, such as forward-facing video, running speed (acceleration/deceleration), ON/OFF of braking and turn indicator lights. This limitation, in many cases, makes it difficult to judge which factor should be counted in each event.

In this study, the factor is countered only when it can be clearly judged that the factor has caused the event. If multiple causative factors are highly probable in one event, all of them are counted. In those cases where it is difficult to determine the reason, the cause is classified as “unknown”.

3.2. Results and Discussion

Figure 4 shows the breakdown of factors involved in the extracted near-miss incidents (a) and accidents (b). These results indicate that there were relatively few factors involved in low-speed rear-end near-miss incidents/accidents and the following two factors accounted for quite a high percentage of the total. Factor 1, in particular, accounted for 80%/59% of all extracted near-miss incidents/accidents.

[Factor 1] Prediction error regarding the motion of the car ahead
[Factor 2] Operational/cognitive careless mistake



(a) Near-miss Incident (N=173) (b) Accident (N=16)

Fig.4 Breakdown of factors involved in low-speed rear-end near-miss incidents/accidents in the near-miss incident database

Figure 5 shows a typical example of a rear-end near-miss incident caused by Factor 1. In this case, the driver braked too late, causing a near-miss incident. It is apparent that Factor 1 caused late braking. In other words, while the driver mistakenly assumed that the car ahead was going to turn left smoothly, it actually stopped suddenly. There are also several similar cases in the recorded accidents.

Accidents caused by Factor 2 mainly included the following: a rear-end collision after creeping ahead by inadvertently releasing the brake pedal, a rear-end collision caused by the driver mistakenly thinking that a different traffic signal (e.g., a traffic signal turning green) meant that he could safely start moving forward. The former reason should be classified as an operational careless mistake, and the latter as a cognitive careless mistake. It is often difficult, however, to determine which reason caused the accident because of the limited information available from a DR. This is why it is difficult to separate Factor 2 into more detailed reasons in this study, which is why Factor 2 includes both given reasons. Figure 6 shows an example of an accident caused by Factor 2. In this case, the DRCAR suddenly started moving ahead and collided with the stationary car ahead.

The fact that there were no cases of Factor 2 involvement in

1. The left-turn signal of the car ahead starts blinking

2. The car ahead stops suddenly while turning left

3. This driver is forced to brake suddenly because of his mis-prediction of a smooth left turn

Fig.5 An example of a low-speed rear-end near-miss incident that seems to have been caused by Factor 1

1. Both cars are stationary for a red light

2. This car suddenly starts moving ahead while the signal is still red

3. This driver brakes just before the collision but it is too late to avoid the rear-end collision

Fig.6 An example of a low-speed rear-end collision that seems to have been caused by Factor 2

Figure 8 was incorrect in the final manuscript, so it has been revised in this revision.

near-miss incidents (other than actual accidents) suggests that, in practice, such operational/cognitive careless mistakes can easily lead to a collision.

In cases involving Factor 1 or 2, the drivers obviously made errors. Such wrong moves certainly increased their collision risk, and they should have been able to brake sooner than they did. In other words, only the drivers are at fault for such dangerous situations in almost all low-speed rear-end collisions. In addition, the motions of the cars involved are all one-dimensional; that is, braking is the key to avoiding a collision. This means that some kind of assist system for a driver's braking [11-13], such as a danger-warning system or autonomous emergency braking (AEB), would be quite effective in decreasing the number of low-speed rear-end collisions in Japan, if it could be activated appropriately.

On the other hand, many more factors can be expected in relatively high speed rear-end collisions, compared with incidents/accidents occurring at low speed. Here, "relatively high speed" means moving at more than 20 km/h just before braking or just before collision. Many more potential factors can be seen in the relatively high speed rear-end collisions in the NIDB; for example, sudden cut-in motion (two-dimensional motion) of OTCARs, insufficient braking force due to insufficient foot force used by the driver. There are also several cases in which DRCARs could narrowly avoid collision by steering. In addition, there are many more "unknown" cases in relatively high speed cases than low-speed ones.

The abovementioned findings of this study lead us to conclude that there are significantly fewer factors involved in low-speed rear-end collisions than in relatively high speed cases. This difference makes it necessary to consider rear-end collisions in the two speed ranges (and the events associated with them) as completely different phenomena.

4. Relative Approach Speed

4.1. Methodology

Using the distance-measuring function of the NIDB described in section 2.3., changes in distance from the front edges of DRCARs to the rear ends of OTCARs were calculated in all the extracted cases. Comparison of the changes in near-miss incidents with those in accidents is expected to help us to grasp their features.

Rear end points to be measured are out of frame of recorded images when a DRCAR is very close to the OTCAR. Such situations lead to missing distance data, which should be obtained by interpolation in some way.

In an accident, missing distance data is interpolated linearly with one end of the interpolated line corresponding to an actual measured distance, and the other end corresponding to zero distance at the trigger moment (approximately at the collision moment), because there actually was a collision.

In a near-miss incident, missing distance data is interpolated with a constant value, using the last measured distance value before the trigger moment (approximately the sudden-braking moment). In many near-miss incidents, however, all the distances prior to the triggers could be measured because DRCARs

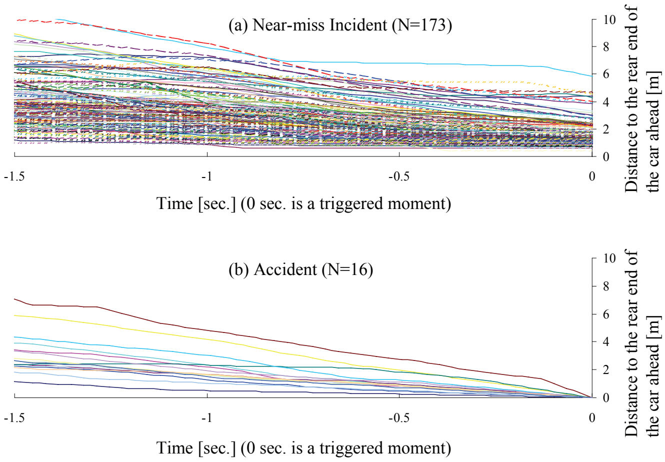


Fig.7 Before-the-trigger changes in separation distance between the front edges of DRCARs and the rear ends of OTCARs in all recorded low-speed rear-end incidents/accidents in the NIDB

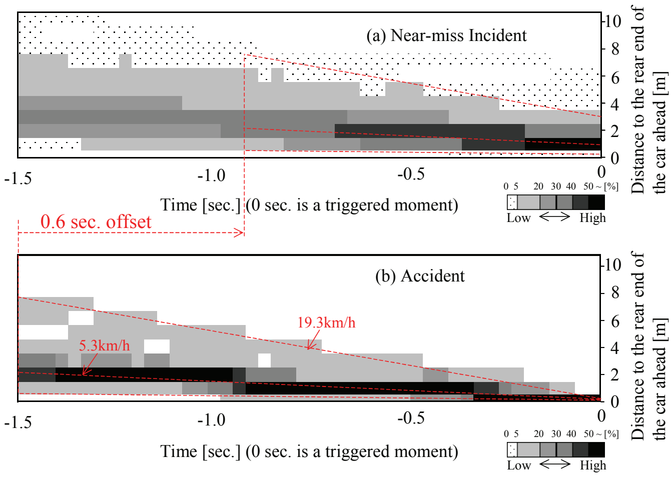


Fig.8 Density distributions of the approach speeds of DRCARs to OTCARs (monochrome color), and the likeness between incidents and accidents with a parallel shift of 0.6 seconds (Red color), based on the charts shown in Figure 7

generally braked farther away from the OTCARs than in actual collisions. 34% of all incident data was interpolated.

4.2. Results and Discussion

Figure 7 shows the distance changes from the front edges of DRCARs to the rear ends of OTCARs during the 1.5 seconds before the triggers. These charts include all the data on low-speed rear-end incidents (a) and accidents (b) recorded in the NIDB. The "0 second" of the horizontal axes is the moment the triggers of DRs were activated; that is, approximately, the moment of the start of a collision in the case of accidents, and the moment of pushing a brake pedal in the case of near-miss incidents.

Monochrome distribution charts in Figure 8 show the density distributions of the approach speeds of DRCARs to OTCARs, which are derived from the charts in Figure 7. A darker color indicates more cases in the corresponding situation with respect to time and distance.

In these distribution charts, the shapes of dark ranges are quite similar to each other when the time axis (horizontal axis) of the accident chart (b) is delayed for approximately 0.6 seconds. Red dotted lines in Figure 8 show the similarity. We are convinced that this indicates that the features of a large number of low-speed rear-end near-miss incidents resemble (accurately represent) those of actual low speed rear-end collisions. Moreover, this indicates that most drivers start their avoidance braking or steering more than 0.6 seconds before the collision. The value 0.6 seconds is just equal to one of the collision avoidance limits in the technical guideline for a braking device to mitigate “low speed” collision with obstacles ahead, issued by the Ministry of Land, Infrastructure, Transport and Tourism in Japan on May 22, 2009. In the guideline, the collision avoidance limit by steering is set at 0.6 seconds, and this value is basically used as the collision avoidance limit for a target safety device, in the range that collision avoidance by braking takes longer than avoidance by steering. Although it is true that the target condition in this guideline does not exactly correspond with that in this study, we can assume that the value “0.6 seconds” in the guideline is quite appropriate for the effective reduction of actual low-speed rear-end collisions.

In addition, several representative values describing approach speed are obtained from the slopes of the dark ranges in Figure 8. As shown by the words in red, the average and maximum relative approaching speeds are 5.3 and 19.3 km/h respectively. Here, “maximum” means that more than 95% of all the cases occurred at an approach speed of less than 19.3 km/h. This value, 19.3 km/h, is natural because the speeds of the extracted cases are limited to 20 km/h or less in this study. From the monochrome distribution in Figure 8, incidents and accidents at around the average speed (5.3 km/h) occurred quite frequently; and the frequency in the other speed ranges seems to be relatively constant. Such characteristics should be utilized for effective development or assessment of automotive active safety devices.

5. Overlap Percentage

5.1. Methodology

Using the same distance-measuring function as in the preceding section, the lateral offset to the center of the rear end of an OTCAR can be measured at the trigger moment (the “0 second” moment). Any missing lateral position data are interpolated with a constant value, using the last position measured before the trigger, for both near-miss incidents and accidents. Based on the lateral offset (L_O), the width of the DRCAR (W_D) and the width of the OTCAR (W_O), the overlap percentage (P_O) is simply calculated using the following formula in this study; i.e., obliquity is ignored (as outlined in Figure 9).

$$P_O = \frac{W_D + W_O - 2\cdot|L_O|}{2\cdot W_D} \times 100 \qquad (1)$$

1.7 m is used for W_D in all cases. 1.7 m and 0 m are used for W_O of a car and a motorcycle, respectively.

All cases including near-miss incidents and accidents are classified into two types, based on the relative angle of the longitudinal direction of the body of the OTCAR to that of the DRCAR at the trigger moment. One type is “ANGLED”, meaning that the heading direction of the OTCAR is, to some extent (approximately more than 20 degrees), different from that of the DRCAR. The other category is “PARALLEL”, which means they are almost completely aligned in parallel (all cases except for ANGLED). This classification is subjectively judged based on video images. ANGLED, for example, is assumed to cover a situation where the car ahead is turning, as shown in Figure 5. PARALLEL is assumed to be a rear-end collision like that in Figure 6.

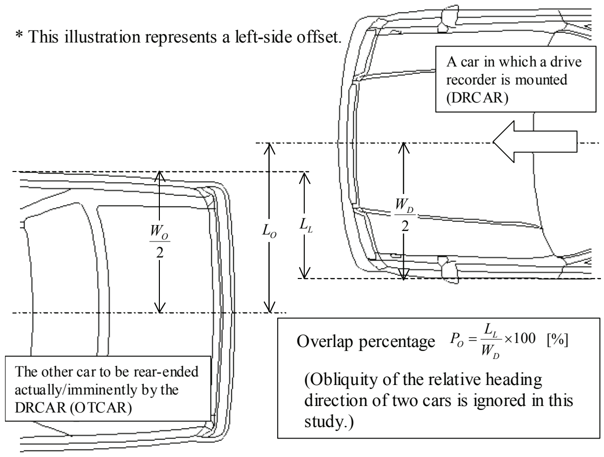


Fig.9 The definition of “overlap percentage” in this study

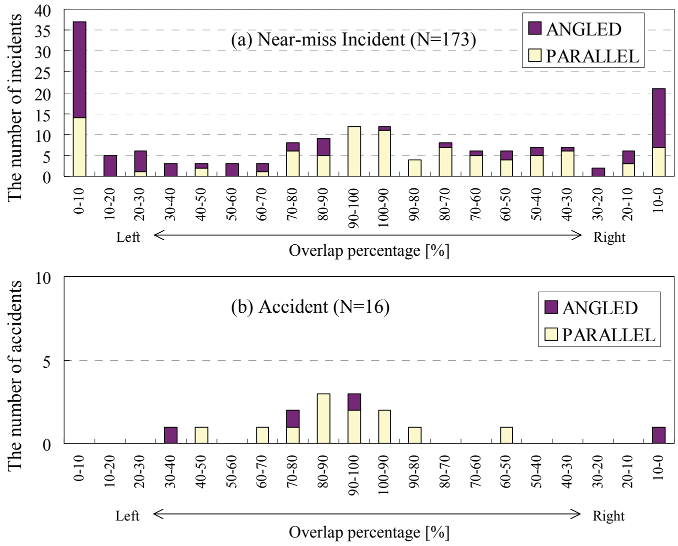


Fig.10 Frequency distributions of the overlap percentages by the relative angle classifications (ANGLED/PARALLEL) in the low speed rear-end incidents and accidents in the NIDB

Regrettably, this classification is based on subjective judgment. This is because only two-dimensional video images can be obtained, so accurate angles cannot be calculated. Even so, we think that this analysis is quite important because this kind of analysis has never been conducted at all.

5.2. Results and Discussion

Figure 10 shows the frequency distributions of the overlap percentages by classification into relative angles in the low speed rear-end near-miss incidents and accidents in the NIDB.

From the chart of the near-miss incidents (a), incidents with under 10% overlap account for quite a high percentage in both cases of left and right sides, and the secondary peak can be seen around 100% overlap (full-wrap). Another tendency can also be seen; the lower the overlap percentage is, the higher the proportion of ANGLED cases. These trends seem to be due to the large number of prediction-error near-miss incidents (Factor 1), like the cases described in Figure 5.

Comparing the right side distribution with the left side, the left side bars include many more ANGLED cases. It is assumed that the position of the traffic lanes causes this difference, which is related to the fact that auto drivers must keep to the left side of the road in Japan. This means that the turning radius while left-turning is generally smaller than for right-turning. As a result of this asymmetry, there are more ANGLED incidents with left side offset than right side.

In the bar chart of the accidents (b), most cases can be seen around 100% overlap. This large departure from the abovementioned trend of near-miss incidents is assumed to be caused by the ease of lateral avoidance by steering; the less the overlap percentage is, the more easily the driver can avoid colliding with the car ahead by corrective steering. For example, in Japan, the technical guideline for a braking device to mitigate low-speed collision with obstacles ahead permits a change in the collision avoidance time limit related to the overlap percentage. This changeability of such a limit value is quite appropriate from the viewpoint of this result.

On the other hand, it would be difficult to conclude that this result represents a major tendency of target accidents, because the bar chart (b) regarding accidents in Figure 10 is based on a small amount of data (N=16) and there are a few cases in which the overlap percentage is quite low. Considering chart (a) in Figure 10, there is no doubt that automobile drivers have more chances to meet imminent collisions (dangerous situations) in small-overlap states than in fully-wrapped states. Therefore, we are certain that situations with a small overlap must not be neglected. Also, studies on such small-overlap cases are as important as nearly fully-wrapped cases for the proper performance of various active safety devices.

AEB systems, for example, must be able to select the appropriate mode (e.g., activation or cancellation of automatic braking) according to many factors: not only distance and velocity, but also overlap percentage, relative heading angle, the possibility of corrective steering, and so forth.

Moreover, similar studies of small overlap collisions with pedestrians or bicycles are also important, because there are likely to be many accidents in which a car runs over them with a small overlap percentage, though this report does not target such situations. We think that such situations should be analyzed in the next stage of this study.

6. Circumstances

6.1. Methodology

In this section, we analyze three kinds of circumstances present at the moment when rear-end near-miss incidents occurred in the NIDB – time, weather and visibility. The aim of this section is to determine whether or not there is a difference in these circumstances for low-speed (20 km/h or less) and relatively high speed (more than 20 km/h) events. Mechanical braking performance is somewhat impaired by weather (rain wet roads); and the cognitive performance of drivers is sensitive to darkness, which is, of course, affected by weather and time of day. Poor visibility due to a fence or a building also affects their cognitive performance.

Here, the breakdowns of low-speed rear-end near-miss incidents are compared with those of relatively high speed ones. Not only data sets for low-speed rear-end incidents are considered, as in the preceding sections, but an additional 331 data sets for relatively high speed cases are analyzed.

6.2. Results and Discussion

This comparison revealed no significant difference under any of the environmental conditions. Their frequency of occurrence in all the speed ranges seems to be almost equal. Nevertheless a few small differences can be seen, whether significant or not.

Figure 11 shows the frequency distributions by hour (time of day) in the respective speed ranges (low speed and relatively high speed). Almost the same quite natural tendency can be seen: there are more incidents in the daytime than at night. This is because of the mileage traveled during the respective hours (the frequency is proportional to the mileage). However, there seem to be a few more of the relatively high speed cases at night (approximately 1 a.m. to 6 a.m.). This tendency is assumed to be due to the amount of traffic; i.e., average speed is usually lower in the daytime than at night, because there are more cars running in the daytime.

Comparisons regarding weather and visibility are shown in Figure 12(a) and (b).

As for weather (a), the incidence of wet conditions (rainy or snowy) is almost the same across all the speed ranges. In other words, the occurrence of such incidents is not influenced by bad weather. Only one range, 30~40 km/h, has a slightly larger percentage of wet data than the other ranges, for reasons currently unknown.

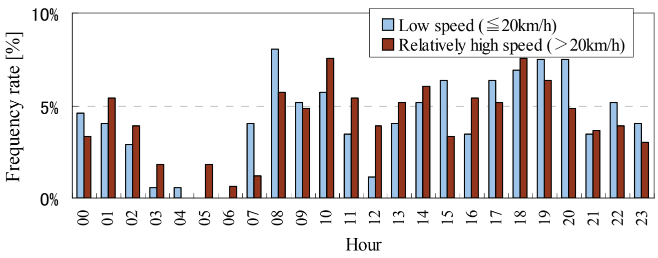


Fig.11 Occurrence frequency rates, as a function of the time of day, of rear-end near-miss incidents in the NIDB, for each speed range at low speed (20 km/h or less) and relatively high speed (more than 20 km/h)

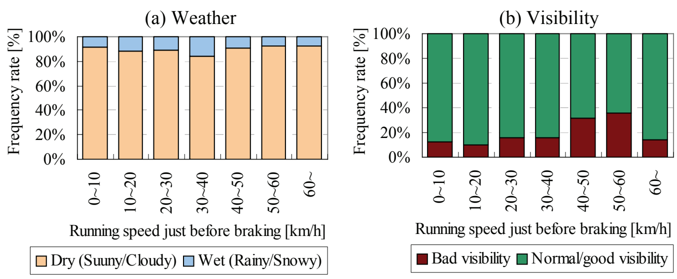


Fig.12 Occurrence frequency rates, as a function of the speed just before braking, of rear-end near-miss incidents in the NIDB, including weather and visibility conditions

From the trend under 60 km/h in the visibility chart (b), the higher the speed, the more frequently incidents occur. Most of the cases at over 60 km/h occurred on expressways, because the legal speed on local streets is limited to less than 60 km/h in Japan, and expressways have good visibility. This is why the incidence above 60 km/h is quite low. On the other hand, in local streets, bad visibility is likely to affect the probability of relatively high speed rear-end near-miss incidents. Certainly, the existence of surrounding fences/buildings is assumed to have little to do with the occurrence of low speed rear-end collisions/incidents.

The charts obtained here indicate that any active safety technology should not be specialized to deal with particular environmental circumstances, but should be versatile enough to be useful in any situation. When priorities must be assigned, the most frequently occurring situations should be considered first.

7. Conclusion

Based on the numerous data sets recorded by DRs and stored in the NIDB, several characteristics of low speed rear-end collisions/near-miss incidents emerge:

1. There are significantly fewer factors involved in low-speed rear-end collisions than in relatively high speed cases. This difference makes it necessary to consider the two speed ranges for rear-end collisions (and the events associated with them) as completely different phenomena.
2. The approach processes relative to a car ahead in low-speed rear-end accidents and near-miss incidents are quite similar to each other when the times for the accident cases are delayed for approximately 0.6 seconds. This indicates that most drivers start their collision avoidance actions more than 0.6 seconds before the collision. It was also found that the average relative approach speed is 5.3 km/h; and incidents/accidents at around the average speed occurred quite frequently. Such patterns of events should be utilized for effective development or assessment of automotive active safety devices.
3. Low-speed rear-end near-miss incidents with under 10% overlap account for quite a high percentage in both left- and right-side cases, and a secondary peak can be seen around 100% lateral overlap (full-wrap). Moreover, the less the overlap percentage, the more higher the proportion of ANGLED cases (where the heading directions of the two involved cars are different). However, accident data sets have another type of trend, showing a much lower frequency of cases with small overlap. Considering these trends, AEB systems, for example, must be able to select the appropriate mode (activation or cancellation of automatic braking) according to many factors, including not only distance and velocity, but also overlap percentage, relative heading angle, and the presence or absence of corrective steering.
4. No single dominant feature of the circumstances surrounding rear-end near-miss incidents could be found, though three particular environmental variables were considered – time, weather and visibility. This indicates that any active safety technology should not be specialized for any particular set of circumstances, but should be versatile enough to deal with any situation. When priorities must be assigned, the most frequently occurring situation should be considered first.

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