International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 08 – Issue 02 || February 2023 || PP. 136-142

Assessment of the Functional Operating Life of Horizontal Road Markings on the Basis of the Theory of Risk

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Abstract: This paper presents the results of a study of the functional operating life of horizontal road markings in order to assess the probability of a dangerous event. The lighting characteristics of the marking were considered as parameters affecting the risk of a dangerous event. Measurements of the lighting parameters of road markings were carried out on the highways of I–III categories in the Russian Federation in 2019-2021. Based on the measurement results, the probability of occurrence of a dangerous event (risk) for various types of lines was calculated. It was found that not all of the lighting parameters of road markings provided a "moderate" level of risk of a dangerous event, adopted for the road sector. Ways to reduce risks and directions for further research have been supposed.

Keywords: horizontal road markings, functional operating life, theory of risk.

One of the most important consumer properties of a highway is traffic safety. The national project “Safe and High-Quality Roads”, developed by the Ministry of Transport of Russia in order to fulfill the provisions of the Presidential Decree “On National Goals and Strategic Objectives for the Development of the Russian Federation for the Period up to 2024”, is aimed at ensuring road safety.

The reasons for the increase in accidents on roads can be very diverse: from non-compliance by drivers with the rules of the road (human factor) and the technical condition of the vehicle (factor - car) to the presence of defects on the roadway or the lack of means of organizing traffic (factor - road).

Therefore, when making decisions on establishing the minimum necessary safety requirements, it is advisable to use the theory of risks, which makes it possible to assess the influence of various factors on the occurrence of emergency situations. Also, risk theory allows you to analyze emerging risks and make decisions to manage them (reduce or eliminate).

To ensure the required level of road safety on roads, technical means of organizing traffic are used, such as: traffic lights, road signs and road markings. The quality and durability of technical means of traffic management directly affect the safety on roads. In the absence of technical means of organizing traffic or the presence of their defects, the driver does not receive the necessary information to make the right decision when the vehicle is moving, which in turn can lead to a traffic accident. Therefore, ensuring the functioning of traffic management facilities at the level established by regulatory requirements throughout the entire service life is an important task.

Horizontal road markings are an effective means of organizing traffic, as they constantly, throughout the entire length of the road, inform drivers about the correct behavior on the road. Of particular importance is the presence and condition of road markings at night on road sections where there is no artificial lighting, as evidenced by the statistics of traffic accidents.

According to the Ministry of Internal Affairs of the Russian Federation and the Scientific Center for Road Safety, for 9 months of 2021, 96,314 road accidents were registered in the Russian Federation, while 121,573 people were injured and 10,516 people died. It was also found that the largest number of accidents occurred in the time interval from 17:00 to 20:00 (every fifth accident); the most severe road accidents occurred in the time interval from 01:00 to 07:00 (13 deaths per 100 injured) [1].

During operation, horizontal road markings are subjected to significant impacts of vehicle wheels, working bodies of harvesting equipment and natural and climatic factors, which leads to the destruction of the

marking material, a decrease in its area and a deterioration in lighting characteristics, that is, a decrease in its functional properties. The most important parameters of horizontal road markings that directly affect its visibility are lighting characteristics [2]:

- coefficient of brightness of the surface of horizontal road markings β_V – daytime visibility characteristic of horizontal road markings for pedestrians;
- specific coefficient of light reflection in diffuse daylight or artificial lighting Q_d – characteristic of daytime visibility or visibility from artificial lighting for the driver;
- specific coefficient of light reflection of road markings in dry pavement R_L is a characteristic of night visibility of road markings for drivers.

Studies of the lighting characteristics of horizontal road markings were carried out on highways of I–III categories (M-2 "Crimea", M-4 "Don", M-5 "Ural", M-8 "Kholmogory", M-9 "Baltic" , A-103 Shchelkovskoye Highway, A-104 Moscow-Dmitrov-Dubna, A-105 Domodedovo airport entrance, A-107 MMK, A-108 MBC) in 2019-2021 years. Measurements of the lighting characteristics of the road markings Q_d and R_L were carried out with a ZRM 6006 instrument. The luminance coefficient β_V was measured with an X-Rite 962 instrument. Based on the data obtained, the arithmetic mean values and standard deviations of the studied parameters for each observation period were calculated.

It was found that in all the studied areas, the specific coefficient of light reflection under diffuse daylight or artificial lightingQ_d practically does not decrease within the established regulatory period (3 months) and complies with the requirements established by GOST R 52289-2019 [3].

During the observation period, a decrease in the values of the coefficients $\beta_V$and R_L was registered. Therefore, in the future, these lighting indicators were considered.

To calculate the probability of a dangerous event occurring(risk$r$) the technique of V.V. Stolyarov (method of 50% risk) [4, 5].

The probabilities of occurrence of a dangerous event were calculated for various values of the actual indicators of the lighting parameters $\beta_V$and R_L, measured on roads in different periods of operation (May, June, July, August). Calculations were made for various permissible values of the lighting parameters $\beta_V$and R_L. This article presents the results of studies for highways of category II. The calculation results are presented in tables 1-4. Figures 1-4 show graphs of the probability of occurrence of a dangerous event (risk) for the lighting characteristics $\beta_V$and R_L for the center and edge lines of horizontal road markings. The required levels of $\beta_V$and $R_L$are set according to GOST R 52289-2019 [3], risk levels are set according to GOST R 58137-2018 [4].

Table 1
Risks of occurrence of a hazardous event with different allowable values of the luminance factor for centerlines

Month	Average actual value β_V, %	The risk of a dangerous event r at an acceptable value β_V, %		
		30	40	50
May	59,42	0,000001	0,000013	0,00018
June	54,93	0,000002	0,0000496	0,00072
July	50,45	0,0000175	0,000259	0,0029
August	45,96	0,000072	0,001152	0,00935

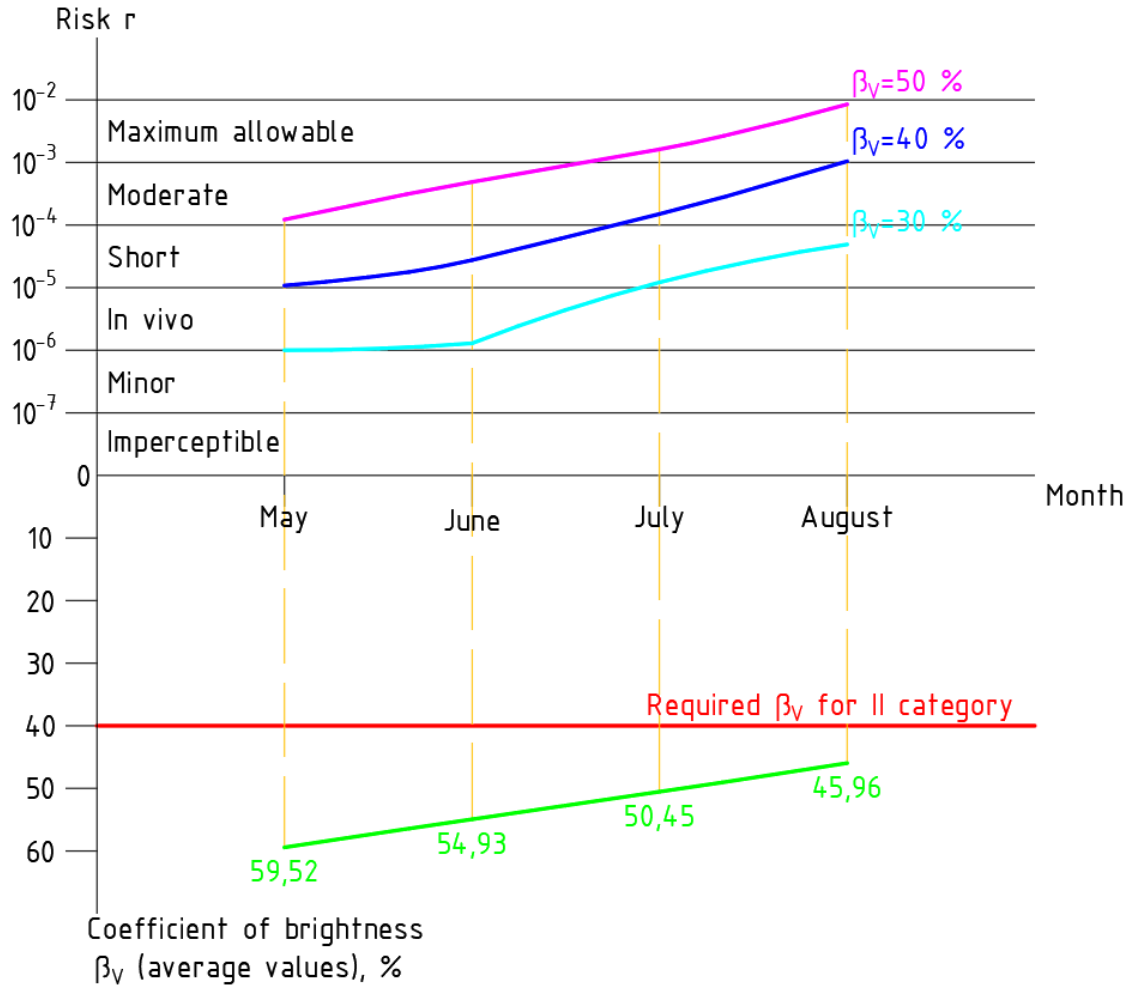

Figure 1 Graph of the probability of occurrence of a dangerous event (risk) for the luminance factor β_V for centerlines

Table 2
Risks of occurrence of a dangerous event at different allowable values of the luminance coefficient for edge lines

Month	Average actual value β_V, %	The risk of a dangerous event r at an acceptable value β_V, %		
		30	40	50
May	61,53	0,000001	0,000004	0,0001
June	56,85	0,0000015	0,00002	0,0004
July	52,16	0,000003	0,00008	0,00135
August	47,48	0,0000175	0,00034	0,0048

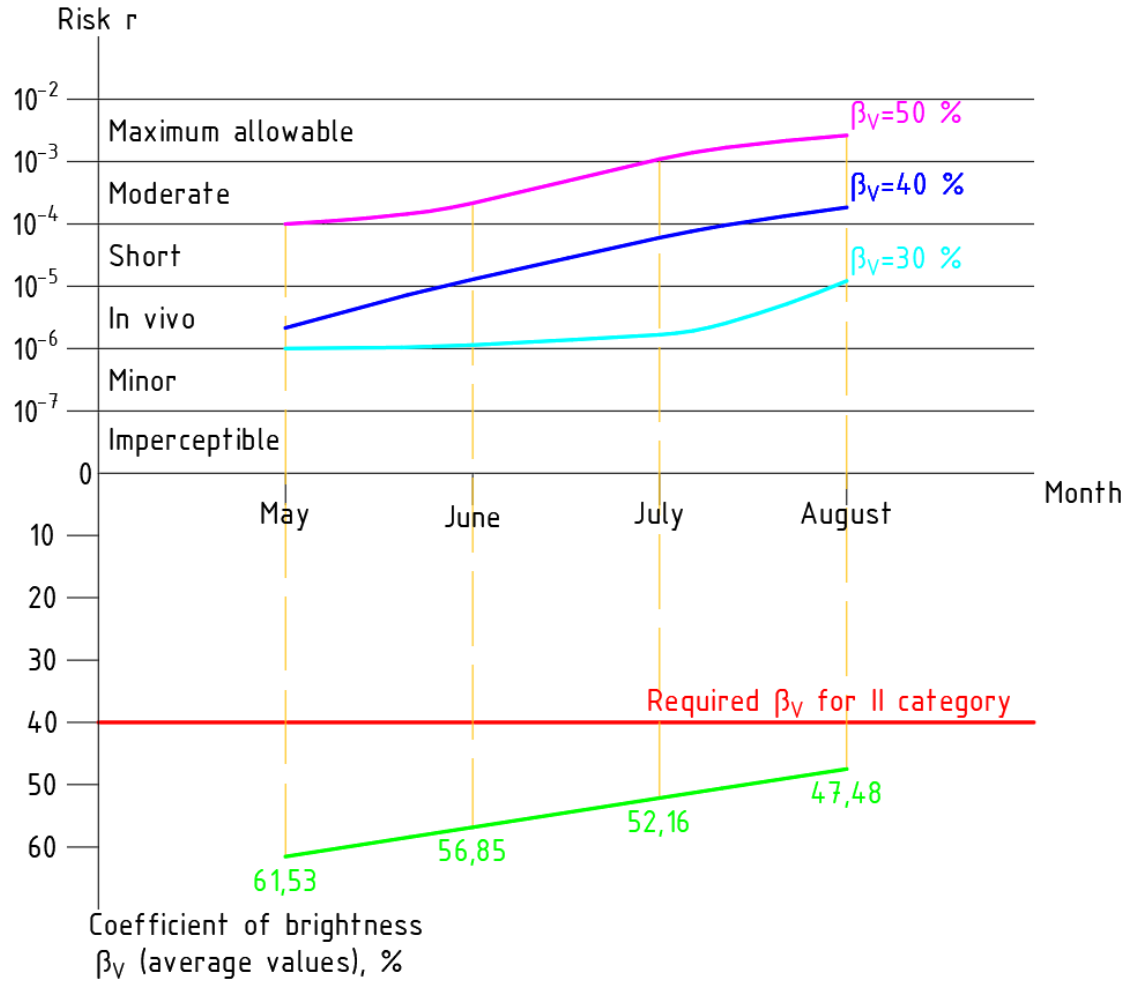

Figure 2 Graph of the probability of occurrence of a dangerous event (risk) for the brightness coefficient β_V for edge

Table 3
Risks of occurrence of a dangerous event with different allowable values of the specific coefficient of retroreflection for center lines

Month	Average actual value R_L, mcd / l×m^2	The risk of a dangerous event r at an acceptable value R_L, %		
		100	150	200
May	357,52	0,0005	0,00112	0,00235
June	321,91	0,0028	0,00505	0,0089
July	286,30	0,0107	0,0166	0,0244
August	250,69	0,0301	0,0401	0,0537

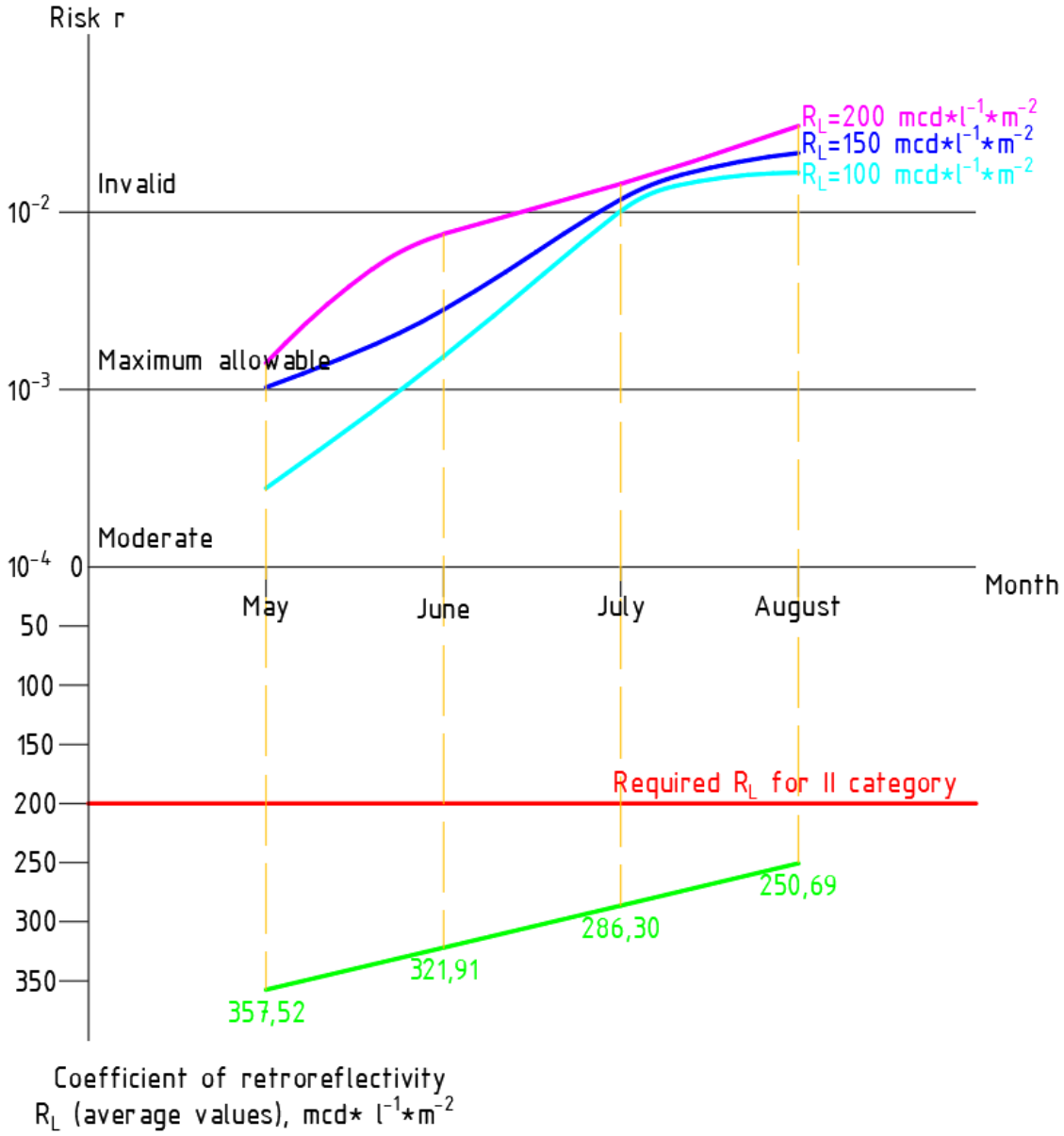

Figure 3 Graph of the probability of occurrence of a dangerous event (risk) for the specific coefficient of retroreflectivity of the marking at R_L for center lines

Table 4
Risks of occurrence of a hazardous event with different allowable values of the specific retroreflection coefficient for edge lines

Month	Average actual value R_L, mcd /l×m^2	The risk of a dangerous event r at an acceptable value R_L, %		
		100	150	200
May	357,47	0,00069	0,00145	0,0026
June	317,92	0,0041	0,0069	0,0116
July	278,38	0,0154	0,02225	0,0322
August	238,83	0,0409	0,0526	0,0681

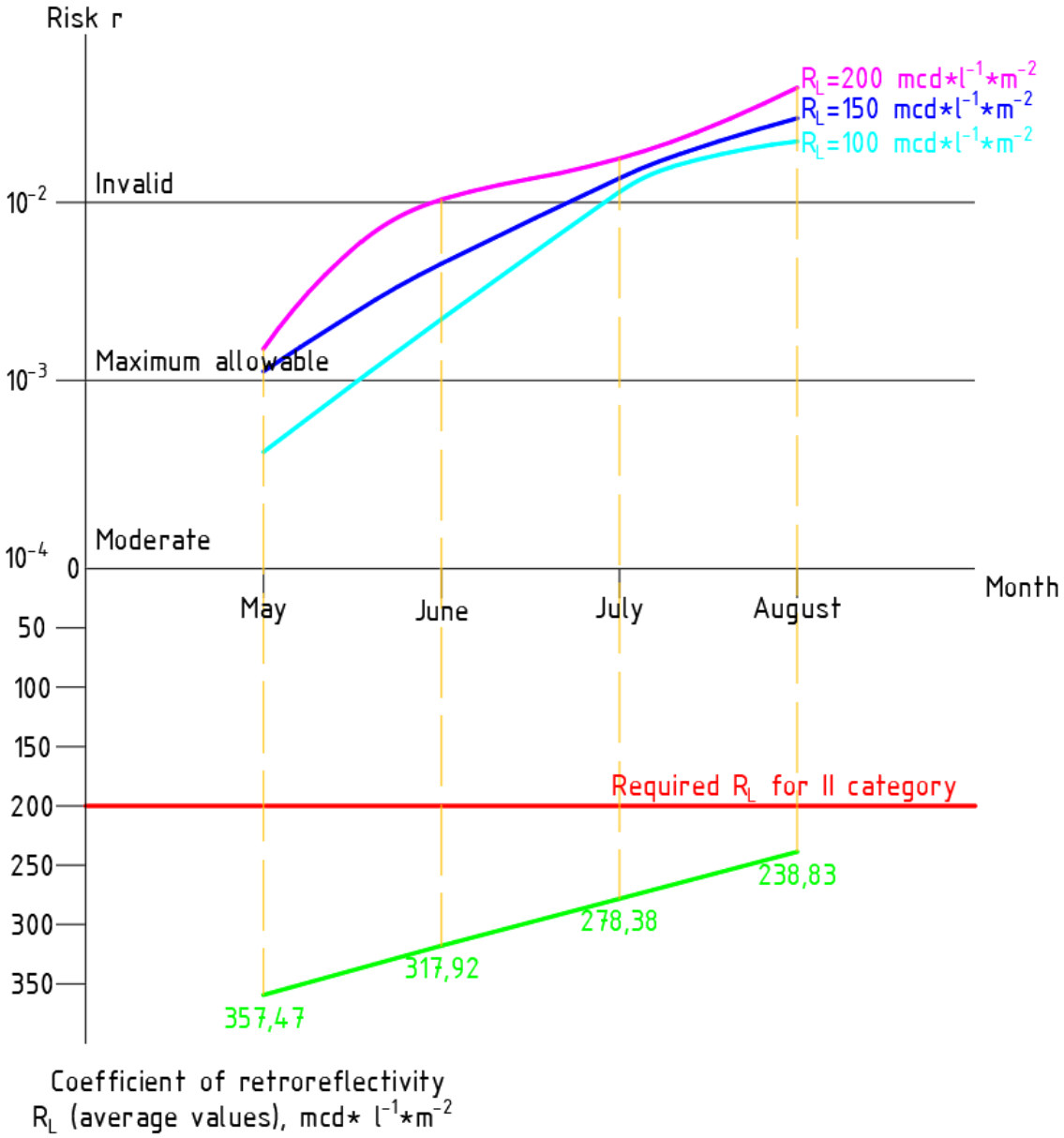

Figure 4 Graph of the probability of occurrence of a dangerous event (risk) for the specific coefficient of retroreflection of the marking R_L for edge lines

The analysis of the graphs showed that in each period of operation under study, the average actual values of the parameters β_V and R_L are higher than the standard values.

When calculating the probability of occurrence of a dangerous event, the permissible level of the parameter under study (parameters β_V and R_L) is taken into account.

It can be seen from the graphs that the higher the permissible level of the parameter under study (the regulatory requirement for the parameter under study), the greater the likelihood of a hazardous event. For the road sector, a "moderate" risk level is adopted according to GOST R 58137 [4].

For the β_V indicator, it was found that for an acceptable level of 40% [3], the risk level is "moderate" and lower for the axial lines (Fig. 1) for 3 months, for the marginal lines (Fig. 2) – more than 3 months.

For the R_L indicator, it was found that for an acceptable level of the indicator equal to 200 mcd /l×m^2 [3], the "moderate" risk level is not provided even in the initial period (immediately after drawing the marking line) both for axial (Fig. 3) and for edge lines (Fig. 4). Considering that ensuring night visibility of road markings is a top priority, especially on sections of roads where there is no artificial lighting [6], it is necessary to reduce the likelihood of a hazardous event (risk level).

Theoretically, in order to reduce the level of risk, one should either provide values of the $R_L$parameter at the time of drawing the road markings that are much higher than the regulatory requirements, or reduce the regulatory requirements.

Unfortunately, it is impossible to provide $R_L$values much higher than 200 mcd/l×m^2 at the time of road marking at the current level of development of technology and technology. Therefore, it is necessary to investigate the possibility of a reasonable adjustment of existing requirements. Moreover, foreign requirements for the $R_L$indicator during the operation period are lower than domestic ones (Table 5) [7].

Table 5
The minimum values of the specific coefficient of retroreflectivity of the markings with a dry coating for white markings

Regulatorydocument	Initial value, mcd / l×m^2	Mid-life value, mcd / l×m^2	Value at end of life, mcd / l×m^2
ONORM B 2440:1998 04 01	240	130	110
GOST R 52289-2019 (for roads II category)	200	150	150

Conclusions

It has been established that the functional durability of the markings in terms of daytime visibility (brightness factor β_V) is ensured during the required period of operation, and a "moderate" level of the probability of a hazardous event is also provided.

It has been established that the functional durability of the marking in terms of night visibility (the specific coefficient of light reflection of the marking with a dry coating R_L) is ensured during the required period of operation, but the probability of a hazardous event occurring corresponds to the "maximum permissible" or "unacceptable" level immediately after the lines are drawn.

It is necessary to investigate the possibility of a reasonable adjustment of the existing requirements for the initial value of the night visibility indicator. To do this, additional measurements of this indicator on roads should be carried out.

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