RELATIONSHIP BETWEEN TREE DENSITY AND VISIBILITY IMPROVEMENT FOR HIGHWAY SNOWBREAK WOODS

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ABSTRACT

In highway snowbreak woods that have grown to maturity, the branches of adjacent trees overlap and the leaves shade each other. This causes branches near the ground to die. Such dying allows snow to penetrate through the woods, which reduces visibility on the road. To prevent low branches from dying, stand thinning at the appropriate time is necessary. However, such thinning reduces tree density, which raises concerns about temporary reductions in visibility improvement. Because of this concern, there are highway snowbreak woods that have not been properly thinned.

To examine the relationship between the tree density of highway snowbreak woods and the visibility improvement they afford, the authors conducted field surveys and wind tunnel tests. From those surveys and tests, the minimum tree density that maintains visibility improvement was determined.

The study found the following:

1) Highway snowbreak woods improve visibility under snowstorm conditions.
2) The tree density of a snowbreak woods greatly influences the visibility improvement afforded by the woods.
3) Leaf-area index influences visibility improvement.
4) To improve visibility, the tree density for a 32-m-wide snowbreak woods should be at least 400 trees per hectare.

KEYWORDS

BLOWING SNOW / WOODS / VISIBILITY / TREE DENSITY

1. INTRODUCTION

Highway snowbreak woods are formed by planting tree zones either on the windward side or on both sides of highways, lowering the wind speed to reduce snowdrift formation and the visibility reductions caused by snowstorms.

Highway snowbreak woods in Japan debuted in 1978. The woods planted at that time are now more than 10 m in height. Snowbreak woods and snow fences are among Japan's main snowstorm countermeasures.

In mature highway snowbreak woods, the branches of adjacent trees overlap, contributing to the death of lower branches. This allows snow particles to penetrate through the woods, including below the branches, whereby the woods become less effective at improving visibility on the highway. To keep lower braches from withering and dying, the planted trees need to be thinned and other trees need to be culled at the appropriate times. This raises concerns about temporarily reductions in the visibility improvement afforded by the woods, because thinning lowers the tree density. Due to such concerns, there are highway snowbreak woods where thinning has been delayed.

To clarify the relationship between tree density and the visibility improvement afforded by highway snowbreak woods, we conducted field surveys and wind tunnel tests. Field surveys of visibility and other data were done for a highway snowbreak woods in Hokkaido. The wind tunnel tests modeled the surveyed highway snowbreak woods so as estimate the tree density that affords visibility sufficient for driving.

2. Field Survey

2.1 Survey locations

Field surveys comparing the visibility improvement afforded by tree zones with differing tree densities were performed at a snowbreak woods on a national highway in the town of Teshio, northern Hokkaido. The observed road consists of two mostly straight lanes oriented northwest to southeast. The planting of the snowbreak woods began in 1981 and the trees are now more than 10 m high (Figure 1). Figure 2 shows the transverse structure of this highway snowbreak woods.

Figure 1 - The observed snowbreak woods

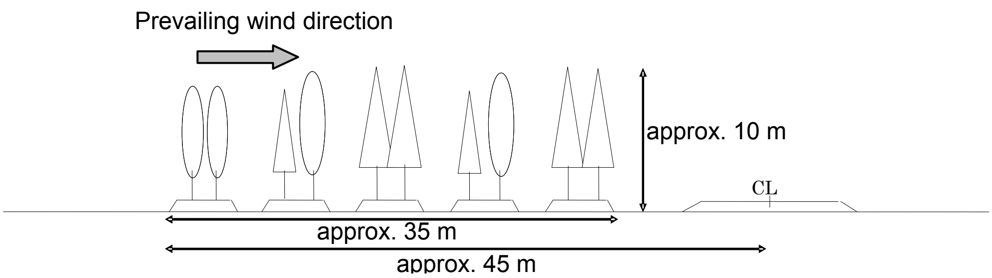

Figure 2 - Structure of the woods

Tree zone A Tree zone B

Tree zone C Reference point

Figure 3 - The survey locations

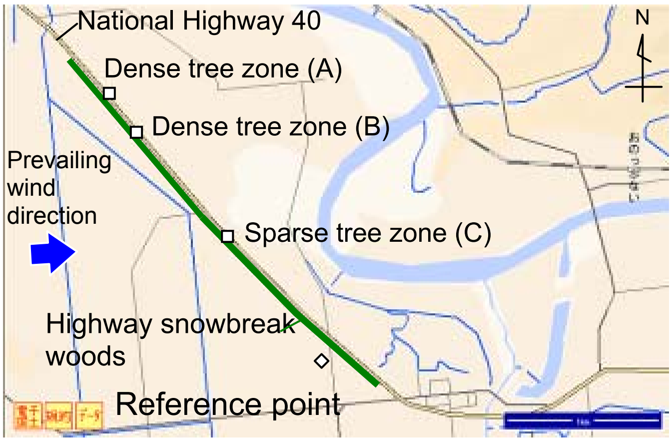

Figure 4 - The survey locations

Tree survey was made at the highway snowbreak woods. Visibilities were measured along the highway snowbreak woods at four locations: three in tree zones A, B and C, and one (a reference point) that was near the three zones but that was not influenced by the snowbreak woods (Figs. 3 and 4). The tree survey was performed in November and December 2003. The visibility was measured from November 15, 2004 to March 14, 2005.

Table 1 shows the stand conditions at the survey locations. The table shows the average stand parameters for each tree zone, which were measured in an area between the road and the survey point for a distance of 10 m along the road. The leaf area index (LAI) is the total of the area of leaf surfaces per unit area of ground (m^2/m^2), and the higher this value, the denser the tree zone.

Table 1 - Stand conditions for each survey location

	Planting year	Mean tree height (m)	Tree density (trees/ha)	Mean height of lowest branch (m)	Mean branch spread (m)	Mean conifer height (m)	Mean leaf area index (LAI)
Tree zone A	1987	6.1	1733	1.2	3.4	6.5	1.2
Tree zone B	1985	6.7	1733	1.3	3.9	7.4	1.7
Tree zone C	1982	7.3	700	1.4	4.7	8.5	0.7

A comparison of the three tree zones reveals that the tree density of zone C is less than half of that for the other two locations, and that the foliage density is highest in zone B, followed by zone A and then zone C (Fig. 3). The differences between the tree densities are a result of fallen trees and the death of trees: These densities were identical when the woods were planted.

2.2 Survey method

The visibility was measured using a reflection visibility meter (Meisei Electric Co., Ltd.: TZE-4) and a windmill anemoscope - anemometer (Kona System, KADEC21-KAZE). These instruments were installed at 5 m downwind from the downwind side of the road shoulder in each tree zone at a height of 2 m above the road (3.5 m above the ground), and at the reference point at a height of 2 m above the ground.

2.3 Survey results

Considering conditions under which snowstorms occur [1], the analysis was performed for data when the wind speed was 5 m/s or more, air temperature was 0°C or less and visibility was 1,000 m or less at the reference point. The visibility improvement afforded by each tree zone (hereinafter: “visibility ratio”) is represented as a ratio of the visibility at each tree zone to the visibility at the reference point.

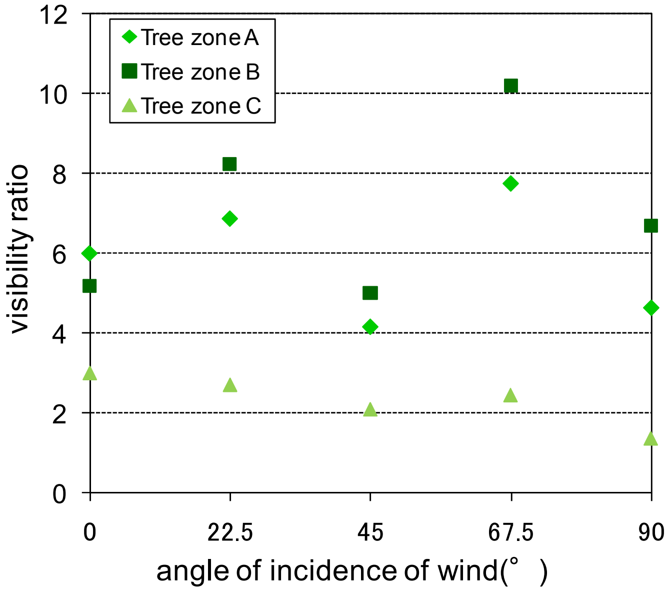

Figure 5 - Visibility ratios of tree zones with different densities

Figure 5 shows the visibility ratios in tree zones A, B, and C. Of the values in Figure 5, other than those for 90° angle of incidence, data with the same angle of incidence were averaged.

According to Figure 5, regardless of the angle of incidence, the visibility ratio was greater than 1 in all three tree zones. Visibilities for the survey points in the tree zones were higher than that for the reference point. The visibility improvement was greater in the dense tree zones (zones A and B) than in the sparse tree zone (zone C). Although zones A and B have equivalent tree density, zone A had a higher visibility ratio and a higher average leaf area index than zone B. This shows that tree density and leaf area index affect the visibility improvement.

The greatest improvement in visibility ratio for tree zones A and B was for incident winds of 67.5º, followed by 22.5º, 90º and 45º. The visibility ratio was identical at all angles of incidence in tree zone C. A snowfence has the greatest wind-reduction effect when the incident wind is at a right angle to the fence. In contrast, a snowbreak woods provides high visibility improvement under both right-angle winds and oblique winds.

3. Wind tunnel test

3.1 Introduction

The field survey clarified the effect of tree density on the visibility improvement afforded by each tree zone. Because restoration after thinning is impossible in a highway snowbreak woods, we made a wind tunnel test to estimate the minimum tree density that improves visibility enough for the road to be trafficable during a snowstorm, using a model in which tree density could be freely varied.

3.2 Test method

The test was performed using a sealed circulating, low-temperature wind tunnel system (cross-section: 1 m x 1 m; measurement section: 14 m) (Figure 6) at the Shinjo Branch of the Snow and Ice Research Center of the National Research Institute for Earth Science and Disaster Prevention. Drifting snow was generated using artificial snow. The mass flux of snow (i.e., the number of saltating snow particles passing through a unit area per unit time) was measured. The temperature inside the wind tunnel and the wind speed at the center of the wind tunnel during the test were set at approximately -10ºC and at approximately 10.5 m/s, respectively. The snow particles were supplied by crushing and stirring up artificial snow with a rotating brush at the windward end of the survey section of the wind tunnel. (Figure 6, right).

The artificial snow was prepared by storing snow made from artificial ice balls in a low-temperature room at -10ºC for two days, until it became compacted. Then, the compacted snow was pulverized with a stirring machine and a 1-mm sieve. A snow particle counter (SPC) was used to measure the mass flux of snow around the tree zones and near the road. The measurements were done at 89 locations. The measurement time per survey point was between 25 and 60 seconds.

Figure 6 - Wind tunnel testing system

The models were prepared by modelling one of the dense tree zones (tree zone B) and the sparse tree zone (tree zone C) from the observation data, and by forming 10 patterns considering thinning according to maturity (abbreviated: P1 to P10 below) (Figure 7). They were modelled to a scale of 1/100. The widths of the tree zones were all 32 m (model size: 32 cm). Table 2 shows the materials used to make the models.

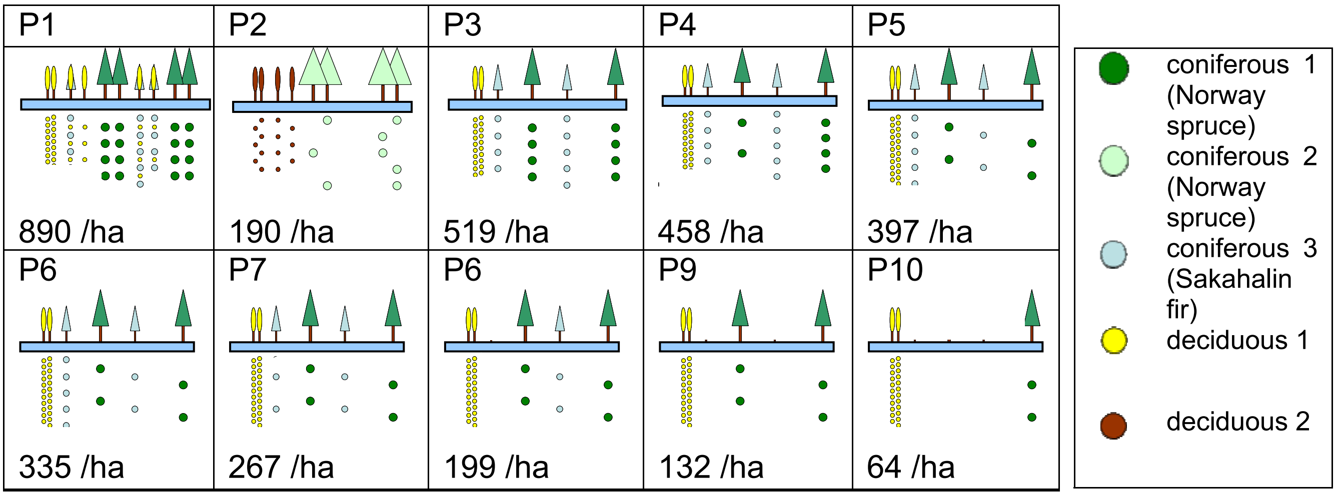

Figure 7 - Arrangement of test patterns

Table 2 - Model wood materials

Item		Material and product number
Tree (conifer)	Leaf	Moltofilter (INOAC, MF-8)
	Trunk	Hardened stainless steel rods
Tree (deciduous broad-leaf)		Galvanized soft wire (0.28 mm

The model trees were placed about 8,500 mm downwind from the upwind end of the survey section of the wind tunnel system (Figure 8). Inside each model woods, six 7-mm-thick woodchips were placed to simulate snow accumulation inside the snowbreak woods (Figure 9). Cotton gauze was attached to the woodchips to increase their roughness. The ground surface around each model woods was made of a wooden panel with gauze applied to its surface. Corn snow that had been stored for a long time in a low-temperature room was placed in front of and behind the wooden panel. The snow was spread and a fine spray of water applied to its surface to form a crust. The coordinates of the inside of the wind tunnel for the measurements were: x-axis in the wind direction, with the road center x at 0 mm.

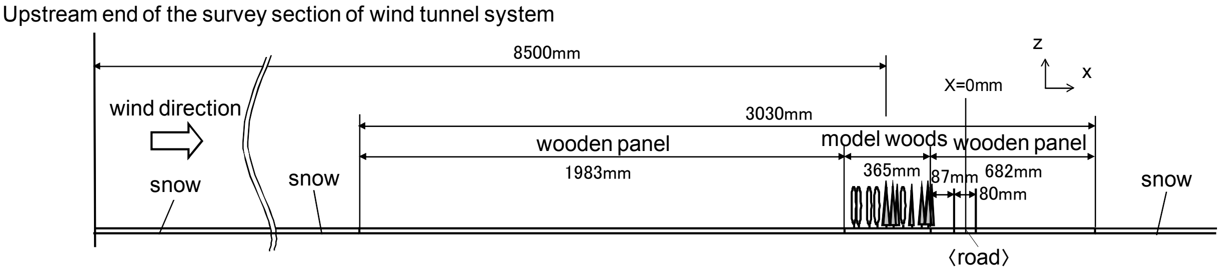

Figure 8 Layout of the models

Figure 9 - Woodchips being placed in the model woods

3.3 Test Results (Correcting ratio of mass flux of snow obtained in the wind tunnel test)

The snowbreak woods effectiveness was assessed using the ratio of mass flux of snow (*RMf*). This is the ratio of the mass flux of snow at the survey point to the mass flux of snow at a distant point (X = -1,500 mm) at the same height above the ground level. First, the mass flux of snow in the wind tunnel test *(RMfe)* and the mass flux of snow in the field survey (*RMfo)* were compared, verifying the reproducibility of the scaled-down model.

The field mass flux of snow (*MFo)* was not measured in the field survey. It was calculated by solving Equation (1) using the visibility data.

$\log(Vis)=-0.773\cdot\log(Mf)+2.845$・・・・・・・・・・・・・・・・・(1)

where, Vis: visibility (m), Mf: ratio of mass flux of snow (g/m^2/s)

According to Kajiya et al. [2], when visibility is reduced to 200 m during snowstorms, driving speeds begin to gradually fall. Visibilities measured upwind from the snowbreak woods and near the road that fell to less than 200 m were extracted for analysis because they were considered to have been measured during a snowstorm. The ratio of mass flux of snow of the field measurements *RMfo* was obtained using the data.

Although tree zones where the visibility was measured by field survey were only two (tree zone B and tree zone C), based on a comparison of the mass flux of snow ratios obtained by the field measurements (*RMfo*) and obtained by the wind tunnel test *(RMfe)*, a proportional relationship was hypothesized, and Equation (2) was obtained (Figure. 10).

$RMf_o=1.68\ RMf_e$・・・・・・・・・・・・・・・・・・・・・・・・・・・・・(2)

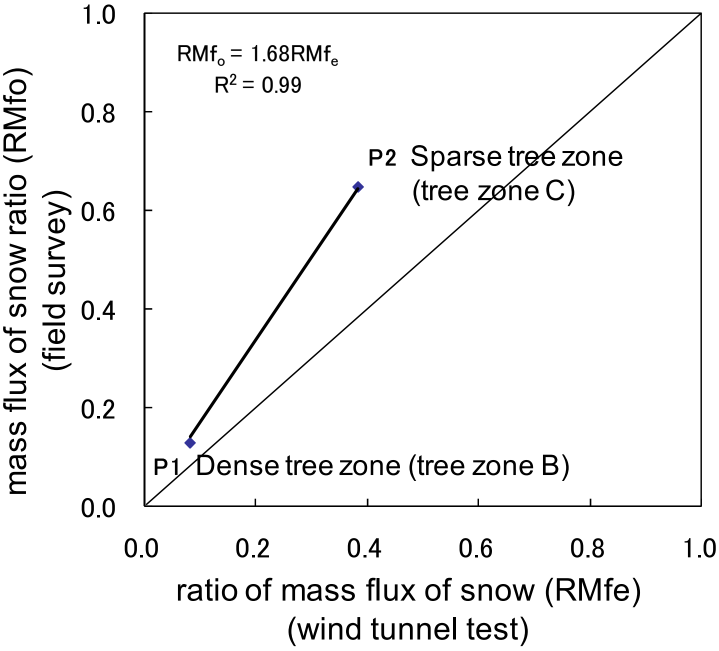

Figure 10 - Relationship of ratios of mass flux of snow in the wind tunnel test to that in the field survey

3.4 Test results (relationship between tree density and ratio of mass flux of snow)

RMfo' is a theoretical value of the ratio of mass flux of snow of the field survey. It is obtained by correcting the ratio of mass flux of snow in the wind tunnel test by solving Equation (2). Figure 11 shows the relationship between *RMfo'* and the tree density ρ_t (trees/ha).

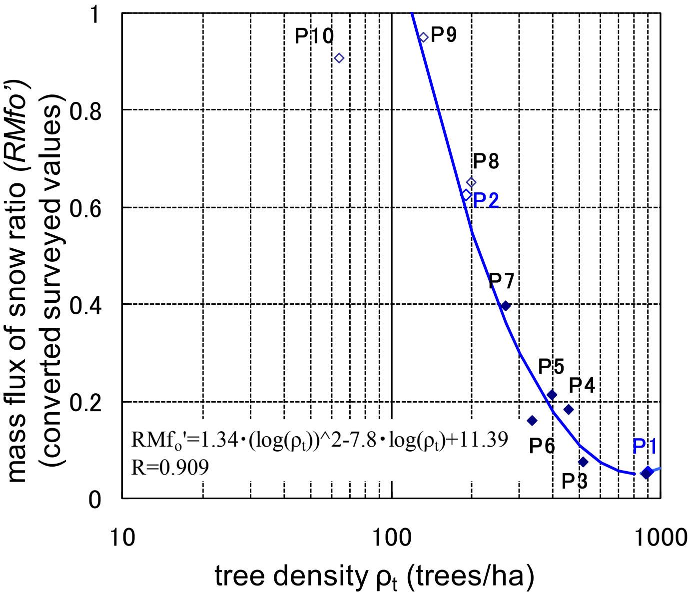

Figure 11 - Relationship between tree density and ratio of mass flux of snow

Figure 11 shows that *RMfo* near the road increases as ρ_t decreases. From P1 to P6, the increase in *RMfo'* is small, but then it increases remarkably beginning at P7. From Figure 11, the relationship between *RMfo'* and ρ_t was approximated by a secondary regression equation, obtaining Equation (3).

$RMf_o' = 1.34 \cdot \log^2 \rho_t - 7.80 \cdot \log \rho_t + 11.39 \cdots\cdots\cdots\cdots (3)$

3.5 Test results (relationship between tree density and visibility improvement)

To estimate the relationship between tree density $\boldsymbol{\rho_t}$ and visibility improvement, the visibility for each ρ_t was estimated based on RMf_o'. When visibility falls below 200 m, the driving speed declines. The ρ_t that can restore visibility on the road to 200 m (hereafter: "Vis_r") was obtained.

Here, we set *RMf* as the ratio of Mf_w (the ratio of mass flux of snow on the upwind side of the snowbreak woods) to Mf_r (the ratio of mass flux of snow on the road). Assuming that *RMf* is equivalent to RMf_o' (Equation (6)), the visibility at the upwind side of the snowbreak woods when Vis_r = 200 m (hereafter: Vis_w) is estimated using Equations (1), (3) and (4) and is shown in Figure 12.

$RMf = RMf_o' = Mf_r/Mf_w \cdots (4)$

Figure 12 shows that the visibility improvement differs according to $\boldsymbol{\rho_t}$. When visibility at the upwind side of a snowbreak woods is less than 50 m (Vis_w <50 m), driving is extremely difficult (Kajiya et al. [2]). However, if the tree density of the snowbreak woods exceeds 400 trees/ha (ρ_t >400 trees/ha), then the visibility on the road improves to 200 m (Vis_r >200 m). Visibility of 200 m on the road allows normal driving. Therefore, the ρ_t that can maintain visibility sufficient for normal driving is about 400 trees/ha.

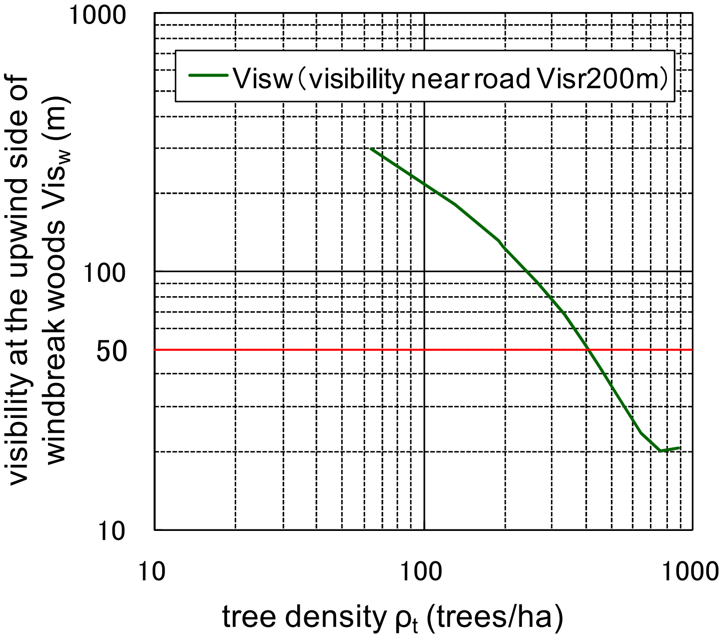

Figure 12 - Tree densities that achieve visibility of 200 m on the road

4. Summary

To clarify the relationship between tree density and visibility improvement of highway snowbreak woods, field survey and wind tunnel tests were done. In the field survey, visibility at highway snowbreak woods of differing densities were measured and the following results were obtained.

1) Highway snowbreak woods improve visibility under snowstorm conditions.

2) The tree density of a snowbreak woods greatly influences the visibility improvement afforded by the woods.
3) Leaf-area index influences visibility improvement.

The wind tunnel testing was performed using model woods with differing tree density ρ_t to measure the mass flux of snow. The following results were obtained.

- When the visibility on the upwind side of a 32-m-wide snowbreak woods in northern Hokkaido is less than 50 m, in order to maintain a visibility of 200 m on the road, the tree density the woods should to be at least 400 trees/ha.

Highway snowbreak woods is a living snow protection measure. In this study tree density was considered only from the perspective of the visibility improvement afforded by the snowbreak. In determining the appropriate tree density, other aspects should also beconsidered, such as competition with grass when trees die or the treedensity declines.

Acknowledgments

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References

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[2] Kajiya Y. et al. (2004): Study of Drivers' Driving Behavior under Conditions where Visibility is Obstructed by Falling or Blowing Snow, Cold Region Science and Technology, vol. 20, 2004, pp. 325 – 331.