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MODELLİNG AUTOMATİON PROCESS OF RAİLWAY TRANSPORTATİON İN MOUNTAİNOUS REGİONS

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Abstract

To study the development of an automated control system for railway lines used in mountainous terrain, the goals and objectives of optimal modeling of a railway route in the mountainous region of Karabakh were defined. Safe turning angles and train speeds were determined for optimal modeling of the railway route in mountainous terrain. To study the dynamic parameters that may arise during rail transport movement in mountainous terrain, an algorithm for determining safe speed and acceleration was developed through theoretical and computer experiments, and computer modeling of each parameter was conducted. Based on these parameters, the architecture of an automated control system was proposed to ensure safe train movement in mountainous terrain. To create an automated system for managing a safe route for a railway line in the mountainous region of Karabakh, the types of information-measuring, regulatory, management, and control equipment and their functions were determined.

Keywords: Automated control system for railway, mountainous region, automated control system, information-measuring, ensure safe train movement.

1. Introduction

One of the widely used freight and passenger transportation technologies in modern times is considered to be railway transport. The importance of this type of transport is increasing, especially in mountainous areas. This is due to the fact that due to the complexity of the relief in settlements located in mountainous landscapes, logistical transportation [1, 2] is limited, road construction becomes more difficult, and the use of safety measures [3, 4] is increased.

Analysis of logistics and transport infrastructures of countries with mostly mountainous areas [5-9] shows that railway transport infrastructures in mountainous areas with complex relief are outdated, safety issues are not sufficiently exploited, and automation technology and global network equipment are outdated and do not fully meet modern requirements. In this regard, it can be noted that designing the logistics and transport infrastructure of countries with mountainous areas according to modern requirements, and constructing railway transport in accordance with high safety principles in accordance with mountainous terrain, is considered one of the urgent scientific problems of the modern era.

Thus, railway transport for mountainous areas plays a major role in freight and passenger transportation in terms of economy, ecology and safety. The introduction of automation increases the efficiency of transportation, reduces errors caused by the human factor, lowers operating costs and enhances safety.

The purpose– Karabakh region to justify the construction of a railway line in mountainous areas, determine the safe route and speed of the train, and develop the architecture of its modern automated control system.

Main research tasks:

1. Analysis of the main directions of railway transportation automation, main problems and technological approaches, and solutions.
2. Determination of the route of a railway line created by mountainous terrain and study of the dynamic parameters of the train during its movement through theoretical and computer experiments.
3. Development of the architecture of an automated control system for railway transport in mountainous areas.
4. Selection, application and study of information-measuring and control tools for the automated control system of railway transport in mountainous areas.

One of the areas that ensure the rapid economic development of countries is the creation of an efficient logistics infrastructure. This issue has become even more relevant in countries with complex mountainous terrain. As an example, the mountainous terrain of the Gadabay and Kalbajar regions of the Republic of Azerbaijan, which are considered mountainous regions, can be cited [10]. When analyzing the existing railway infrastructure in the mountainous areas of these areas, we see that due to the occupation of our territories over the past 40 years, railway logistics communication lines have not been built. In mountainous areas with complex terrain, automobile transport lines are currently used [11-13].

However, after the complete liberation of the Karabakh territories in 2020 and 2023, the issues of building new railway lines in mountainous areas and equipping them with modern automation and artificial intelligence technologies have been raised, and innovative scientific and engineering work is being carried out in this direction.

In this sense, the issue of selecting the route of the railway line passing through the mountainous parts of the Kalbajar region and designing its automated control system should be raised and resolved. In order to design the railway line passing through the mountainous area of the Kalbajar region, we will conduct an analysis of the railway lines designed in this area. Based on experience, it can be noted that the project of the Georgian Barjomi - Bakuriani railway line passes through the foothills of the mountain ranges (Fig. 1), and was laid along a safe route in terms of safety [14, 15].

The Borjomi-Bakuriani railway line, which was commissioned in 1901, is a 38 km long narrow-gauge railway line with a width of 900 mm. This railway line connects the resort of Borjomi with the mountain resort of Bakuriani, and also offers attractive views of the mountainous areas during the journey.

Safety measures in the process of public passenger transportation moving along the existing railway route Barjomi-Bakuriani through mountainous areas are ensured due to the experience and professionalism of drivers, dispatchers and other specialists. However, it is not enough to provide modern railway transport technology in mountainous areas due to driving, management and engineering knowledge. In this regard, complex automation of the railway line and vehicle control system in mountainous areas should be ensured. Measurement, control, monitoring and dispatching stations should be installed on the route of the railway line in mountainous areas [16-18]. The railway line should be installed on the basis of narrow gauge rails [19]. The design of the railway vehicle should fully meet modern requirements, and the required movement speeds in the process of linear and angular displacements should not exceed.

Figure 1: *Images of the Barjomi-Bakuriani railway line.*

2. Methodology

2.1 Notations

The following notations are used in this model.

1. a: Speed of the train.
2. θ: Slope of the road.
3. R: Radius of the curved trajectory.
4. μ: Coefficient of friction between the road and the tire.
5. v_{max}: Maximum speed of the railway in mountainous.
6. P_{elec}: Minimal energy consumption.
7. $v_{opt}(x)$: Optimal speed of a train in mountainous terrain.

2.1. Assumptions

It plays an important role in determining the linear, angular, and speed of a railway vehicle on terrain and slope.

In mountainous areas, the slope of the road **(**θ**)** directly affects the speed of the train. Therefore, the speed of the train is determined as follows [20]:

$$a = g(sin\theta - \ f_r cos\theta) \tag{1}$$

where g= *9.81 m/s²*; f_r – friction is a coefficient .

From the destination dependent as, mountainous in the area railway line with movement what of the train mass and optimal movement speed provide to do for engine strength welcomed from force dependent it happens. Train kutlese as it increases slowdown and acceleration ability decreases. Engine strength with welcomed force following like appointment is [21]:

$$F_{traction} = ma \tag{2}$$

Kalbajar of the district mountainous in relief project done the railway on the slope bridges , tunnels and crooked Since trajectories are taken into account , speed crooked to the radius mainly is regulated. In this case of the train maximum speed following like appointment is [22]:

$$v_{max} = \sqrt{R\, g\, \mu} \tag{3}$$

where R is the radius of the curved trajectory; μ is the coefficient of friction between the road and the tire.

As is known, since the Kalbajar region has a sharply continental climate, environmental factors should be taken into account in the process of designing the communication line of the railway vehicle. Rain, snow, and icing during the movement of the train limit its speed. Safety factors should be taken into account for changeable weather conditions. In this case, when moving in mountainous terrain, the optimal speed of the train should be calculated. The optimal speed (v_{opt}) is determined in terms of both energy consumption, safety and the speed requirements of the route.

For minimal energy consumption, the speed of the train, adjusted for gradients and curves, is determined as follows [23]:

$$P_{elec} = F_{total} v, \tag{4}$$

where $F_{total} = F_{rolling} + F_{gravity} + F_{aerodynamic}$

When moving through mountainous terrain, the maximum permissible speeds must be ensured for the safety of the railway train due to the radius of curvature, slope, friction and tunnel limits. In this sense, the following expression is written to determine the maximum safe speed:

$$v_{max} = min\left(v_{curve}, v_{slope}, v_{infratructure}\right) \tag{5}$$

The minimum energy consumption of a train moving along a railway line designed for mountainous terrain must be ensured depending on the maximum safe speed. Therefore, the following expression is used to select the optimal speed of a train in mountainous terrain [24]:

$$v_{opt}(x) = \arg \min_{v \le v_{\max(x)}} E(v) \tag{6}$$

where *E(v)* is the energy consumption per *km* .

Table 1: *Experimental initial parameters that ensure the safe construction of a railway route for mountainous terrain*

No	Train mass (t)	Radius formed in mountainous terrain R (m)	Slope angle in mountainous terrain θ (°)	The friction coefficient of the train μ
1	225	250	9	0.003
2	150	270	4	0.001
3	200	300	5	0.002
4	175	330	7	0.004
5	250	360	8	0.005

Experience shows that when a train is moving, depending on the characteristics of the mountainous terrain, experimental values should be determined for the selection of the maximum safe speed. In this regard, let us determine the experimental initial parameters that ensure the safe construction of a railway route for mountainous terrain (table 1).

Based on the experimental values in Table 1, the maximum speed of a train moving along a curved line of mountainous terrain is determined by the following equation:

$$v_i = \sqrt{R_i g \mu_i} \quad (7)$$

3. Results

3.1. Maximum permissible speed on curved sections

When the experimental values in Table 1 are used in equation (7), the velocities formed under the influence of the slope are determined as follows:

$$v_1 = \sqrt{R_1 g \mu_1} \approx 2{,}71\frac{m}{s}$$
$$v_2 = \sqrt{R_2 g \mu_2} \approx 1{,}63\frac{m}{s}$$
$$v_3 = \sqrt{R_3 g \mu_3} \approx 2{,}43\frac{m}{s}$$
$$v_4 = \sqrt{R_4 g \mu_4} \approx 3{,}60\frac{m}{s}$$
$$v_5 = \sqrt{R_5 g \mu_5} \approx 4{,}20\frac{m}{s}$$

Taking into account the slope angles and train friction coefficients given in Table 1, θ the acceleration is determined as follows, according to the maximum speed of the train :a_i $(i = \overline{1,5})$

$$a_i = g(sin\theta_i - \mu_i) \quad (8)$$

When the experimental values in Table 1 are used in equation (8), the acceleration formed under the influence of the slope is determined as follows:

$$a_1 = g(sin\theta_1 - \mu_1) \approx 4{,}01\ m/s^2$$
$$a_2 = g(sin\theta_2 - \mu_2) \approx -7{,}43\ m/s^2$$
$$a_3 = g(sin\theta_3 - \mu_3) \approx -9{,}41\ m/s^2$$
$$a_4 = g(sin\theta_4 - \mu_4) \approx 6{,}41\ m/s^2$$
$$a_5 = g(sin\theta_5 - \mu_5) \approx 9{,}66\ m/s^2$$

Thus, the v_i obtained as a result of the experiments A table of indicators of the velocities and the acceleration a_i formed under the influence of the slope is created (Table 2).

For a train moving through mountainous terrain is determined by the curve radius, slope, friction and tunnel limits from a safety perspective. The graphs of the velocities and the accelerations a_i formed under the influence of the slope are constructed according to the experimental results obtained (Fig. 2, Fig. 3).

Table 2: *Indicators of the speeds v_i and accelerations a_i*

No	Experimental speed v_i (m/s)	Experimental acceleration a_i (m/s^2)
1	2.71	4.01
2	1.63	-7.43
3	2.43	-9.41
4	3.60	6.41
5	4.20	9.66

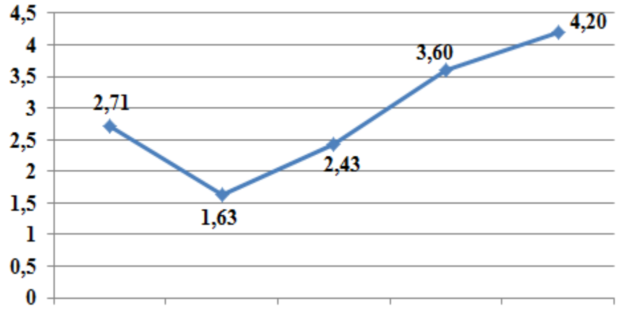

Figure 2: *Maximum permissible v_i due to the curve radius, slope, friction and tunnel limits of the train for safety reasons speed graph*

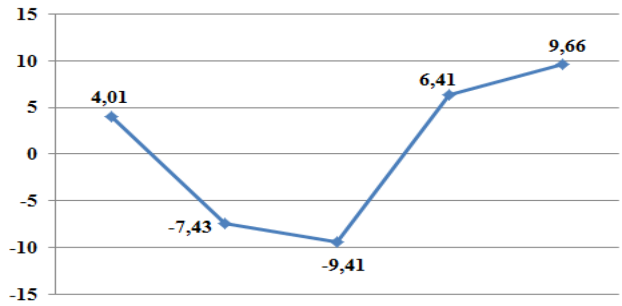

Figure 3: *Graphical representation of the acceleration a_i formed under the influence of the slope from the point of view of the safety of the train*

As a result of the experiment, it was determined that during the movement of a train through mountainous terrain, the maximum permissible speed increase due to the curve radius, slope, friction, and tunnel limits must be controlled in accordance with the maximum speed.

In the process of train movement in mountainous terrain, an automated control system should be created for operational control of safe turning and speed in order to control the maximum speed according to the curve radius, slope, friction and tunnel limits. In this regard, the architecture of an automated control system that ensures the safe railway route of a train in mountainous terrain is proposed (Fig. 4) .

An automated speed control system (ASCS) is installed in the safe movement zones of the train in mountainous terrain. At the 1st level of the SANS architecture, train speed sensors, slope and turn sensors, and an automatic braking system are applied. At the 2nd level of the architecture, a centralized programmable control controller (CPCC) is used. The interface of the ASCS operational control with automated workplaces with a global computer network system and a programmable operator visual monitoring system based on SCADA are applied.

Sensors implemented in the 1st level of ASCS architecture are train wheel rotation sensors. (tachometer) It measures the wheel rotation frequency during movement and, based on this indicator, the train speed is determined and constantly monitored by the operator. The encoders used are the train's It measures the angle and frequency of rotation with high accuracy, allowing you to calculate speed and distance. The speed is determined by the frequency of pulses generated by contact transmitters installed on the railway rails. The speed of the train is measured by magnets installed on the rails.

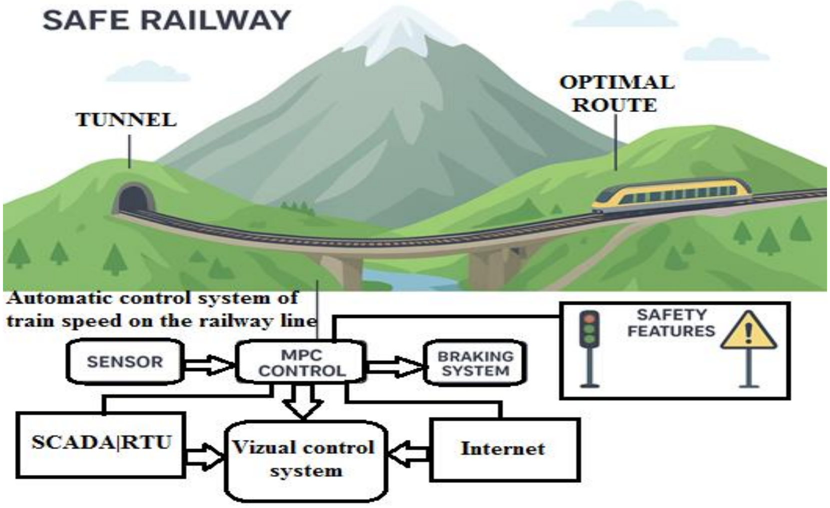

Figure 4: *Architecture of the system for safe turning and automated speed control during train movement in mountainous terrain*

In mountainous areas, inertial and satellite-based transducers are used. The GPS/GNSS modules used determine the exact speed and coordinates of the train during its movement in open areas. Modern inertial measurement unit it measures the acceleration, direction and angular velocity of the train using a combination of accelerometers and gyroscopes. As the train moves, radar-based sensors measure the speed of the train by analyzing the reflection of radio waves in the direction of travel.

The following blocks are used in the 2nd level of the ASCS architecture: OCC/CTC/TMS (route planning, train sequencing, delay management); RBC/CBTC Zone Controller (traffic management) and operational control; DMI (Driver-Machine Interface), BTM (Balise Transmission Module), GNSS/IMU, wheel encoder; SCADA/RTU; ATP (Automatic Train Protection); speed control, maximum permissible speed (V_{perm}); ATO (Automatic Train Operation); Automatic adjustment of speed according to the profile.

At the 3rd level of the ASCS architecture, within the framework of the region's global network organized via the Internet, the functions of measuring safe train speeds on straight and angled lines, automatic adjustment of speed based on the profile, and movement control in zones are provided.

4. Conclusion

1. The main directions and problems of railway transportation automation have been analyzed, and research objectives have been set.
2. An algorithm has been developed and studied through computer experiments to determine the route of a railway line created in mountainous terrain and to determine safe speed and acceleration parameters during train movement.
3. The types of information-measuring and control devices of the automated control system of railway transport in mountainous areas have been determined.
4. The automated control system for railway transport in mountainous areas has been proposed.

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