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Evaluating the Degree of Visibility Deterioration Perceived by Drivers during Snowstorms

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ABSTRACT

Road closures and multi-vehicle collisions often result from poor visibility caused by snowstorms in cold snowy regions. It is therefore important to grasp visibility conditions in snowstorms. Currently, visibility meters are used to determine visibility based on the MOR (meteorological optical range) value calculated from atmospheric extinction coefficients or scatter coefficient measurements. However, in road traffic environments, delineators and various other visual guides are installed along routes, and the visibility perceived by drivers in snowstorms may vary even for the same MOR value. Despite this, no parameter has yet been devised to support comprehensive evaluation of visibility deterioration. Accordingly, this study investigated the relationship between MOR values measured using a visibility meter and visibility/driving difficulty as perceived by drivers, and also examined a method for the rating index of visibility deterioration.

Keywords: winter road, snowstorm, poor visibility, driving difficulty

1 INTRODUCTION

As road closures and multi-vehicle collisions often result from poor visibility caused by snowstorms in cold snowy regions, it is important to grasp snowstorm visibility conditions to enable appropriate implementation of traffic restrictions and to support the provision of appropriate information to drivers. According to the World Meteorological Organization (WMO), the meteorological term visibility refers to the maximum distance at which a dark object against a sky background can be discerned with the naked eye during the day [1]. Currently, visibility meters are used to determine visibility based on the MOR (meteorological optical range) value calculated from atmospheric extinction coefficients or scatter coefficient measurements because of problems such as visibility measurements being influenced by the subjectivity of observers, and continuous visibility monitoring is impossible. The MOR defined as the length of path in the atmosphere required to reduce the luminous flux in a collimated beam from an incandescent lamp, at a colour temperature of 2700 K, to 5 per cent of its original value [1].

Another indicator known as RVR (runway visual range) is used as a visibility index for aircraft taking off and landing. RVR is the maximum distance over which an aircraft pilot can see the runway surface, lights and markings in the touchdown zone [1]. In this regard, it can be seen as an indicator related to aircraft operation. In road traffic environments too, delineators and various other visual guides are installed along routes, and the degree of visibility as perceived by drivers in snowstorms is considered to vary even when the MOR value is the same. Despite this, no parameter has yet been devised to support comprehensive evaluation of visibility deterioration. Accordingly, this study investigated the relationship between MOR values measured using a visibility meter and visibility/driving difficulty as perceived by drivers, and also examined a method for the rating index of visibility deterioration.

2 HUMAN SUBJECT EXPERIMENT

It is difficult to have subjects with varying attributes drive on actual roads in snowstorm conditions to determine the degree of visibility as perceived by drivers, as such experiments would involve a high risk of traffic accidents. In addition, as snowstorm intensity varies with time, it is impossible to conduct surveys under uniform climatic conditions. Against this background, video footage taken from a moving vehicle in a snowstorm was displayed on an indoor screen in this study to allow the subjects to safely assess forward visibility and driving difficulty.

2.1 Survey Method

To clarify the effects of roadside facilities on the degree of perceived visibility, video footage was recorded from a vehicle traveling in a snowstorm. The vehicle was equipped with a visibility meter, and visibility was measured while the road conditions were filmed. From the video obtained, the following roadside conditions were identified:

- Delineating facilities (fixed-post delineators, delineators) – Fig. 1
- Snow control facilities (collector snow fences, blower snow fences) – Fig. 2
- Continuous woods along routes
- Roadside barriers
- Roadside houses
- Utility poles

Fixed-pole delineators with arrow-shaped pointers were classified as either LED-embedded light-emitting or non-light-emitting types. A total of 172 ten-second videos recorded during the day with a measured visibility of less than 500 m were analysed.

The videos were shown indoors on a screen measuring 2.10 m high by 3.05 m wide to the subjects, who were then asked to complete questionnaires. Beforehand, the subjects were seated at approximately 3.5 m from the screen so that the visual angle would be the same as that from a driver's seat (see Fig. 3 and Fig. 4). Around 10 subjects participated in each experiment, and it was assumed that there was no difference in view by seating position. First, a sample video (Fig. 5) was shown to the subjects to help them evaluate distances on roads before the test videos were played. To avoid subject fatigue, the number of videos shown per experiment was limited to 46. After each one, the subjects were asked to fill out a survey sheet as shown in Fig. 6 to assess visibility and their driving intentions. It should be noted that driving intentions were assessed for certain videos only. Table 1 shows the number of subjects and their attributes. All had driver's licenses. The vision in both eyes required to obtain/renew a regular driver's license in Japan is 0.7 or more.

Fig. 1 Delineating facilities (left: fixed-post delineators with arrow-shaped pointers; right: delineators)

Fig. 2 Snow control facilities (left: collector snow fence, right: blower snow fence)

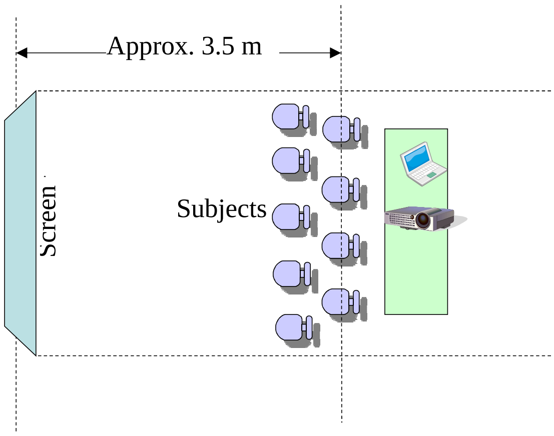
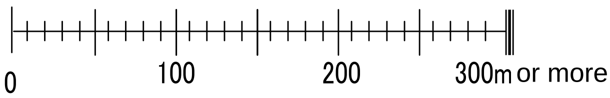


Fig. 3 Plan view of the subject experiment

Fig. 4 Experiment setup

Fig. 5 Sample Image, which indicates the lines of 70 m and 140 m distance

Question No. 1: Perceived Visibility



Question No. 2: Driving intention

Options	***Driving behaviour the subject would choose based on the road conditions shown in the video***
5	I'd keep driving at normal speed because visibility is relatively good.
4	I'd keep driving slowly due to poor visibility.
3	Driving would barely be possible, but I'd stop the car if there was a convenience store, a gas station or some other place to park.
2	I'd rather pull over because it would be difficult to drive, but I think I'd have to keep driving.
1	I'd pull over because it would be impossible to drive.

Fig. 6 Questionnaire on perceived visibility and driving intentions

Table 1 Number of subjects (respondents) and their attributes

		No. of respondents to the question on perceived visibility	No. of respondents to the question on driving intentions
Gender	Male	178	73
	Female	190	88
Age	20s	82	40
	30s	135	53
	40s	78	36
	50s	37	15
	60s +	36	17

2.2 Experiment Results

Figure 7 shows the relationship between assessed visibility and MOR values measured using a visibility meter with and without roadside facilities such as delineators. The median value of all the assessments was taken as the level of perceived visibility for each video. In the figure, the subject experiment results for roads with delineating facilities are shown on the left, those with snow fences and safety barriers in the middle, and those with houses, woods and utility poles on the right. For comparison purposes, the results for cases without roadside facilities are shown in all the figures.

The figures indicate that perceived visibility was less than 100 m for a MOR value of 300 m when there were no roadside facilities. Thus, it was confirmed that visibility as perceived by subjects on roads without roadside facilities in a snowstorm was lower than the MOR value. For roads where fixed-post delineators with arrow-shaped pointers, delineators and other delineating facilities were installed (Fig. 7, left), perceived visibility was between 50 m and 150 m for MOR values from 100 m to 200 m (i.e., less than the MOR value). However, the difference in perceived visibility and MOR decreased with lower MOR values. This trend was also seen with other roadside facilities. Figure 7 also shows that visibility as perceived by the subjects was greater for roads with delineating facilities than for those without.

Figure 8 shows the relationship between driving intention responses and visibility measured using a visibility meter. For the evaluation of driving intentions for each image, the median of all responses was used. Figure 8 indicates that Option 1 ("I'd pull over because it would be impossible to drive") was chosen only when there were no roadside facilities in conditions with MOR values of less than 100 m. In cases where roadside facilities (e.g., delineators) were present, the subjects indicated driving intentions between Option 2 ("I'd rather pull over because it would be difficult to drive, but I think I'd have to keep driving") and Option 4 ("I'd keep driving slowly due to poor visibility") even when the MOR value was less than 100 m. As stopped vehicles are known to cause multi-vehicle collisions in snowstorms [2], eliminating such stopping is expected to greatly contribute to the prevention of snowstorm-induced traffic accidents.

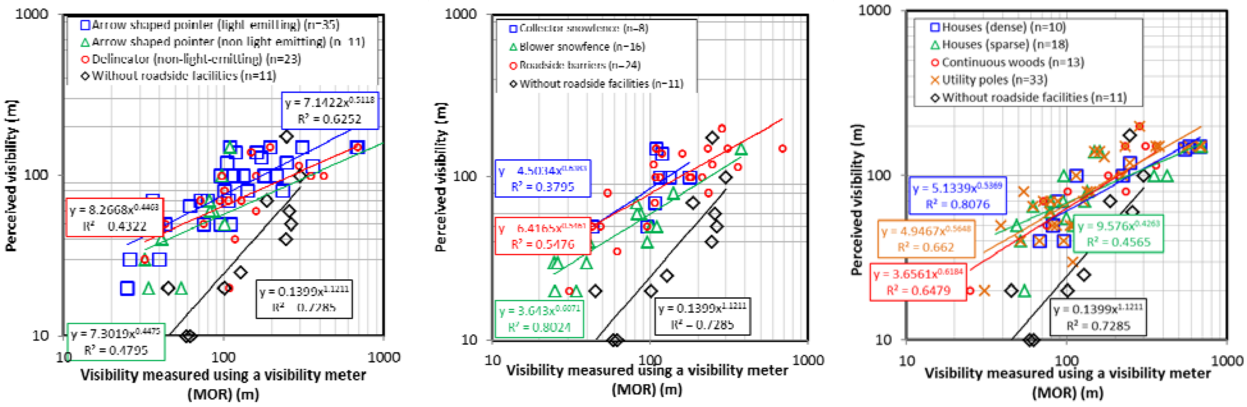


Fig. 7 Relationship between perceived visibility and that measured using a visibility meter: comparison of conditions with and without roadside facilities and comparison among roadside facilities.

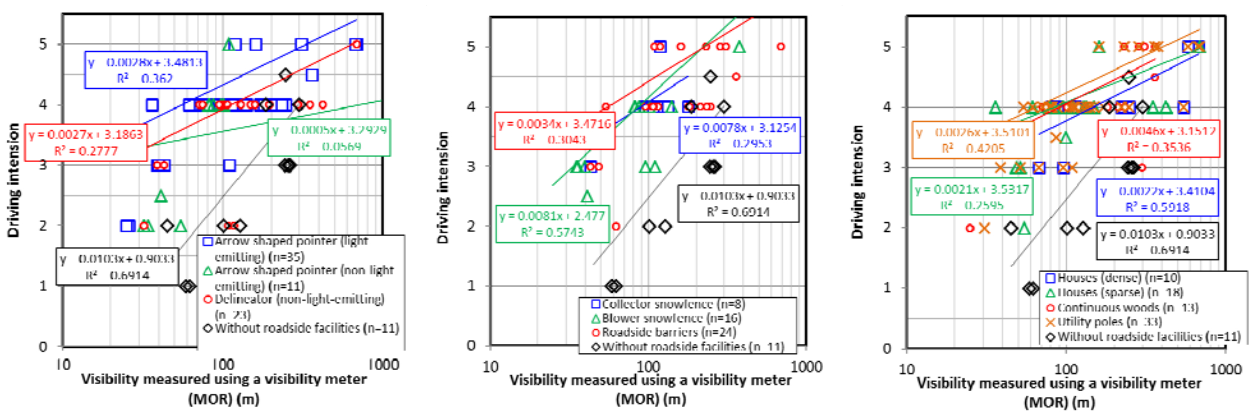


Fig. 8 Relationship between driving intentions and visibility measured using a visibility meter: comparison of conditions with and without roadside facilities and among roadside facilities.

3 EFFECTS OF ROASIDE/METEOROGICAL CONDITIONS ON PERCEIVED VISIBILITY

As indicated by the results shown in Fig. 7, perceived visibility is influenced by the presence of delineating facilities, snow control facilities, utility poles, roadside houses and so on. However, the effects of roadside facilities other than those studied in the experiment are not taken into account. In fact, numerous types of roadside facilities are installed along roads, exerting combined impacts on perceived visibility and driving intentions. In addition to issues of visibility (MOR) measured using a visibility meter, meteorological conditions (e.g., snowfall) are also considered to affect perceived visibility and driving intentions. Accordingly, this chapter discusses quantitative determination for the effects of roadside and meteorological conditions on perceived visibility through multivariate analysis. The following five items were used as roadside environment explanatory variables:

- Fixed-post delineators with arrow-shaped pointers
- Delineators
- Snow control and other facilities (snow fences, woods along routes and roadside barriers)
- Utility poles
- Houses

The following were used as meteorological condition explanatory variables:

- Visibility (MOR) measured using a visibility meter
- Visibility fluctuation (Equation 1) [3]
- Snowfall

$$I = \frac{\sqrt{\left(\bar{V} - V\right)^2}}{\bar{V}} \cdot 100 \quad \cdots\cdots\cdots\cdots\cdots \quad (1)$$

Where, I: Visibility fluctuation (%),
V: Visibility (m)
$\bar{V}$: Average visibility (m) during each ten-second video clip

All the explanatory variables except for visibility (MOR) measured using a visibility meter and visibility fluctuations are qualitative (categorical variables). Quantification method I was therefore used for analysis in this study. Table 2 shows the number of categories for each explanatory variable and their descriptions. As it was found in the process of analysis that delineators had little effect on perceived visibility, they were excluded as explanatory variables. The analysis results are shown in Table 3, which suggests that the presence of fixed-post delineators, continuous facilities (e.g., snow control structures) and utility poles improved perceived visibility by approximately 13 m, 21 m and 18 m, respectively. This indicates that the impact of roadside facilities on perceived visibility is small in low-visibility conditions, but is relatively large when visibility is extremely low.

Table 2 Objective and explanatory variables

Objective variable	***Explanatory variables***	***No. of categories and their description***	
Poor visibility	**Visibility measured using a visibility meter (average for the survey period)**	1	Less than 50 m
		2	From 50 to 100 m
		3	From 100 to 200 m
		4	200 m or more
	Visibility fluctuation	1	Less than 50%
		2	From 50% to 100%
		3	100% or more
	Snowfall.	1	Yes
		2	No
	Fixed-post delineator with arrow-shaped pointers	1	Yes
		2	No
	Snow control and other facilities	1	Yes
		2	No
	Utility poles	1	Yes
		2	No
	Houses	1	Yes
		2	No

The results shown in Table 3 were organized to create an evaluation sheet in order to support the estimation of perceived visibility based on meteorological conditions and roadside facilities (Table 4). As visibility fluctuation is not usually measured, and the extent of its impact on perceived visibility is low, it is considered that the score for such fluctuation can be set to -2 assuming that its scale is 50% or more.

Figure 9 shows the results of comparison between perceived visibility as determined in the subject experiment and that estimated based on Table 4. The determination coefficient was 0.55. It is considered that assessing the severity of visibility deterioration in snowstorms on a several-point scale is highly feasible, and that there is no need to evaluate with a meter-scale level of accuracy. Accordingly, this method is deemed suitable for assessing perceived visibility.

Table 3 Results of multivariate analysis (quantification method type I)

Items	*Category*	*Category score*	*Partial correlation coefficient*
Visibility measured using a visibility meter	1	-33.5504	0.6521
	2	-17.3166	
	3	16.9696	
	4	40.1106	
Visibility fluctuation	1	1.7069	0.0604
	2	-1.8146	
	3	-1.8766	
Snowfall.	1	-3.9284	0.3139
	2	24.2249	
Fixed-post delineator with arrow-shaped pointer	1	6.8296	0.2031
	2	-6.3692	
Snow control and other facilities (snow fences, woods along routes and roadside barriers)	1	12.1277	0.2837
	2	-8.5254	
Utility poles	1	8.9204	0.2623
	2	-9.1303	
Houses	1	13.0103	0.2826
	2	-7.7098	
Constant term		72.8779	

Multiple correlation coefficient = 0.7411
Determination coefficient (squared multiple correlation coefficient) = 0.5492

Table 4 Perceived visibility evaluation sheet

Items	**Rating standard**	**Score**	
a. Visibility measured using a visibility meter (average for the survey period)	< 50m	-34	
	50-100m	-17	
	100-200m	17	
	>=200m	40	
b. Visibility fluctuation	<50%	2	
	>=50%	-2	
c. Snowfall.	Yes	-4	
	No	24	
d. Fixed-post delineators	Yes	7	
	No	-6	
e. Snow control and other facilities	Yes	12	
	No	-9	
f. Utility poles	Yes	9	
	No	9	
g. Houses	Yes	13	
	No	-8	
h:Total (=a+b+c+d+e+f+g)			
Visibility (=h+73) (m)			

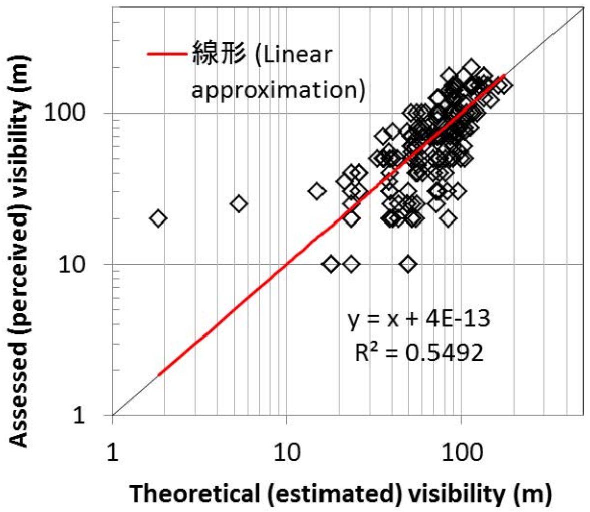


Fig. 5 Comparison of visibility: assessment in the experiment vs. estimation

4 PROPOSAL OF A RATING INDEX FOR VISIBILITY DETERIORATION

As stated previously, stopped vehicles in conditions of poor visibility are known to cause multiple-vehicle collisions [2]. Difficulty in driving can be regarded as an effective indicator of the degree of visibility deterioration. Driving intentions indicated in the experiment were influenced by driving difficulty as perceived by the subjects according to snowstorm-induced poor visibility conditions. Accordingly, it was decided to create a rating index for visibility deterioration based on driving intentions in snowstorms.

The relationship between perceived visibility and driving intentions identified in the subject experiment is shown in Fig. 10, which indicates a trend toward lower driving intentions (higher driving difficulty) with reduced visibility. As there is a high correlation between these two, it is considered that driving difficulty can be determined from visibility as perceived by drivers in snowstorms. A method for rating visibility deterioration on the basis of Table 4 and Fig. 10 was examined with driving difficulty taken to represent poor visibility. As a result, a technique for rating snowstorm-induced visibility deterioration on a five-level scale was developed (Table 5).

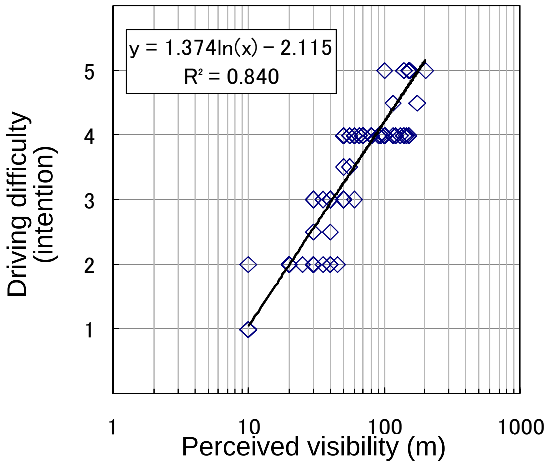


Fig. 10 Perceived visibility and driving difficulty (intentions)

Table 5 Rating of snowstorm-induced visibility deterioration

Rank	Visibility (m)	Driving difficulty
A	125 or more	Driving at normal speed is possible.
B	60 - 125	Driving at low/reduced speed is possible.
C	30 - 60	Driving is barely possible and risky.
D	15 - 30	Driving is difficult and extremely risky.
E	Less than 15	Driving is extremely difficult.

5 CONCLUSION

The subject experiment revealed that visibility as perceived by drivers tended to be shorter than visibility (MOR) measured using a visibility meter. It was also found that perceived visibility tended to be better when roadside facilities were present to provide visual targets than when there were no such facilities. In addition to the use of MOR values measured using a visibility meter, multivariate analysis was also performed in consideration of the presence of roadside facilities to examine a method for estimating visibility as perceived by drivers on roads. Further, a technique for evaluating visibility deterioration on a five-level scale based on perceived visibility and driving intension was proposed. The results also enabled quantitative evaluation of the influence of roadside facilities on perceived visibility in snowstorms.

6 REFERENCES

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