Winter Road and Human Factors  
- A Study on Driving Behaviors under Snowstorm-Induced Visibility Hindrance -

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INTRODUCTION

In winter, drivers in cold, snowy regions face the severe driving environment of snow-induced visibility hindrance and icy roads. The lack of visual orientation that accompanies snow-induced visibility hindrance leads many drivers to tailgate in an attempt to orient themselves by following the taillights of the car running ahead. Since these drivers must make risk avoidance rapidly and properly when the car ahead slows or stops, their driving behaviors are considered to be a major factor in the occurrence of road accidents. Research done by the Civil Engineering Research Institute of Hokkaido has revealed the tendency for drivers who have more difficulty driving on winter roads, such as elderly drivers, to show greater individual differences in obstacle avoidance maneuvers under visibility hindrance. Such drivers are found often to take extreme actions, such as sudden and forceful brake application or sharp turning of the steering wheel.

The authors have been involved in the development of a driving safety support system that uses the ITS technology of Cold-Region AHS, toward establishing measures to prevent car accidents in winter. A comprehensive examination of various factors such as driver response and car behaviors is needed, in order to implement the system effectively. Thus, the authors experimented on driving behaviors of test drivers under snowstorm on a road in service.

EXPERIMENTAL METHOD

The experiment was done on National Route 275 in the Kakuyama district of Ebetsu City (Figure 1). The experiment site is a two-lane road surrounded by flat open land and including a gentle curve. Because multi-vehicular collisions had occurred several times before the experiment period, a snowbreak forest and snow protection fences had been installed on the west side of the road. The test car, a visibility hindrance observation vehicle (Figure 2), was used to measure driving behaviors, car behaviors, and weather conditions. Measurement data were recorded at 10 Hz, and the conditions of any cars running ahead were filmed using a video camera installed beside the driver's seat. Five test drivers were chosen, all males age 22 to 35 who were accustomed to driving on winter roads. In the test, the drivers drove back and forth on the test section several times.

DRIVING BEHAVIORS UNDER FINE WEATHER AND SNOWY WEATHER

Examples of driving behaviors of the test drivers in fine weather and snowy weather selected from among the measurement data of 38 driving test runs are shown in Figure 3. The case of fine weather was measured in daytime on March 7, when the road was wet.
The case of snowstorm was measured in the daytime on the following day, when the road was covered with compacted snow and the visibility was intermittently reduced to between 50 and 100 m by severe snowstorm. The horizontal axis in the figure indicates distance by kilopost (KP); the vertical axis indicates driving maneuver and car behavior.

In the case of fine weather, the test car accelerated at the signalized intersection (KP 6.5), maintained a constant speed, then slowed down (KP 9.0). It showed a smooth change of speed. After forceful accelerator application at acceleration, the car kept a generally constant speed, the steering angle remained steady, and there was no brake application.

Under snowstorm, the test car showed considerable variation in speed and the speed was lower than under fine weather. There were also changes in accelerator application force and acceleration, which were accompanied by changes in steering angle and in the number of brake applications, despite the test section not containing any sidestreets.
IMPACT OF VISIBILITY HINDRANCE ON DRIVING BEHAVIORS

Driving behaviors are believed to become unsteady under severe visibility hindrance, as shown in the case above. Such changes in behaviors are expected to be affected by factors including the presence of other vehicles, road alignment and the presence of an intersection. Accordingly, data were sampled on several sections without sidestreets and with a uniform surrounding environment and on a single section with a signalized intersection where cars tend to stop frequently. The impact of visibility hindrance on driving behaviors was examined for each of these two types of section.

Sections without sidestreets

We chose five sections with a monotonous (non-varied) surrounding environment from the test sections, to sample the measurement data at 10 Hz of each section.

Figure 4 and Figure 5 respectively indicate the relationship between the traveling speed and the visibility range, and that between standard deviation in traveling speed and the visibility range. The traveling speed shows a tendency to drop with the decrease of visibility range, a trend that was particularly noticeable when the visibility range was 200 m or less. Traveling speed (standard deviation) also showed a tendency to increase with the decrease of visibility. Although the traveling speed is believed to be affected by the behaviors of the car ahead, the daytime test of visibility hindrance indicated a considerable change in traveling speed irrespective of the presence of the car ahead. Since the data of acceleration (a positive value for acceleration and a negative value for deceleration) and the accelerator application force showed a tendency similar to that of traveling speed.

Figure 6 shows the relationship between maximum brake application force and the visibility range. Two cases of relatively forceful brake application were observed when the visibility range was approximately 100 m. In all cases, the test car was surrounded by other cars. The video image taken from inside the car indicated that such brake
application did not result directly from obstruction by surrounding cars but rather from
the driver's extreme reaction to the presence of other cars. Moreover, gentle brake
application was recorded in the case with visibility hindrance and the occurrence of
gentle brake application showed a tendency to increase with the decrease of the visibility
range even though the traveling speed remained unchanged. Such cases are attributed to
test drivers touching the brake pedal so as to be able to respond quickly to unexpected
events, such as the stopping of cars under reduced visibility.

Figure 7 shows the relationship between the visibility range and the number of brake
applications, excluding inevitable brake application such as that due to obstacles or
traffic congestion, on a section without sidestreets (KP 7.0 to KP 8.6). Although under
fine weather no braking was recorded even when vehicles were running ahead, the test
driver applied the brakes once or twice under the visibility range of 100 m or less
despite the absence of obstacles. Because the video image showed intermittent
reduction of the visibility range, such braking is attributed to sudden visibility reduction.

With regard to the relationship between the standard deviation of the steering angle and
the visibility range (Figure 8), although no clear relationship is observed, the steering
fluctuation tended to increase with the decrease in the visibility range in the absence of
the car running ahead.

Signalized intersection

The test section has one signalized intersection, through which each driver passes twice
(once in each direction). An experiment focused on driving behaviors when the vehicle
enters the intersection.

(1) Under green traffic light

The driving behavior at the intersection under green light is expected to be similar to
that the sections without sidestreets. Examination of the 10 seconds of driving
behavior before entering the intersection showed the same tendency as that on the
sections without sidestreets (i.e., a tendency for the driving behavior to become
unsteady with a decrease in the visibility range), except regarding brake application
point and force.
Figure 8. Standard deviation of steering angle, and visibility range

Figure 9. Braking maneuvers when entering the intersection under green light

Figure 9 shows the relationship between the maximum brake application force and the visibility range when the test car entered the intersection under green light. Relatively forceful brake application was noted under visibility hindrance when there was no car ahead or when the car ahead was far ahead. The driver is believed to exercise more care in passing through the intersection than in traveling on the road without sidestreets, although the cause of braking on the road without sidestreets (the presence of a car immediately ahead or beside) differed from the cause for braking at the intersection.

(2) Under red traffic light

In focusing on the connection between braking and the visibility range when the car stops at the red light, we examined the relationship between the maximum brake application force and the brake application point (relative to the stop line) under fine weather and under snowstorm (visibility range of 200 m or less) (Figure 10). The points of maximum brake application force were widely and irregularly distributed between 100 m from and immediately before the stop line under fine weather. Under snowstorm, the points of maximum brake application force showed a tendency to concentrate about 50 m from the stop line. This is result of the driver's inability to distinguish the traffic light in the distance, which prompts sudden forceful brake application before an intersection that he considers dangerous. When the car was close to the stop line, the brake application force was great in several cases.

Figure 11 shows the maximum increase in brake application force for 0.1-second intervals and the distance between the brake application point and the stop line, to reveal the conditions of forceful brake application. (In contrast to Figure 10, the focus here is on the suddenness of brake application rather than the force of brake application.) While the points of forceful brake application were distributed widely between 100 m from the stop line to immediately before the stop line under fine weather, those under snowstorm were concentrated closer to the stop line. Thus, the closer to the stop line became the brake application point, the more sudden brake
application became.

The above observation clarifies that before the intersection under red light, the brakes are applied earlier under snowstorm than under fine weather; but that the later the brakes are applied (i.e., the closer to the stop line), the more forceful is brake application. Under decreased visibility, such braking is likely to cause an accident or dangerous situation.

**DRIVING BEHAVIORS OF THE ELDERLY UNDER VISIBILITY HINDRANCE**

Because the test was conducted on an ordinary highway under severe snowstorm, the test drivers were chosen as males accustomed to driving in winter, in consideration of safety. A driver not accustomed to driving on a winter road is expected to be more greatly affected by visibility hindrance. Therefore, the results of a test of driving behaviors of elderly (conducted on a test course in 1998 by the authors) were compared with those of the test described in the preceding sections.
Data of steering angle in the straight section under similar test conditions were chosen from data of both tests, for mutual comparison (Figure 12). This revealed that the change in steering angle of elderly driver exceeded that of the test driver accustomed to driving on a winter road. Considering that the test in 1998 was done on the test course without sidestreets or the presence of other cars, the change in steering angle for the elderly driver will be much greater on an ordinary road.

CONCLUSION

The test of driving behaviors under visibility hindrance in winter clarified the following. The traveling speed shows a tendency to decrease with a decrease in visibility range, while the changes in driving behaviors such as acceleration/deceleration and steering angle tend to increase. Moreover, braking was observed to be due to changes in circumstances, such as in visibility range under severe visibility hindrance.

A comparison of the previous test results of driving behaviors for elderly drivers with the test results of the present experiment has clarified that steering control for elderly drivers changes more greatly under severe visibility hindrance than it does for the non-elderly drivers of the present experiment. The test conditions, however, were not identical.

Under snowstorm, driving behavior at the intersection under green light is largely the same as that on the section without sidestreets, except that drivers are more careful at the intersection. Also, drivers show a tendency to apply the brake closer to the intersection under red light in snowstorm than in fine weather. It was also found that the closer the brake application point becomes to the stop line, the greater becomes the brake application force and the earlier the brake application becomes.

The tests clarify driving behaviors under snowstorm to the extent described above. Under snowstorm, where there are few points for visual orientation, many drivers use half-visible signs along the road. Even so, they tend to slow down suddenly when they encounter other cars or reduced visibility, and such driving behaviors are likely to cause accidents. As snowstorm countermeasures, the government has installed snow protection fences, snowbreak forests, and delineators. In addition, ITS technology has been used recently to prevent accidents. We would like to investigate human factors more thoroughly, toward enhancing the effectiveness of these ITS safety measures.

REFERENCES