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On the substantiation of promising areas for improving road design safety

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Introduction. The article considers the increasing role of highways in the economy of the modern state. A number of advantages of motor transport are listed and described: flexibility of delivery, speed and reliability of transportation, absence of unnecessary overloads of delivered materials, and economy.

Problem Statement. The authors substantiate the claims that the quality of roads significantly affects road safety, and the critical excess of the number of permissible shortcomings in their operation, deviations from standards and norms lead to the risk of losing the complex of operational qualities of road construction objects.

Theoretical Part. The paper analyzes the dynamics of road construction in our country in the past century. The features of road construction caused by the influence of a number of heterogeneous factors are determined. Examples of modern reconstruction of highways in metropolises are given, which allow determining the main requirements for a modern road and its main consumer properties.

Conclusion. Road construction will become more advanced if digital technologies are used — systems based on artificial intelligence, neural networks, etc. The technologies of the next decades, which will control the entire system "design-repair-production-control–transportation", will allow you to get high safety indicators in the field of road construction.

Keywords: roads, operation safety, logistics systems of vehicles, artificial intelligence, neural networks, generative design.

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Introduction. The circulatory system of the economy of any modern state is highways. They are designed to meet the needs of legal entities, the economic complex and individuals in transportation. This task cannot be fully implemented without an appropriate road network.

In logistics systems, vehicles have a number of advantages: flexibility of delivery, high enough speed, reliability, absence of overloads on the delivered materials, relative economy.

According to the technical terms, we can say that highways are a complex of engineering structures that include: earth foundation, road surface, capital construction objects, technical systems for the construction of the road network, special safety elements and structures, as well as buildings and structures of car services, road transport and road maintenance organizations. The vast territory of Russia with various geographical densities of settlements, economic objects and agricultural areas requires an optimal approach to designing a safe road network, taking into account the logistics flows of goods and services.

Theoretical Part. After analyzing the dynamics of road construction, we can conclude that since the beginning of road transport in our country (from about 1925) and until the last decade of the twentieth century, the size of the standard road network has increased by more than 65 times. In the post-war decade (from 1950 to 1960), the size of the standard road network built increased each year by about 9,000 km, and with the introduction of heavy road construction equipment (after 1960) by more than 20×10^3 km per year. The largest increase in the network of state

roads (public roads) with paved surfaces was achieved during the last economic spurt of socialism (1966-1975) — an average of 26 thousand km per year. By the early 80's, the roads stretched for 800 thousand km. At the same time, historical statistics show that for various, mainly economic, reasons, since the mid-70s, the speed of construction of road facilities has been decreasing [1].

Highways in the European part of the Russian Federation diverge in the form of a multi-beam star, as it was in the days of horse-drawn transport more than a hundred years ago. Today, this network topology can be explained by weak horizontal economic links between cities and regions of our country.

The Russian automobile fleet is growing at a significant rate, which requires the development of the road network. The amount of vehicle shipment is 1.5 times higher than by rail, 5 times higher than by pipeline, and 8 times higher than by water.

The increase in the intensity of automobile traffic has led to significant wear and destruction of roads. As a result, the need for repair and restoration work has increased. The analysis of statistical materials has shown that roads in the country today do not meet the requirements of evenness, need strengthening repairs of the coating, have standard fencing structures, and are operated without visible or applied markings.

If you do not pay enough attention to repair and restoration work, road condition will become worse. This will result in reduced labor productivity, increased operating costs, machine wear (by 30%), and the number of accidents.

As of 2020, the state of roads in major metropolitan areas (with the exception of Moscow) is difficult. One of the problems of the Russian Federation, along with the lack of competence of individual managers in the field of construction and operation of highways, is the lack of necessary financial resources for current, major repairs and reconstruction of the street network. For this reason, the allocated limited financial resources are spent inefficiently [2].

Finally, there are positive examples of road reconstruction in the street network. In the early nineties, a complete reconstruction of the Bolshaya Sadovaya street in Rostov-on-Don was made. The reconstruction involved not only removing the top layer of pavement, but also removing the entire base structure to the paving stones laid at the beginning of the 20th century. At the same time, numerous utilities were replaced, entrances to buildings, work was performed on the roadway, and paving slabs were laid. After that, serious repairs were almost not carried out. However, high-quality reconstruction of the street allowed increasing the inter-repair cycle to almost a quarter of a century [3].

In the modern history of the Russian Federation, there are very few such examples in the reconstruction of highways in megacities. The main requirements for a modern highway, taking into account its category, are indicators of technical level and operational condition, namely the following properties:

— cost-effectiveness, which is the most relevant indicator due to the high cost of construction and operation, even when compared with the cost of similar roads in Europe;

— traffic speed, which determines the capacity of the road and is provided by the quality of the design of the route, artificial structures, roadbed and pavement;

— traffic safety, which involves the rational arrangement and maintenance of serviceable technical condition of the road and road structures, traffic regulation with the installation of road signs, various fences, systems for traffic order, which reduces the number of congestion and accidents;

— ease of use of the road due to improved driving and the ability to stop safely for various reasons. For example, in the United Kingdom, motorways provide a roadside in the form of a reduced lane with a road surface. Every 3 km there are free telephones with the road service's information desk. This experience can be used in our country;

— calculated load on the road is provided by the projected design of road pavement and engineering structures. Due to various reasons, including underestimation of design loads, ruts, longitudinal and transverse cracks appear on the road surface, which subsequently leads to the destruction of the road surface. In Canada, where frosts can tear not only concrete, asphalt, metal, but also be stronger than in central Russia, part of the roads (90%) is made of dirt with a crushed stone surface, on which you can move up to 100 km/h. Road sections are assigned to teams equipped with scrapers, rollers, and tipper trucks.

In Russia, measures to charge for the use of roads for heavy-payload vehicles using the Platon system solve economic problems of improving the quality of roads with less than optimal efficiency [4].

Problem Statement. In order to improve the quality of road construction and operation, it is necessary to implement a set of measures integrated into a system that provides, for example, the following parameters:

— $К_д$ — processing of legal and regulatory documentation for compliance with the best world analogues;

— $К_р$ — increasing the level of training for managers and specialists involved in the design of new construction, reconstruction, capital and current repairs of roads in localities and outside the urban road network;

— $К_м$ — increasing requirements for the quality of materials products and structures used in the road sector;

— $К_т$ — application of advanced methods and technologies in the road sector under various conditions of work.

These parameters are determined by the past historical and modern levels of development of road construction equipment and technology in the Russian Federation and in the world. The level of development of road construction equipment and technology does not always allow ensuring high quality and reliability of key parameters (for example, road surface) [5].

Exceeding the permissible norms in the construction of road surface may not be related to the total current level of development of techniques and technologies of road construction, but can lead to road traffic accident (RTA). Then an accident is a probabilistic event, where, for example, the cause may be a person or a technological failure.

The probability of an accident is determined by the probability of an event: in the first case — an anthropogenic error when driving a vehicle in difficult road conditions or physical inability to control the vehicle in difficult road conditions(simultaneously and/or sequentially) {P(A)}, in the second — {P(A)} and the probability of technical and/or technological failures (man-made causes) - {P(T)}.

The risk of an accident can be determined by the condition of the main objects (person, car, road) that are "normal" or "not normal". "Normal" also does not exclude risks for a certain time of human activity, road or car operation. The risk of an accident is determined by the probability P of a negative situation and its consequences X:

$$R= \{P, X\}.$$

In this case, the scalar value — the mathematical expectation of consequences can be described as an indicator of the risk of an accident:

$$R= PX.$$

The normal operation of road transport network facilities is characterized by small (permanent) loads (microdamage) that affect people (this issue is addressed by labor protection) and the environment (environmental problems from internal combustion engine emissions). These loads may be small, but they are mandatory, with a probability close to one (P_{norm} ~1).

Emergency situations, such as road accidents, are characterized by much greater but short-term loads (significant damage X_i and consequences) on people and the environment ($X_{extr}>>X_{norm}$), but with less likely negative event ($P_{extr}<<1$; $P_{extr}<<P_{norm}$).

The analysis allows us to conclude that the quality of roads significantly affects road safety, and a critical excess of the number of permissible comments on their operation, deviations from standards and norms leads to the risk of losing the complex of operational qualities of road construction objects [6].

In addition, it can be noted that on certain road sections there are places that are characterized by a high risk of road accidents. These include railway crossings, intersections with main oil and gas pipelines, overpasses, and bridges. These places are potentially dangerous, since the probability of accidents, especially in case of transportation of particularly dangerous goods, will be significantly higher than the probability of these events occurring on other road sections.

Let us analyze an example related to the quality and integrity of the N-th road surface. Let us assume that the N-th road surface has n = 10,000 elements (one meter each), which independently of each other for a certain period of time T could receive damage with parameters that do not correspond to GOST with a probability $q = 10^{-4}$. If at least one element is damaged, the road on a section of 10,000 elements becomes unsafe. What is the probability of road failure during T?

Let the event A_i = [for a period of time, the Ti element of the road is in good condition (not damaged)]. Then the event C = [the road is serviceable and not damaged during the time period T] can be represented in a simple way

$$C = A_1A_2\ldots A_n,$$

the probability of which

$$P\{C\} = P\{A_1\}\, P\{A_2\}\ldots P\{A_n\} = p^n,$$

where $p = P\{A_i\} = 1 - P\{A_i\text{прот}\} = 1 - q = 1 - 10^{-4} = 0{,}9999$. In this case, the probability of failure of the road along the entire section of 10,000 elements when it becomes unsafe,

$$P\{C_{\text{прот}}\} = 1 - P\{C\} = 1 - (1 - q)^n = 1 - (1 - 10^{-4})^{10000} = 1 - e^{-1} = 0{,}632.$$

You will not be able to move safely along the road of this quality (the reliability of its many elements). It is necessary to constantly replace the coating that has become unusable, carry out patching repairs and similar works [7].

Discussion and Conclusions. The main idea of today's promising directions in improving the safety of road design and construction is that the engineer does not design the road surface, but only sets the necessary parameters and conditions. The program calculates the specified parameters and offers a number of ready-made optimized solutions. As a result, you may get roads that look like natural objects.

Such technologies will become real after the appearance of promising powerful programs with algorithms based on artificial intelligence and powerful construction 3D printers.

We will divide the promising areas into the following types:

– topological optimization (saving non-load-bearing material);

– application of trabecular porous structures in the form of a small beam, rod, road fence post;

– use of artificial intelligence based on neural networks and other computer decisions after they are made by each individual and society as a whole [8].

The main application domain of these promising technologies is a significant reduction in the weight of the materials used while maintaining or increasing the strength of the road surface. The main obstacle to the introduction of

promising technologies is not software, but production. It is very likely that everything will change soon. These technologies will appear in the next decade, possibly simultaneously with the widespread use of unmanned vehicles, which can also take over the functions of monitoring the integrity of the road surface. As part of the system "design–repair–production–control–transportation" with probability indicators $q = 10^{-9}–10^{-12}$, you can expect safety indicators that tend to one.

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Contribution of the authors:

O. V. Denisov – problem statement, theoretical materials, consideration of the example related to the road surface quality and integrity, participation in the preparation of materials to discuss promising directions in improving road design safety, general editorship of the article. L. A. Londareva – preparation of the analysis of road construction dynamics, historical references, main requirements for a modern highway, taking into account its category, indicators of technical level and operational condition, work with bibliographic references, preparation of the article.