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Improving the methodology for setting adaptive speed limits and mandatory reductions based on the integrated risk index in mountainous road areas (on the example of mountainous areas of the M-39 road)

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Abstract: This article studies the issue of developing effective mechanisms for mandatory reduction of vehicle speed on mountainous roads. The mountainous areas of the M-39 international highway, passing through the Jizzakh region, within the range of 982–1013 km, were selected as the object of research. During the study, factors affecting the turning radius of the road, longitudinal slope, width of the carriageway, traffic flow intensity, speed, pavement condition and accident probability were studied. A methodology for setting an adaptive speed limit by assessing road geometry, traffic flow parameters and external environmental factors based on a single integrated risk index was proposed.

Keywords: Mountain highway, M-39 highway, traffic flow, adaptive speed limit, mandatory speed reduction, integral risk index, road geometry, turning radius, longitudinal slope, interactive road sign, automatic speed control, road traffic accident, intelligent control system, safe speed.

Introduction. In this scientific research work, a comprehensive methodology was proposed to develop effective mechanisms for mandatory reduction of vehicle speed in mountainous areas. The main essence of this methodology is to reduce road geometry, traffic flow parameters and external environmental factors to a single integral indicator and, on this basis, to set an adaptive speed limit. In particular, foreign and domestic scientists O.A. Divochkin, V.F. Babkov, R.S. Kartanboev, A.A. Eshanbabayev, K.Kh. Azizov, who made their proposals on increasing traffic safety in mountainous areas [1,2]. It allowed us to clarify the value of the accident coefficient used in the road safety assessment methodology. The mountainous area of the M-39 international highway passing through the territory of Jizzakh region was selected as the object of research. Analysis of the area revealed that the daily traffic volume is over 40,000 vehicles. Local articles have also indicated the need to develop mandatory speed reduction measures specifically for this mountainous area [3,4].

Methodology. The research methodology consists of the following main steps:

• determination of the geometric parameters of the road (curve radius R, slope i, slope e);
• collection and analysis of traffic flow indicators (intensity Q, density k, speed v);
• consideration of road surface conditions and weather factors;
• study of statistical data on road accidents (RAs) and conflict situations.

The mountainous areas of the M-39 international highway in Jizzakh region were selected as the research object [5.6]. The following parameters were measured and analyzed during the research:

Table 1

Parameters to be measured and their measurement method

№	Measured parameter	Belgilanishi	O‘lchash usuli
1	Curve radius	R	Curve radius
2	Longitudinal grade	i	Longitudinal grade
3	Carriageway width	B	Carriageway width
4	Traffic-flow intensity	q	Traffic-flow intensity
5	Vehicle speed	v	Vehicle speed
6	Pavement adhesion	φ	Pavement adhesion coefficient

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	coefficient		
7	Accident probability	*Pav*	Accident probability

The turning radius of a road is a key parameter in determining the safe speed of vehicles. The radius value was determined from the geometric plan of the road and using geodetic measurements on site [8]. The turning radius was estimated using the following formula:

$$i = \frac{h}{l} \cdot 100\% \qquad (1)$$

here: i= road slope;

h - height difference;

l- horizontal distance.

In the study, i=12% was taken as the base value.

The width of the roadway affects the stability and safety of traffic flow. The width of the roadway was determined using a tape measure, measuring the distance between the two edge lines (Figure 1).

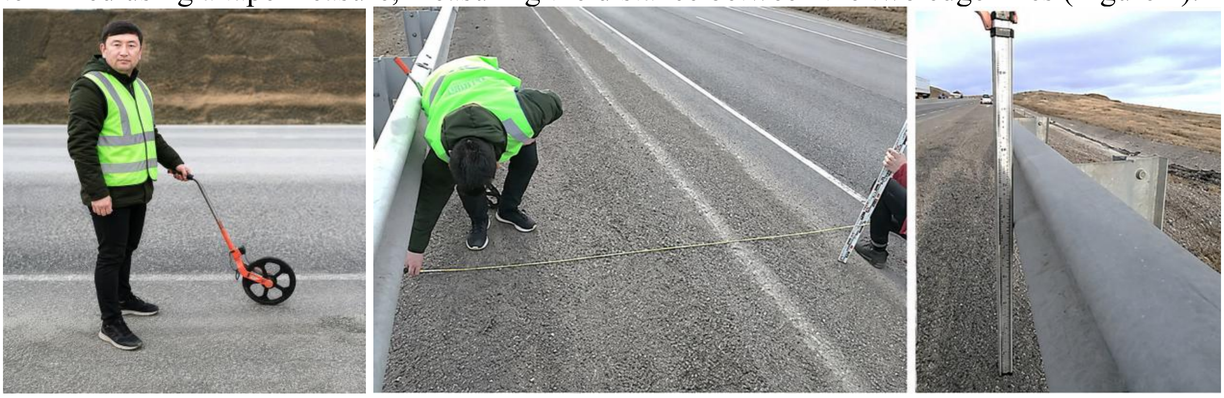

Figure 1. The process of measuring the longitudinal slope of the road and the width of the roadway.

The intensity of the traffic flow was determined using video surveillance and manual counting methods (Figure 2). According to the results of the study, the daily traffic flow in the selected mountainous area was *Q=42000* vehicles/day [4,7].

Figure 2. The process of monitoring and calculating transport flow.

The problem of vehicle speed control in mountainous road areas is characterized by the complexity of road geometry, uneven traffic flow, and rapid changes in weather and pavement conditions. Therefore, in such areas, speed limits using simple static road signs are not effective enough [5]. Practical studies show that an effective way to reduce speed is to implement a real-time, multi-factor intelligent control system [5,6].

Experimental testing was conducted in a selected mountainous area to evaluate the effectiveness of the proposed model and mandatory speed reduction measures.

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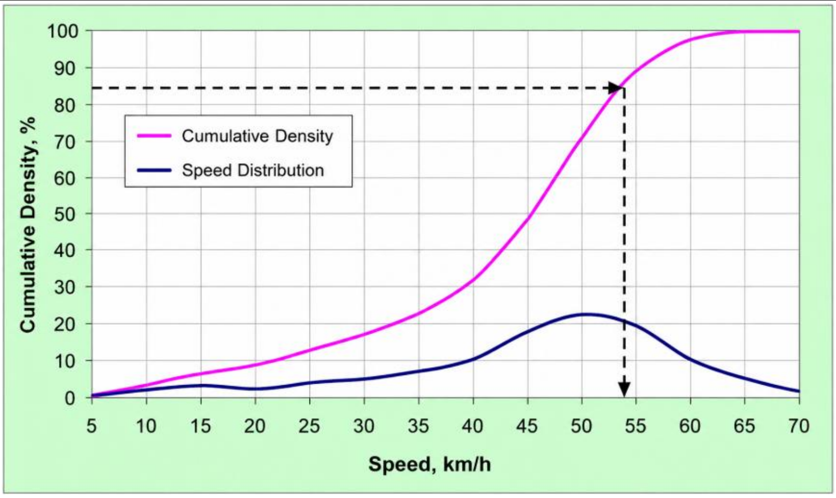

Figure 3. Comparative analysis of aggregate density and velocities.

During the study, the turning radius, longitudinal slope, road width, and vehicle speed were determined using modern measuring instruments, and the results of experimental observations were recorded [6].

Theoretical basis of the methodology: The safe speed of vehicles on mountain roads depends on several factors:

– geometric characteristics of the road (radius, slope, cross slope);
– density and intensity of traffic flow;
– composition of vehicles;
– weather and road surface conditions;
– probability of accidents.

Taking these factors into account, the methodology identifies three main velocity components:

1. Geometrically safe speed

$$\upsilon_{geom} = \sqrt{127(e+f)} \quad (2)$$

here:
R – turning radius, m;
e – cross slope;
f- coefficient of friction.

1. Speed along the stream

$$v_{stream} = v_{\text{free flow}}\left(1-\frac{k_{\text{current}}}{k_{maks}}\right)^{\beta} \quad (3)$$

here:
Vfree flow– free flow rate;
kcurrent– current density;
kmak – maximum density;
β – empirical coefficient.

2. Talking into acoount the impact of weather:

$$v_{weather} = v_{geom} \cdot (1-\gamma W) \quad (4)$$

here:
γ – weather sensitivity coefficient;

W – weather coefficient.

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3. The probability of an accident or the level of conflict can be determined in the following way:

$$P_{av}(t) = 1 - \exp(-\lambda(t)) \qquad (5)$$

here:

$P_{av}(t)$ - probability of an accident at time t;

$\lambda(t)$ – the possibility of conflict during this period;

exp - exponential function.

This formula means that as the intensity of conflicts decreases, the probability of accidents also increases. Based on the results of the study, the optimal speed for mountainous areas is considered to be 70 km/h [8]. On this basis, the final permissible adaptive speed is determined as follows:

$$V_{set}(t) = \min\{70, V_{geom}, v_{flow}, V_{weather}\} \qquad (6)$$

This approach allows you to limit the speed not by a normative value, but according to real conditions. Here: 70 km/h is the target speed limit based on research [6,8].

On a mountain road, the speed depends not only on the flow, but also on the geometry of the road. In curved areas, the safe speed is determined by the radius, slope, surface condition and cross slope. These indicators can be seen in the “Geometric model of safe speed”. The classic connection for a horizontal curve:

$$e + f = \frac{\upsilon^2}{127R} \qquad (7)$$

here:

e— superelevation;

f — coefficient of lateral friction;

V — speed, km/h;

R — turning radius, m.

This formula is widely used to estimate safe speeds based on road geometry [5]. Shundan keskin burilishli hudud uchun ruxsat etiladigan nazariy xavfsiz tezlik:

$$\upsilon_{geom} = \sqrt{127(e+f)} \qquad (8)$$

Another existing model is the current observation model for a mountain road. In practical studies of mountain road areas, video surveillance is often used to measure the travel time at the beginning and end of the area and determine the average speed. This methodology was used for mountain roads in Uzbekistan, and it was shown that speeds for categories M1, N1, N2, N3 decrease with increasing slope [1,3].

The model in the research paper is described as follows:

$$v_{\text{there is}} = f(q, k, R, i, e, f) \qquad (9)$$

here:

i— slope of the road, %;

vcurrent– current speed. km/h;

q – traffic flow intensity, vehicles/hour;

k- traffic density, car/km;

R - road curve (radius), m;

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e- Cross slope of the road, % or m/m;

φ - coefficient of friction between the road surface and the tire, unitless (between 0.2-0.8).

According to this model, the available speed of vehicles is determined by a complex functional relationship that depends on the geometric parameters of the road, the characteristics of the traffic flow, and the condition of the pavement. In particular, the speed varies depending on the traffic flow intensity q, density k, curve radius R, slope i, cross slope e, and friction coefficient φ [6,7].

Conclusion. During the research, a methodology for mandatory speed reduction was developed to improve vehicle traffic safety in mountainous areas. This methodology allowed for a comprehensive consideration of the impact of the turning radius, longitudinal slope, traffic flow intensity, and pavement adhesion coefficient on vehicle speed.

The developed measures were tested in a selected mountainous area. According to the calculation and experimental results, as a result of reducing the speed of vehicles from 100 km/h to 70 km/h, there was a decrease in sudden braking, stabilization of the traffic flow, and a decrease in the number of dangerous situations. The results of the study showed that by reducing the speed by 10–20%, the number of road accidents can be reduced by 15–30%.

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