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Improving Transportation and Traffic Safety with Digital Infrastructure and Telematic Systems for Mountain Vehicle Operations

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ABSTRACT

Digital transformation strategies have been developed and approved in the federal constituent entities of the Russian Federation. The strategy of digital transformation of the Republic of Dagestan has comprised transport among main areas.

The strategy of digital transformation in the field of transport involves introduction of navigation systems on public transport, ensuring the comfort of passenger travel, including ease of payment, and reduced waiting time.

Research has shown that in recent years the number of road traffic accidents in the mountainous regions of Dagestan and their severity has increased. This is due to an increase in the number of cars operated on the road network of the Republic, especially by motor tourists, a decrease in driver discipline, and the low level of development of telematics systems and digital infrastructure on mountain roads.

In this work, the authors have proposed organisational, technical and engineering measures for development of digital infrastructure for the mountainous road conditions of the Republic of Dagestan, which include the creation of a Situation Centre in the Traffic Control Centre (TCC) with introduction of an automated transport mobility management system, systems for monitoring meteorological and road conditions, installation of dynamic information boards, updating of navigation maps and enhancement of the functions of voice messages.

The implementation of the proposed measures will improve transportation and road traffic safety when transporting passengers in the mountainous areas of Dagestan and reduce the number of road traffic accidents.

Keywords: *transport, Dagestan, digital transformation, mountain roads, telematic systems, digital infrastructure, road traffic safety.*

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INTRODUCTION

The objective of the digital transformation strategy is the scaling of competitive national solutions into different sectors of Russian economics, social sphere, and public administration.

Following the commission of the President of the Russian Federation, digital transformation strategies were developed in all country's regions.

The head of the Republic of Dagestan approved in 2021 the «Strategy in the field of digital transformation of sectors of the economy, social sphere and public administration of the Republic of Dagestan»[1] (hereinafter called Strategy). The strategy comprised seven sectors, particularly transport, 43 projects, including a project in transport and logistics.

New edition of the Strategy was approved by the decree of the Government of the Republic of Dagestan No. 461-r of October 11, 2022.[2]

As of 2023, «the Strategy of the digital transformation of the Republic of Dagestan has incorporated 17 sectors with 77 on-going projects. Most activity is held within the framework of primary sectors: public administration, education, public healthcare, construction and urban environment, roads, which have been complemented by tourism, culture, sports which are topical for the region… Dagestan has exceeded the planned performance indicators regarding growth of digital maturity… In 2021 the digital maturity indicator of the region was of 37 %, at the end of 2022 it attained the value of 58 % while it was planned to attain 46 % by the end of the year».[3]

In accordance with the Strategy, the challenges (guidelines) for the development of the transport and logistics industry are as follows: «1) creating conditions for building optimal routes and information and navigation provisions for planning passenger trips; 2) increasing the safety of passenger transportation; 3) ensuring the possibility of cash-free payment for travelling in buses carrying out regular passenger transportation; 4) creating conditions for the development of electronic platforms for ordering freight transportation, logistics services and e-commerce services; 5) development of a system for tracking cargo transportation using electronic navigation seals; 6) creation of an intelligent transport system within Makhachkala agglomeration on the territory of the Republic of Dagestan; 7) integration of regional transport systems with the Situation information centre of the Ministry of Transport of the Russian Federation; 8) digitalisation of public services in the field of transport safety and security; 9) creation of conditions for the introduction of technology of information modelling of capital construction objects of transport infrastructure; 10) introduction of artificial intelligence technologies in the design, construction, repair and maintenance of transport infrastructure facilities; 11) application of the technology of 3D modelling in the development of transport infrastructure facilities» [2].

Given the difficult conditions of mountain roads in the Republic of Dagestan, special attention is required to comprehensive measures aimed at improving road traffic safety.

The *objective* of the study is to analyse the current traffic conditions in the Republic of Dagestan, to develop and propose organisational, technical and engineering measures for the development of digital infrastructure to improve road traffic safety for mountain conditions.

RESULTS

Analysis of the Digital Maturity of the Transport Industry of the Republic of Dagestan

Appendix No. 19 to Decree No. 542 of the Government of the Russian Federation dated April 3, 2021, approved the «Methodology for calculating the Digital Maturity Indicator of the Public Authorities of the Constituent Entities of the Russian Federation, Local Self-Government Bodies and Organisations in the Field of Healthcare, Education, Urban Economy and Construction, Public Transport, Implying the Use of Domestic Information Technology Solutions».[4] In accordance with the appendix to the Methodology, taking into account

[1] Strategy in the field of digital transformation of sectors of the economy, social sphere and public administration of the Republic of Dagestan. In Russian. [Electronic resource]: https://digital.gov.ru/uploaded/files/respublika-dagestan_JwoZYnH.pdf. Last accessed 21.03.2023.

[2] In Russian. [Electronic resource]: https://digital.gov.ru/uploaded/files/respublika-dagestan.pdf. Last accessed 21.03.2023.

[3] The number of the sectors of the economy included in the Strategy of the digital transformation of Dagestan has grown from 7 to 17. Ministry of digital development of Dagestan. 23.05.2023. In Russian. [Electronic resource]: https://dagestan.digital/press/50853. Last accessed 15.05.2023.

[4] Decree of the Government of the Russian Federation dated April 3, 2021, No. 542, on «Approval of the techniques to calculate indicators to assess the performance of the senior officials of the federal constituent entities of the Russian Federation and of the executive bodies of the federal constituent entities of the Russian Federation, as well as on recognition of some provisions of the Decree of the Government of the Russian Federation dated July 17, 2019, No. 915 invalid» (as amended and enlarged). In Russian. [Electronic resource]: https://base.garant.ru/400584539/. Last accessed 15.05.2023.

the changes made by Decree No. 1094 of the Government of the Russian Federation dated July 1, 2023, the composition of indicators characterising the achievement of the digital maturity indicator in terms of public transport includes: «the share of buses engaged in regular passenger transportation in urban, suburban and intercity (within the federal constituent entity of the Russian Federation) equipped with cashless fare payment systems; the share of buses engaged in regular urban, suburban and intercity transportation (within the federal constituent entity of the Russian Federation) for which information on their actual movement along the route is available in open access mode; share of buses engaged in regular urban, suburban and intercity passenger transportation (within the federal constituent entity of the Russian Federation) equipped with video surveillance systems (with a recording function) that comply with the requirements for the protection of personal data».[5]

At the same time, in accordance with the Strategy in the field of digital transformation of sectors of the economy, social sphere and public administration of the Republic of Dagestan, the share of buses for which information about their real-time positioning on routes was provided in open access mode in 2022 was of 5 %, by 2024 it should reach 17 %. The share of bused equipped with cashless fare payment systems is of 3 % and 15 %, respectively. The share of bused equipped with video surveillance systems in passenger compartments with a recording function that comply with personal data protection requirements is of 3 % and 10 % respectively [2]. The appropriate tasks have been implemented consistently. With the total number of buses in the Republic of Dagestan, estimated in April 2023 to attain 3900 units, as of «August 25, 2023, the number of vehicles equipped with cashless fare collection systems has reached 340 units. The possibility of cashless payment is implemented in trolleybuses and small-class buses in the cities of Makhachkala and Kizlyar, as well as in small and medium-class buses transporting passengers on the new inter-municipal routes Makhachkala – Airport and Kaspiysk – Makhachkala – Leninkent».[6]

Currently, a digital platform for managing the public transport system is being created in Makhachkala. In 2021, as part of implementation of an intelligent transport system in the city, 2 modules and 7 subsystems, a data processing centre and a traffic management centre (TMC) were created.

These systems cover several public transport management modules. In particular, a coordinated traffic management module, a subsystem for traffic lights control, monitoring of traffic flow parameters and a video surveillance subsystem for detecting road traffic accidents and emergency situations on the region's roads have been introduced in Makhachkala agglomeration.

In addition, for monitoring public transport, a traffic control module, a subsystem for monitoring movement of transport, a subsystem for priority emergency vehicles and route management, as well as «smart public transport stops» have been developed [1–3].

The analysis of the issue showed that the digital transformation strategy in the field of transport is generally aimed at optimising the operation of urban public transport and ensuring comfortable passenger transportation.

At the same time, according to authors' opinion, insufficient attention is paid to ensuring safety of transportation and traffic on mountain routes.

The Relevance of the Problem of Road Traffic Safety for Mountain Roads

The urgency of the problem is due to the increase in the number of road traffic accidents on mountain routes, the increase in severity of accidents, and a significant increase in the number of tourists travelling by car in mountainous areas.

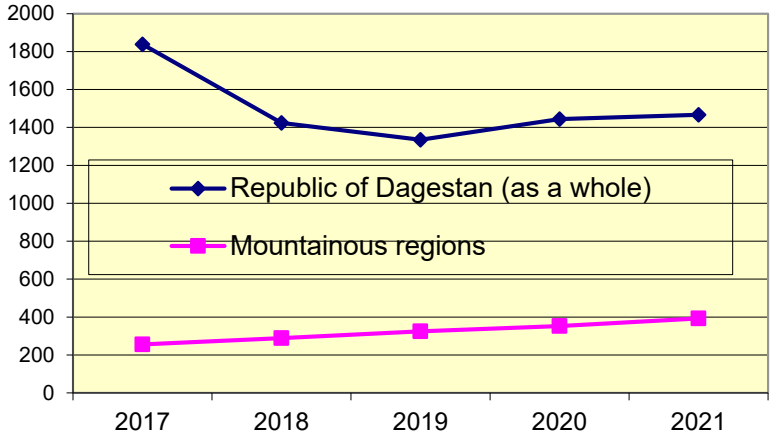
The diagram (Pic. 1) shows the dynamics of changes in the number of road traffic accidents in the Republic as a whole and in the mountainous regions of Dagestan over the past five years. The share of road traffic accidents on mountain roads, as well as their absolute number, has increased significantly.[7]

In the Republic of Dagestan in the first half of 2022, 655 road traffic accidents occurred, in which 109 people died and 910 people received injuries of varying severity. In recent years, a difficult situation with RTA rates has been observed not only on federal highways, but also in almost all cities and mountainous areas.

[5] In Russian. [Electronic resource]: https://base.garant.ru/400584539/66ac2cc39f09c332a272af3e76947f0b/. Last accessed 15.07.2023.

[6] Yusupova, A. The cashless fare payment will be introduced in public transport in large cities in Dagestan. 26.08.2023. In Russian. [Electronic resource]: https://riadagestan.ru/news/economy/beznalichnuyu_oplatu_proezda_v_obshchestvennom_transporte_vvedut_v_krupnykh_gorodakh_dagestana/. Last accessed 26.08.2023.

[7] Road traffic safety indicators. In Russian. [Electronic resource]: http://stat.gibdd.ru/; https://rusdtp.ru/stat-dtp/respublika-dagestan/. Last accessed 30.11.2022.



Pic. 1. Dynamics of changes in the number of road accidents in the Republic of Dagestan and mountainous regions 7.

Pic. 2. A car with six tourists fell into a ravine [https://erenlar.ru/news/media/2022/7/3/v-dokuzparinskom-rajone-mashina-s-shestyu-turistami-oprokinulas-v-uschele/].

Pic. 3. A Datsun car overturned into the Tobot Falls canyon [https://www.stav.kp.ru/daily/27424/4624519/].

Here are examples of road accidents on the mountain roads of the Republic of Dagestan over the past year.

On July 3, 2022, a car with six tourists, approaching the village of Kurush, fell into a ravine. As a result of the incident, the driver of the car received serious injuries, and the tourists received minor and moderate injuries. The Land Cruiser 200 was driven by an experienced local driver, but nevertheless, when driving uphill due to weather conditions, the driver lost control[8] (Pic. 2).

On July 22, 2022, on the outskirts of the village of Khunzakh, a Datsun car overturned from a height of more than 90 meters into the canyon of the Tobot waterfall. A 35-year-old resident of the Orenburg region was driving, his wife and their two young children were passengers. All four died on the spot[9] (Pic. 3).

On June 14, 2022, in the village of Mitliurib, Shamil district of Dagestan, a Volkswagen Tiguan fell off a 100-meter cliff. A woman tourist from Nizhny Novgorod died after having lost control. An 11-year-old child travelling with her in the car was hospitalised[10] (Pic. 4).

On September 29, 2022, the driver of a KamAZ truck, according to preliminary

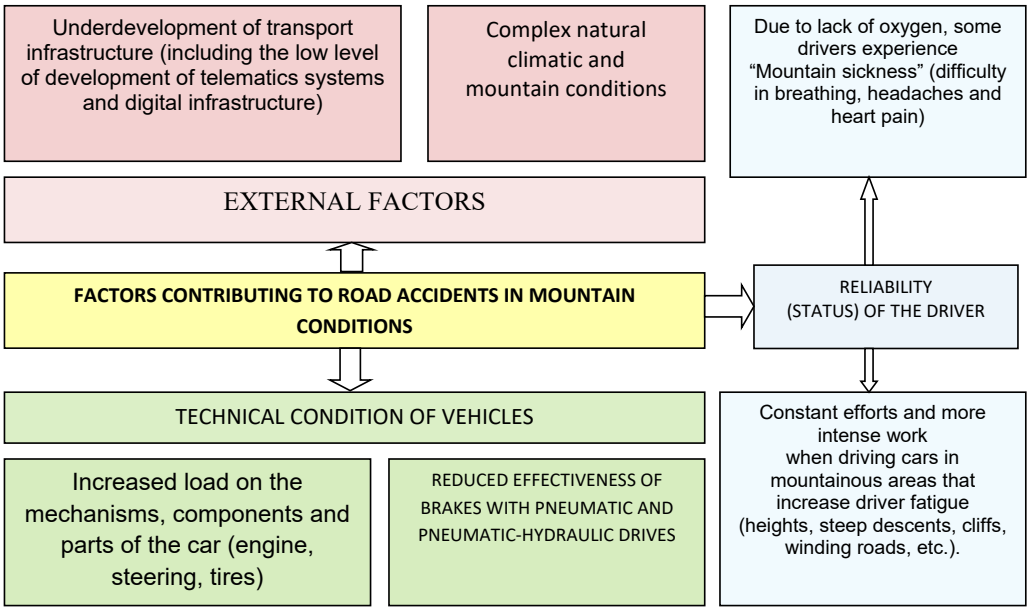
[8] A car with six tourists fell into a ravine in Dokuzparinsky district. In Russian. [Electronic resource]: http://erenlar.ru/news/media/2022/7/3/v-dokuzparinskom-rajone-mashina-s-shestyu-turistami-oprokinulas-v-uschele/. Last accessed 27.11.2022.

[9] A family from Orenburg crashed in the mountains of Dagestan. In Russian. [Electronic resource]: https://rusdtp.ru/semya-iz-orenburga-razbilas-v-gorah-dagestana/. Last accessed 28.11.2022.

[10] A car with tourists flew off a cliff in Dagestan. A woman died. In Russian. [Electronic resource]: https://www.fontanka.ru/2022/06/14/71408972/?ysclid=lnygmvu3lq432147646. Last accessed 28.11.2022.

Pic. 4. A Volkswagen Tiguan fell off a 100-meter cliff.

Pic. 5. A KamAZ car, due to a failure of the braking system on a descent, collided with three cars.



Pic. 6. Factors contributing to the occurrence of road traffic accidents in mountainous conditions [performed by the authors].

information, due to a failure of the brake system on a descent, lost control and collided with a passenger minibus, after which he collided with the LADA Niva and VAZ-2109 cars. As a result of the accident, the driver of the truck and three passengers of the minibus died at the scene. Another 10 participants in the accident were brought to medical institutions in Makhachkala with various injuries[11] (Pic. 5).

[11] In Dagestan, one of the victims of an accident with a minibus remains in serious condition. In Russian. [Electronic resource]: https://tass.ru/proisshestviya/15913905?ysclid=lnyh8c8q8t139153550. Last accessed 28.11.2022.

Features of Ensuring Road Traffic Safety in Mountain Conditions

The share of mountain roads in the Republic of Dagestan is 80 % of the total length of roads, which is about 8 thousand km.

Based on the location above the sea level and operating conditions of vehicles, the relief of Dagestan can be conditionally divided into four parts: flat – up to 500 m, hilly – 500–1000 m, mountainous – 1000–2000 m and high-mountainous – more than 2000 m above sea level.

On mountain roads there are a large number of ups and downs, dangerous turns with limited

Pic. 7. Mountain roads.

visibility, narrow sections of roads where oncoming traffic is difficult or impossible.

The fear of individual drivers, especially motor tourists, to drive in mountainous conditions, thin air, as well as high requirements for traffic safety require drivers to be in good health and have excellent driving experience.

Let us consider the factors contributing to the occurrence of road traffic accidents in mountainous conditions (Pic. 6).

In the mountains of Dagestan, there are currently roads on which oncoming traffic is difficult or impossible due to the fact that there is only a single lane for traffic. On such roads, one of the drivers will have to reverse until the roadway widens, which is a dangerous manoeuvre not only for tourists, but also for local drivers. Such sections of roads are found, for example, in Charodinsky, Laksky, Agulsky, Khunzakhsky, Rutulsky and other districts of the Republic. The same section of road with a single lane is found on the Glavryba – Boat Station segment with a length of 12 km, where there is a large flow of tourists throughout the year. There are chasms on the segment that are more than 100 m deep (Pic. 7).

These factors contribute to the occurrence of road traffic accidents, and the severity of the consequences of RTAs increases significantly.

Digital Infrastructure and Telematic Systems to Ensure Traffic Safety on Mountain Roads

Problems of ensuring safety on mountain sections of roads can be solved by using digital infrastructure and telematic systems for vehicles carrying out mountain transportation [4–6].

Fields of implementation of telematic systems in urban passenger transport and of development of transport digital infrastructure have been widely studied and described in the works of D.Sc. (Eng), Professor of Moscow Automobile and Road Construction State Technical University V. M. Vlasov.[12]

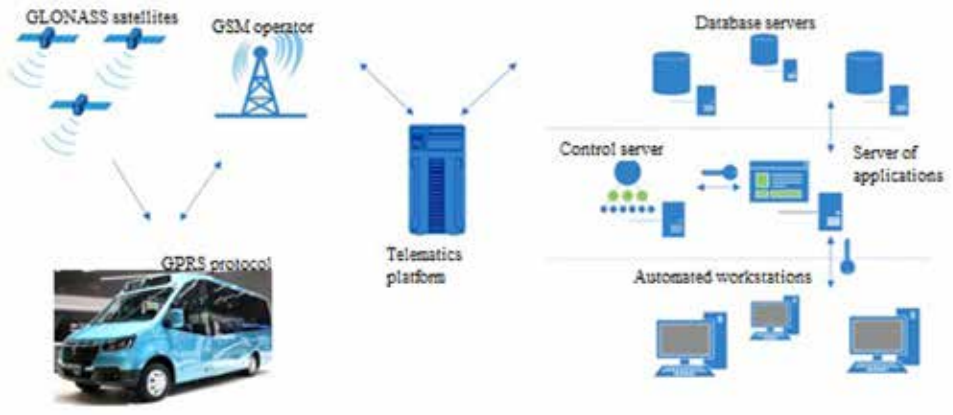
Issues of using digital infrastructure in logistics and development of modern automated control systems in transport are considered in the scientific works of a coauthor of the article, D. Sc. (Eng), Professor N. A. Filippova, including those related to development of TLC (transport and logistics centre), centralisation of planning systems for multimodal cargo transportation to ensure safety, reliability and management of transportation processes [7–9].

An automated system for managing transport mobility in mountainous areas and difficult climatic conditions, proposed by coauthor, Prof. Filippova N.A. for the conditions of Tajikistan can be recommended for implementation when organising passenger transportation in the mountainous conditions of Dagestan (Pic. 8).

In this case, the telematics platform may be configured as the Situation Centre (monitoring department) within the Road Traffic Management Centre (TMC) of the Republic of Dagestan, which is planned to be launched in 2023.

Vehicle monitoring includes displaying the location of vehicles at any time with grouping

[12] Vlasov, V. M., Efimenko, D. B., Bogumil, V. N. Application of digital infrastructure and telematic systems in urban passenger transport: Textbook. Moscow, INFRA M publ., Moscow, 2018, 352 p. ISBN: 978–5–16–013194–8.



Pic. 8. Automated system for managing transport mobility in the mountainous areas of the Republic of Dagestan [authored by N. A. Filippova].

according to various criteria (fleet, type of transport, on-job/off-job, special objects), communication with drivers, complete information about the vehicle in real time, weather in real time with a forecast for the current day anywhere in the country (including wind speed and direction, possible precipitation and air humidity),[13] control of operational tasks with colouring of geofences in real time depending on whether they are visited at the moment [10; 11].

Based on the research of a coauthor, Prof. Filippova N.A. and the analysis carried out by the coauthors regarding the mountain conditions of Dagestan, measures were proposed to minimise risks when organising and managing passenger transportation. They include both external factors (climatic and mountain conditions, level of development of transport infrastructure, social factors) and internal ones (reducing travel and transportation time, ensuring technical condition of vehicles during transportation, ensuring the reliability of personnel involved in the organisation and implementation of transportation) [12; 13].

Currently, to ensure safety of transportation and road traffic in the mountainous areas of Dagestan, road maintenance services and the State Traffic Safety Inspectorate of the Republic of Dagestan are carrying out certain activities and organisational and technical work, which include not only standard and typical activity to install road signs and markings, but also «digitalisation» of transport.[14] These include:

Installation of road warning, prohibition and information signs, primarily in dangerous areas.

Installation of fences with various types of reflectors, as well as protective barriers.

Installation of lighting equipment on dangerous sections of roads (works are scheduled for a long period).

Installation of cat's eye retroreflectors on the roadway (work is planned for the future).

Installation of «smart pedestrian crossings» (installed so far in 5 places in Dagestan, including 3 in mountainous areas).

Installation of two comprehensive road monitoring stations for meteorological data (CRMS MD). Installed so far on 2 segments: 1) Makhachkala – Buinaksk – village Levashi – village Verkhniy Gunib, 2) Buinaksk – village Gimry – village Chirkata.

The automatic weather station is designed to record basic meteorological parameters (Infometeos LLC): air temperature and humidity, atmospheric pressure, wind speed and direction, precipitation (snow, rain, hail, freezing rain, drizzle, sleet are distinguished), CO_2 content (Pic. 9).

CRMS MD can also provide monitoring of the condition of the road surface and its parameters, analysis of traffic flows, identification of the type of vehicle, characteristics of traffic

[13] Vartanov, F. V., Veremeenko. E. G. Information technology to ensure cargo transportation *[Informatsionnye technologii po obespecheniu gruzovykh perevozok*]. Engineering journal of Don, 2018, Iss. 1. [Electronic resource]: http://www.ivdon.ru/uploads/article/pdf/IVD_106_veremeenko-vartanov.pdf_3beda71350.pdf. Last accessed 30.03.2023.

[14] Reforming and digitalisation of public transport of Makhachkala were discussed by the Government of Dagestan. In Russian. [Electronic resource]: https://riadagestan.ru/news/the_government_of_the/reformirovanie_i_tsifrovizatsiyu_obshchestvennogo_transporta_makhachkaly_obsudili_v_pravitelstve_dagestana/?ysclid=lnyhvvn8et635567491. Last accessed 28.11.2022.

Pic. 9. Sensor for recording basic meteorological parameters.

Pic. 10. Road surface condition sensor.

flows by each lane, video recording of road traffic accidents and saving a video fragment for examination. Sensors for measuring the condition of the road surface, included in the CRMS MD, are designed to carry out remote measurements of the temperature of the surface of the road surface, determining the thickness of the layer of water, ice and snow on the road surface (Pic. 10).

Information from CRMS MD is processed using software and then transmitted to the data collection centre in real time. This information is used for various purposes for publishing on the Internet, analysing the current situation, developing forecasts, etc.[15]

Installation of information boards (2 pieces installed so far, see Pic. 11). The cost of one U-shaped board is approximately 11,5 million rubles.

Installation of cameras for photo-video recording of violations (regarding exceeding speed limit and trespassing solid line). Currently, 77 cameras are installed throughout the Republic.

The Ministry of Transport of Dagestan has carried out preparatory work to connect 20 complexes of automatic photo-video recording of traffic offenses to the software called «Web».

Creation of the Situation Centre (monitoring department) in the Traffic Management Centre (TMC) of the Republic of Dagestan. It is planned to install 50 video surveillance cameras in the

[15] Use of video surveillance systems in transport. In Russian. [Electronic resource]: https://radioterminal.ru/resheniya/videonablyudenie-na-transporte/ispolzovanie-sistem-videonablyudeniya-na-transporte. Last accessed 30.03.2023.

Pic. 11. Information board [TMC of the Ministry of Transport of the Republic of Dagestan].

Pic. 12. Light display of variable information.

Republic, recording the condition of the road, weather, information about road load, etc. (Video analytics).

As a result of the research and analysis of this problem, the authors of the paper proposed the following organisational, technical and engineering measures based on telematics systems, including digital infrastructure, aimed at improving transportation and road traffic safety in mountainous conditions[16]:

Opening of a Situation Centre (with a traffic monitoring system) in the Road Traffic Management Centre of the Republic of Dagestan.

Implementation of an automated management system of transport mobility in mountainous conditions based on the Situation Centre's facilities.

It is advisable to extend the use of road information boards linked to the Situation Centre, as well as of automatically controlled road warning, prohibition and information signs on dangerous sections of roads: in places of possible falling stones, strong winds, fog, abysses, steep slopes or descent, limited visibility, as well as to regulate oncoming traffic on a single-lane road in mountainous areas. Signs must be controlled through the Situation Centre.

Light displays of variable information (dynamic information boards) will inform drivers about the location of travel objects (settlements, tourist centres, etc.), weather, road conditions, avalanches, landslides, road traffic accidents and traffic jams, about the nearest motels and shops, and will provide advertising information, and also warn drivers about the inadmissibility of traffic violations and the dangers when driving on mountain roads (Pic. 12).

[16] A digitalisation strategy will be developed in Dagestan. In Russian. [Electronic resource]: https://mkala.mk.ru/politics/2022/10/19/v-dagestane-vyrabotayut-strategiyu-cifrovizacii-transportnoy-otrasli.html. Last accessed 29.11.2022.

Pics. 13, 14. Dynamic information boards.

Installation of additional CRMS MD in mountainous areas, connecting them to the Situation Centre for online transmission of information to drivers about the road situation along the route (Pics. 13, 14).

Updating of the satellite online navigation map for car drivers. This includes, for example, the use of voice messages («100 m from here there is a cliff, be careful», «In 100 m there is a precipice», «In 100 m there is a dangerous turn to the right», «There is a possibility of rocks falling in the area, be careful», «After next 100 m begins a narrow road with 1 lane, be careful», «After 100 m there is the beginning of a steep

ascent», «After 100 m there begins a steep descent»), etc. Online navigation voice messages and dynamic boards should also inform drivers about the correct choice of speed or gear on steep descents, climbs and dangerous sections of roads. In particular, the message «There is a steep descent ahead, driving in 1st gear is recommended. Do not turn off the engine!», «There is a steep climb ahead, driving in 1st gear is recommended».

Equipping road barriers with retroreflectors (reflectors) of various types, including LED ones, installing «cat's eye» retroreflectors on the roadway in cases of lack of artificial lighting, in low light conditions, in the dark and in foggy conditions.

CONCLUSION

The implementation of the listed organisational, technical and engineering measures will improve safety of passenger transportation on the mountain roads of Dagestan, prevent the occurrence of road traffic accidents, reduce their number and severity, ensure the effective functioning of navigation systems and an automated transport mobility management system.

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