

A STUDY OF MINIMUM VISIBILITY ROADS CONDITIONS IN RAINY WEATHER

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ABSTRACT

This article examines the conditions for minimum visibility on roads during rainy weather. Problems of finding a semi-empirical relationship between meteorological visibility on roads and the visibility range for drivers in rainy weather are discussed and solved. Problems of determining the conditions for minimum visibility range for drivers in rainy weather are also solved. A semi-empirical expression linking meteorological visibility and the visibility range for drivers during rain is derived. It is determined that in rainy weather, with a positive regression relationship between background illumination and rain intensity, the visibility range for drivers is reduced to a minimum.

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Introduction

As noted in [1], the deterioration of visibility directly due to rain is usually small. For example, if meteorological visibility is within 400 m, then the rain intensity that could cause such low visibility would be 300 mm/hour. However, rains with such intensity occur quite rarely. At the same time, visibility of the road is significantly affected by rainwater accumulated on the car windshield. In [2], the effect of raindrops falling on the car windshield on visibility on the road in rainy weather was studied. In [3, 4], the conditions for deterioration of visibility were investigated using physical modeling of rain as applied to stationary vehicles. In [5-7], it was shown that an increase in rain intensity leads to a decrease in visibility for the driver. In [5], it was shown that visibility decreases with a decrease in background illumination. Moreover, for moving vehicles, visibility was further deteriorated due to the accumulation of water on the windshield. Based on the obtained experimental results, the following model of the dependence of visibility range on the condition of the windshield of a car in rainy weather was proposed.

$$D = C_0(Rt)^{-C_1} \exp(C_2L_b) \quad (1)$$

where C_0 , C_1 , C_2 are positive constants; R is the rain intensity; t is the windshield wiper operating period; L_b is the background illumination.

According to [1], the following relationship exists between the rain intensity R and the attenuation coefficient:

$$k = aR^\gamma \quad (2)$$

where k is the attenuation coefficient; α and γ are coefficients depending on the experimental conditions.

The optical thickness of the rain factor at a distance L is determined as:

$$\tau = \int_0^L k dr \quad (3)$$

As noted above, rain itself has little direct effect on road visibility.

This has been repeatedly verified in practice, and at a rainfall intensity of 45 mm/hour, the attenuation coefficient did not exceed 4×10^{-3} (Fig. 1) [1].

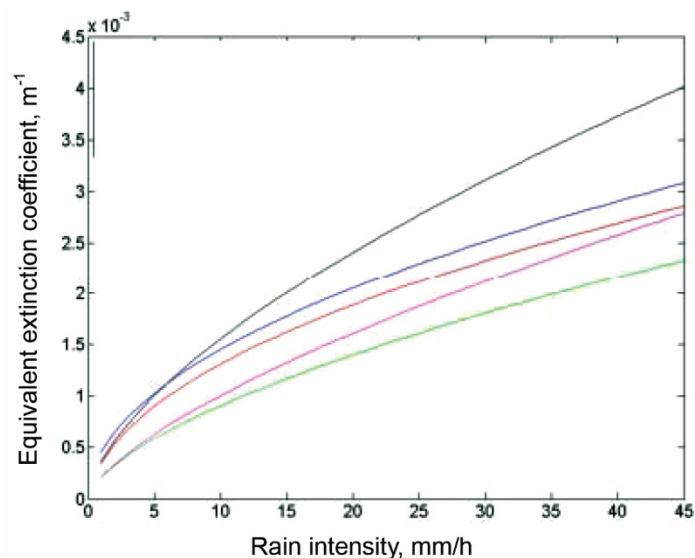


Figure 1. Experimentally obtained curves of dependence of the attenuation coefficient on rain intensity during 1985-2000 [1] by different researchers

However, it should be noted that the driver's workplace is located behind the windshield, and when determining visibility on the road in rainy weather, the effect of the windshield on visibility must be taken into account.

This article further examines the effect of raindrops accumulated on the windshield on the apparent meteorological visibility for drivers driving in rainy weather.

Materials and methods

As indicated in the work [1], meteorological visibility V_{met} is defined as

$$V_{met} = \frac{3}{k} \quad (4)$$

Taking into account expressions (2) and (4), we obtain

$$V_{met} = \frac{3}{aR^\gamma} \quad (5)$$

From expression (5) we find

$$R = \sqrt[\gamma]{\frac{3}{aV_{met}}} \quad (6)$$

Taking into account expressions (1) and (6), we have

$$D = C_0 t^{-c_1} \left[\left(\sqrt[\gamma]{\frac{3}{aV_{met,k}}} \right)^{-c_1} \exp(C_2 L_b) \right] = C_0 t^{-c_1} \left[\left(\frac{3}{aV_{met,k}} \right)^{\frac{-c_1}{\gamma}} \exp(C_2 L_b) \right] = C_0 t^{-c_1} \left(\frac{3}{aV_{met,k}} \right)^{c_0/\gamma} \exp(C_2 L_b) \quad (7)$$

Where $V_{(met, k)}$ is the apparent meteorological visibility for the driver.

As can be seen from expression (7), the indicators D and V_{met} are functionally related. Given t , $L_b = \text{const}$, an increase in D will mean an increase in V_{met} . Consequently, the apparent meteorological visibility $V_{(met, k)}$ for the driver, if D is extreme, will also have an extreme property.

Next, let's consider the extreme properties of the indicator D . To do this, we use expression (1). In this expression, we assume $t = \text{const}$. We rewrite expression (1) as

$$D = C_{01} R^{-c_1} \exp(C_2 L_b) \quad (8)$$

where

$$C_{01} = C_0 \cdot t^{-c_1} \quad (9)$$

Next, in expression (8) we introduce for consideration the function

$$L_b = \psi(R) \quad (10)$$

The physical meaning of (10) is that the background glow should have a regressive relationship with the rain intensity as the vehicle moves along the road. Logically, along the road, one can expect both an increasing and a decreasing regressive relationship between L and R . In the first case, one can assume that an increase in R indicates a concentration of rain clouds in the area where the road passes, and in the second case, one can assume that rain clouds are large-scale, also covering background areas. Given the above assumptions, the following restrictive condition can be imposed on the function $\psi(R)$.

$$\int_0^{R_{max}} \psi(R) dR = C_3; C_3 = const \quad (11)$$

Next, taking into account expression (10) and based on expression (8), we form the following target functional F_1 , where

$$F_1 = \int_0^{R_{max}} C_{01} R^{-C_1} \exp(C_0 \psi(R)) dR \quad (12)$$

A graphical representation of the hypothetical dual version of function (10) is shown in Figure 2.

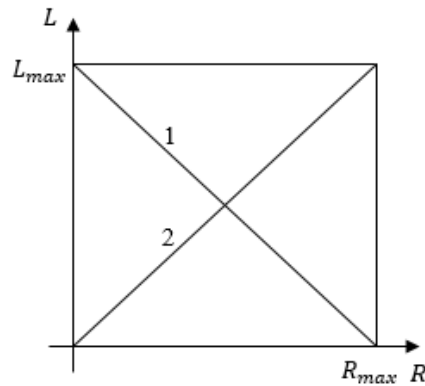


Figure 2. Expected regression curves for L versus R . Numbers indicate: 1 – presence of negative regression; 2 – presence of positive regression

Taking into account expressions (11) and (12), we construct the objective functional F_2 for unconditional variational optimization.

$$F_2 = \int_0^{R_{max}} C_{01} R^{-C_1} \exp(C_0 \psi(R)) dR - \lambda \left[\int_0^{R_{max}} \psi(R) dR - C_3 \right] \quad (13)$$

The solution of the optimization problem (13) according to [8] satisfies the following condition

$$\frac{d\{C_{01} R^{-C_1} \exp(C_0 \psi(R)) - \lambda \psi(R)\}}{d\psi(R)} = 0 \quad (14)$$

From condition (14) we find:

$$C_0 C_{01} R^{-C_1} \exp(C_0 \psi(R)) - \lambda = 0 \quad (15)$$

From expression (15) we find

$$\exp(C_0 \psi(R)) = \frac{\lambda R^{C_1}}{C_0 C_{01}} \quad (16)$$

Taking the logarithm of expression (16) we obtain

$$\psi(R) = \frac{1}{c_0} \ln \left[\frac{\lambda R^{c_1}}{c_0 c_{01}} \right] \quad (17)$$

When solving (17), F_2 reaches a minimum, therefore, with a functionally (logarithmically) direct dependence of L on R , i.e. if an increase in rain intensity is accompanied by an increase in illumination from the background according to law (17), the visibility distance for the driver can reach a minimum.

Discussion

Thus, the conditions for minimum road visibility for drivers in rainy weather were investigated. The following problems were discussed and solved:

- 1) Finding a semi-empirical relationship between meteorological visibility on roads and the visibility range for drivers in rainy weather.
- 2) Determining the conditions for minimum visibility for drivers in rainy weather.

A variational optimization problem was developed to find a possible regression relationship between L (background illumination) and rain intensity (R) while driving on a highway at which the visibility range for drivers in rainy weather reaches a minimum. The possibility of a dual nature for this regression relationship was also considered, i.e., both an increase and a decrease in background illumination with increasing rain intensity are allowed.

Conclusion

The following key findings were obtained as a result of a study examining the impact of rain on road visibility:

1. A semi-empirical expression was derived linking meteorological visibility and the visibility range during rain for drivers, taking into account the accumulation of raindrops on the windshield.
2. It was determined that in rainy weather, with a positive regression relationship between background illumination and rain intensity, the visibility range for drivers is reduced to a minimum.

REFERENCES

- [1] N. Hautiere, E. Dumont, R. Bremond, V. Ledoux, "Review of the mechanisms of visibility reduction by rain and wet road".
- [2] K. Garg and S. Nayar, "Vision and rain," *International Journal of Computer Vision*, no. 75(1), pp. 3-27, October 2007.
- [3] T. Kurahashi, Y. Fukatsu, and K. Matsui, "Method of evaluating visibility provided by windshield wipers in rainy conditions," *In SAE Technical Paper Series*, number 851636, 1985.
- [4] R. Morris, J. Mounce, J. Button, and N. Walton, "Visual performance of drivers during rainfall," *Transportation Research Record*, no. 628, pp. 19-25, 1977.
- [5] V. Bhise, J. Meldrum, L. Forbes, T. Rockwell, and E. McDowell, "Predicting driver seeing distance in natural rainfall," *Human Factors*, no. 23(6), pp. 667-682, 1981.
- [6] D. Ivey, E. Lehtipuu, and J. Button, "Rainfall and visibility – the view from behind the wheel," Technical Report 135-2, College Station, TX: Texas Transportation Institute, 1975.
- [7] R. Morris, J. Mounce, J. Button, and N. Walton, "Field study of driver visual performance during rainfall," Technical Report DOT-HS-5-01172, College Station, TX: Texas Transportation Institute, 1977.
- [8] L. E. Elsgolts, "Differential equations and the calculus of variations," Moscow: Nauka. 1974. 432 p.