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Analysis of the transport sector and ensuring transport safety in the context of globalization

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Abstract: In this work, explores contemporary trends in the development of the transport sector within the framework of globalization, emphasizing its critical role in economic growth and international trade. The study analyzes the current state of railway, road, air, and maritime transport, identifying key challenges associated with transportation safety and the integration of innovative technologies. Particular attention is given to the digitalization and automation of transport processes, including the application of artificial intelligence and intelligent control systems. The research presents data on freight transport dynamics, transport infrastructure development, and the influence of environmental factors on transport policy. The findings underscore the necessity of a comprehensive approach to transport system modernization, incorporating principles of sustainability and technological advancement to enhance safety and operational efficiency.
Keywords: transport sector, globalization, transportation safety, digitalization, innovative technologies, transport infrastructure

1. Introduction

The modern transport sector is an integral part of the global economy, ensuring the efficient movement of goods and passengers. Amid growing volumes of international trade and urbanization, the key challenges include developing transport infrastructure, enhancing its safety and environmental sustainability, and implementing innovative technologies.

The acceleration of interactions across all economic sectors necessitates the continuous development and improvement of the transport sector. Issues related to optimizing operations and effectively coordinating transport systems, including the formalization of automated interaction models among transport process participants, have been examined in the works of authors such as Uwe Clausen, Maike Rotmann [1], G.R. Ibragimova, S.K. Xudayberganov, A.M. Bashirova, Sh.Sh. Kayumov, [2], Muxamedova Z.G. [3], Расулова M.X. [4], Xuefei Li, Maoxiang Lang [5], Jin Guo, Pei-yan Yun [6], Joon-Young Ko, Jae-Young Park [7], Рахмангулов А.Н. [8], Анохов И.В. [9], Гарлицкий Е.А. [10], Мищенко Н.Г. [11] и других.

The growth of industrial production and international trade necessitates changes in the global transport sector, which itself has become one of the key drivers of globalization [**Ошибка! Источник ссылки не найден.**2].

2. Materials and method

The global railway network was largely established in the early 20th century. Although railway transport accounts for only 9% of the world's freight volume, making it less significant than road transport in this regard, it remains an essential mode of land transportation. A comparison of track lengths and freight volumes by transport type is presented in Figure 1.

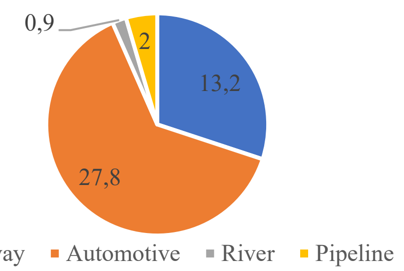

Figure 1. Length of the Global Railway Network, million km, and Share of Freight Transport in the Global Volume

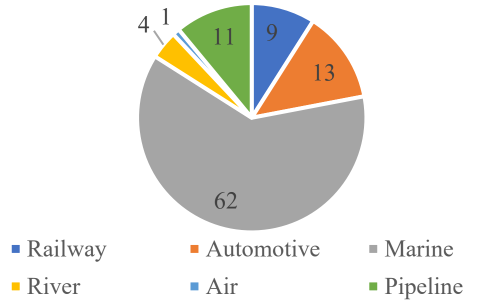

Figure 2. Density of the Railway Network, million km, in "leading" countries

As shown in Figure 1, the total length of the global railway network currently stands at 13.2 million km, with significant disparities in its distribution. Although railways exist in 140 countries worldwide, more than half of the total length is concentrated in the "top ten countries": the United States, Russia, Canada, India, China, Australia, Argentina, France, Germany, and Brazil. In terms of network density, European countries stand out the most (see Figure 2) [13].

Structural processes in the transport sector during the transition to a market economy have a significant impact on

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both the economy and society. Understanding and predicting these changes is essential for making informed decisions in transport policy and infrastructure development.

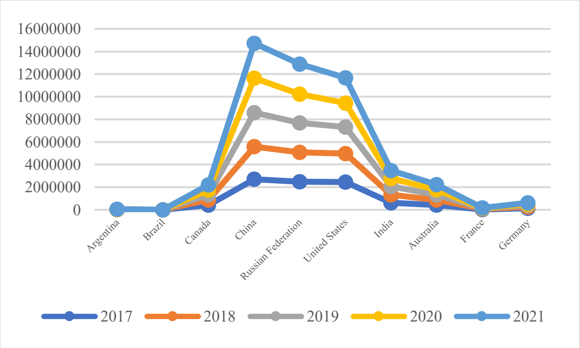

Figure 3. Share of the Global Market Volume in Freight Turnover

To maintain sustainable economic growth, transport systems must undergo continuous modernization. In particular, the introduction of digital technologies such as artificial intelligence and automation enhances transport management efficiency. The development of railway transport, as a key element of freight and passenger transportation, requires substantial investments in rolling stock renewal, track electrification, and the implementation of modern safety systems.

In road transport, the focus is on creating sustainable logistics routes, developing intelligent transport systems, and adopting environmentally friendly fuels. The development of aviation and maritime transport remains a priority, particularly in improving flight and shipping safety.

Mainline railway transport in the country will better meet the national economy's transportation needs if industrial transport operates more efficiently.

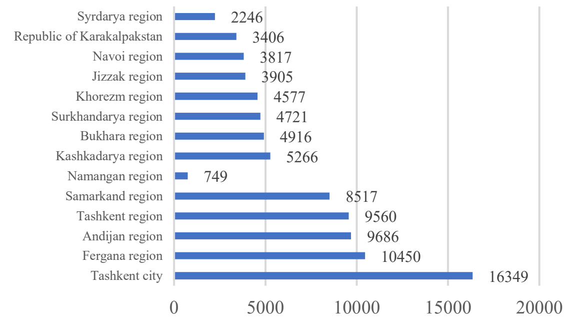

Figure 4. Number of Active Industrial Enterprises by Region of the Republic of Uzbekistan

Recently, industrial transport has been gaining increasing importance in the economic development of the Republic of Uzbekistan, considering the growth of industrial production in the regions. The number of industrial enterprises by region is presented in Figure 4 [14]

As shown in Figure 4, a high concentration of industrial enterprises is observed mainly in Tashkent, the Fergana region, the Andijan region, and the Tashkent region.

The volume of national economic cargo transported by industrial transport is three times greater than that of mainline railway transport, while the volume of loading and unloading operations is six times higher than that of all public transport modes combined. More than 90% of railway freight flow originates at and over 80% is completed at the sidings of industrial and supply-distribution enterprises, organizations, and construction sites.

The initial stage of freight transport is reflected in the indicator "dispatched (shipment) cargo," while the final stage is indicated by "arrived (arrival) cargo." In this regard, it is particularly interesting to analyze freight transport and turnover figures for all transport modes in the Republic of Uzbekistan for 2019-2023, as shown in Figure 5.

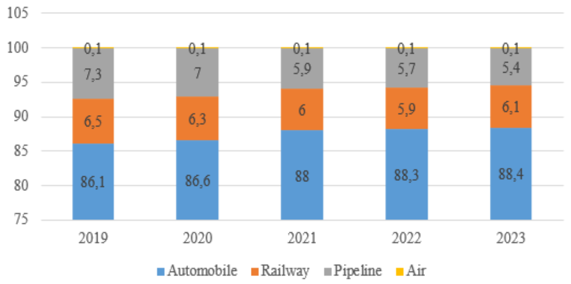

Figure 5. Structure of Freight Transport by Mode of Transport for January-March (in %) for 2019-2023

As seen in Figure 5, from January to March 2023, road transport accounted for a significant portion of total freight transport—88.5%, while other transport modes accounted for 11.5%. For the same period, the total freight turnover share of pipeline transport was 43.6%, railway transport—35.5%, road transport—20.5%, and air transport—0.4%.

The structure of freight turnover by transport mode is illustrated in Figure 6.

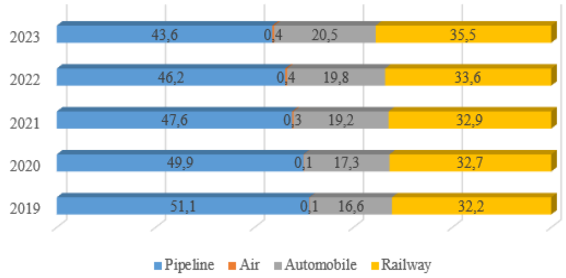

Figure 6. Structure of Freight Turnover by Mode of Transport for January-March (in %) for 2019-2023

As observed in Figure 7, compared to the same period in 2022, changes occurred in the share of certain transport modes within the overall freight transport volume. The share of pipeline transport decreased by 2.6%, while railway transport increased by 1.9%, road transport by 0.7%, and the share of air transport remained unchanged at 0.4%.

Railway transport, as a form of public transport, is part of a unified production-technological complex that includes enterprises, institutions, and organizations of both industrial and social significance. This mode of transport is closely linked to the railway networks of Russia and other countries.

As of January 1, 2022, the total length of railway sidings was 383.6 km, while the operational railway network length of JSC "Uzbekistan Railways" amounted to 7,019.3 km. The locomotive fleet of JSC "Uzbekistan Railways" includes 154 electric locomotives, 111 diesel locomotives, and 199 shunting locomotives, 21 of which are privately leased. These material resources are allocated along the railway sidings of industrial and supply-distribution enterprises, organizations, and construction sites adjacent to railway stations, with 1,350 service contracts in place. Therefore, improving the efficiency and quality of industrial railway transport is of significant economic importance.

The successful operation of industrial railway transport plays a crucial role in the performance of mainline railways. More than 80% of all freight loading and unloading on Uzbekistan Railways takes place at enterprises and organizations.

Despite the steady increase in freight transportation across various transport modes, mainline railway transport remains the dominant mode in the country's freight turnover. Figure 7 illustrates the growth dynamics of freight transported by all transport modes, highlighting railway transport.

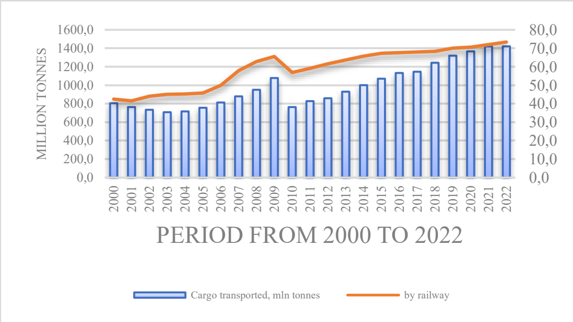

Figure 7. Growth Dynamics of Transported Goods for the Period 2000-2022

Figure 7 demonstrates a significant increase in freight transport across all transport modes, particularly railway transport.

In the first quarter of 2023, the volume of freight transported by railway amounted to 17.9 million tons, reflecting a growth rate of 100.7% compared to the same period in 2022. Freight volumes also increased in 2022 (17.8 million tons, growth rate—101.8%), 2021 (17.5 million tons, growth rate—102.3%), 2020 (17.1 million tons), and January-March 2019 (16.9 million tons, growth rate—101.6%).

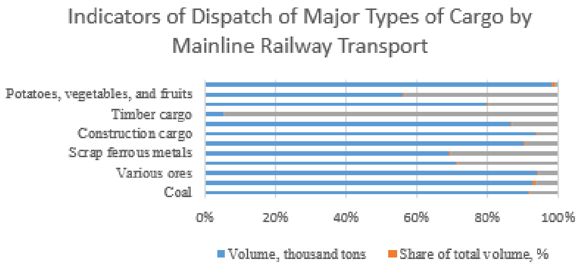

Figure 8. Indicators of Dispatch of Major Types of Cargo by Mainline Railway Transport

The average distance per ton of cargo transported was 329.9 km, exceeding the previous year's level by 1.6%.

In the first quarter of 2023, significant increases were recorded in the volume of railway freight shipments compared to the same period in 2022. The highest growth rates were observed in categories such as various ores (135.4%), forest products (125.9%), and petroleum cargo (113.3%). Conversely, declines were noted in cement (60.4%), potatoes, vegetables, and fruits (68.0%), construction materials (75.9%), chemical fertilizers (77.9%), and ferrous scrap metal (83.1%). The largest shares of total freight shipments by railway were occupied by various ores (12.7%), petroleum cargo (9.0%), construction materials (6.9%), coal (6.6%), chemical and mineral fertilizers (4.3%), and other cargo (52.9%).

3. Conclusion

Based on the analysis of industrial production and transport indicators in the Republic of Uzbekistan, it can be concluded that the railway sector plays a crucial role in the country's economy, highlighting the need for further research into transport infrastructure development, safety enhancement, environmental sustainability, and the integration of innovative technologies.

Transport system security is one of the key factors in its development. To minimize risks in railway transport, automated train control systems and infrastructure monitoring technologies using unmanned aerial vehicles are actively being implemented. Road transport is being improved through the development of intelligent driver assistance systems such as adaptive cruise control, collision avoidance systems, and automatic emergency braking.

In freight transport, safety is ensured through cargo condition monitoring, real-time tracking technologies, and enhanced cybersecurity measures. This is particularly important amid growing international trade volumes, where efficient logistics management helps minimize losses and prevent accidents.

Transport sector development trends indicate increased integration of various transport modes, the creation of multimodal logistics chains, and the expansion of automated and autonomous transport systems. In the long term, the development of high-speed rail and unmanned freight transport systems is expected, significantly reducing transportation time and costs.

Thus, the transport system of the future must ensure not only high-speed and efficient transportation but also maximum safety and environmental sustainability. The development of transport infrastructure, the adoption of advanced technologies, and the strengthening of safety measures will help create a stable and reliable transport network that meets the demands of the modern economy and society.

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Study of the influence of roller disk thickness on the performance indicators of the device

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Abstract: The article describes the results of experiments based on the thickness of the discs of a combined disc roller machine, which are used in preparing new plowed land for planting. In it, when the thickness of the drum discs increased from 17.5 mm to 25.0 mm at a machine speed of 6.7 km/h, the size was greater than 100 mm, and fractions in the range of 100-50 mm decreased by 4.8 and 4.3 percent, respectively, while fractions less than 50 mm increased by 9.1 percent at a speed of 8.3 km/hThey were 4.1%, 5.5% and 9.6%, respectively.
Keywords: disk rollers, diameter, thickness and angle of grinding of disks, vertical load on each disk, speed of movement, multi-factor experiment

1. Introduction

In our country, crops such as wheat, which is sown in the open field, and vegetables and potatoes, which are sown as repeated crops in areas free from wheat, are sown in new, i.e. directly before sowing, plowed land. In this, plowed lands are prepared for row planting and then planting activities are carried out.

At present, the preparation of newly plowed land for planting is carried out several times separately by means of toothed and disk harrows and various levelers. But this leads to the deterioration of physical and mechanical properties of the soil, a lot of moisture loss from the soil, and an increase in fuel consumption and other costs [1].

The analysis of the scientific and technical achievements achieved at the world level and the research carried out in our Republic [2,3,4] shows that the shortcomings in the preparation of newly plowed land for planting are all technological processes for preparing the soil for planting in one pass through the field (complete compaction of the plowed field, leveling of the surface of the field and crushing) can be eliminated by developing a machine that ensures complete processing in one pass before planting. The use of such a machine in the pre-planting treatment of newly plowed land increases productivity, improves the quality of tillage, prevents moisture loss, and reduces the number of trips of aggregates through the field. It allows to plant and harvest the seeds [5].

In the conditions of our republic, when fields empty of wheat or repeated crops are plowed, the upper layer of the soil containing plant residues and weeds is overturned and thrown to the lower layer, as a result of which many gaps and unevenness are formed in the plowed layer. If these are not eliminated or their extent is not minimized, the quality of planting, irrigation and inter-row cultivation activities will deteriorate. In addition, for high-quality planting of crops, the state of the top layer of the soil - its density and flatness - should correspond to the agrotechnical requirements of the planting background. Therefore, when newly plowed land is prepared for planting, the soil clods overturned by the plow bodies should be compacted, crushed and leveled. Based on these points, the author developed a combined machine used in the cultivation of newly plowed land.

2. Materials and methods

Experimental studies to determine the agrotechnical and energy performance indicators of the disc rollers of the combined machine were conducted in the experimental farm of the Research Institute of Agricultural Mechanization on fields irrigated after winter wheat and plowed to a depth of 30-32 cm for growing repeated crops. The soils of the experimental fields are gray soils of medium-heavy loamy mechanical composition, previously irrigated, with groundwater at a depth of 10-12 m. Before conducting experiments, GOST 20915-11 "Testing of Agricultural Machinery. Methods for Determining Test Conditions"[6]. The moisture content, hardness, and density of the soil in the 0-10, 10-20, and 20-30 cm layers were determined.

3. Results and discussion

It is known that in newly plowed fields, large-sized lumps are present in the soil. The planting process cannot be carried out without crushing and compacting them. Disc or gear harrows are usually used for this. The use of disc harrows (harrows) in preparing newly plowed land for planting gives the desired effect. When using these disc rollers, the diameter, thickness and sharpening angle of the discs should be considered in order to achieve the desired effect. For this purpose, experiments were conducted on the basis of the thickness of the discs of the combined machine disc roller [7,8,9,10,11].

In the experiments, the thickness of the roller discs was changed from 17.5 mm to 25.0 mm with an interval of 2.5 mm. In this case, the diameter of the disks, the angle of sharpening, the depth of immersion in the soil, the width between their traces, the vertical load applied to each disk and the longitudinal distance between the rollers are unchanged and was accepted as equal to 450 mm, 60^0, 5-6 cm, 10 cm, 600 N and 60 cm, respectively.

Here, too, experiments were conducted at speeds of 6.7 and 8.3 km/h.

The results obtained in the experiments are presented in Table 1 and Figures 1-4. Their analysis shows that with an increase in the thickness of the discs of the rollers, the quality

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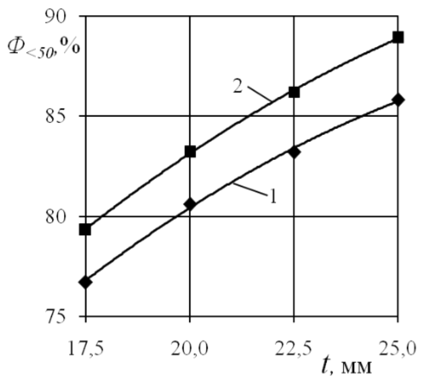
of soil compaction improved, that is, in the 0-10 cm layer, the amount of fractions larger than 100 mm and in the range of 100-50 mm decreased, and the amount of fractions smaller than 50 mm increased. For example, at a driving speed of 6.7 km/h, when the thickness of the roller discs increased from 17.5 mm to 25.0 mm, the fractions larger than 100 mm and 100-50 mm decreased by 4.8 and 4.3 percent, respectively, compared to 50 mm and fractions smaller than increased by 9.1 percent, at a speed of 8.3 km/h, these indicators are 4.1, respectively; It was 5.5 and 9.6 percent. Here, it should be noted that with the increase in the thickness of the discs, the fractions larger than 100 mm and in the range of 100-50 mm decreased, and the fractions smaller than 50 mm increased intensities. For example, when the thickness of discs increased from 17.5 mm to 20.0 mm, the amount of fractions larger than 100 mm and between 100-50 mm decreased by 1.5-1.8 and 2.1-2.4 percent, respectively, and the size of 50 The amount of fractions smaller than mm increased by 3.9 percent, and when increasing from 22.5 mm to 25.0 mm, these indicators were 0.3-0.9, 2.4-2.7, and 2.5-2.6, respectively. percent.

1-table

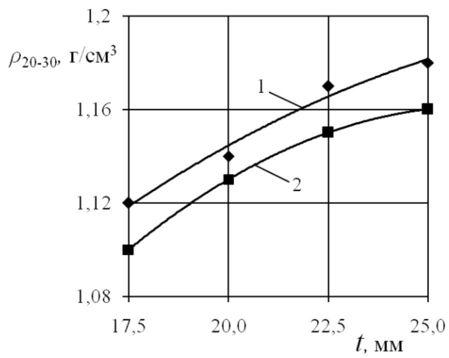
Change in the performance indicators of the laboratory-field installation depending on the thickness of the roller discs

N	Name of indicators	Disc thickness, mm							
		17,5		20,0		22,5		25,0	
		Values of indicators							
1.	Speed of movement, km/h	6,7	8,3	6,7	8,3	6,7	8,3	6,7	8,3
2.	Soil crumbling quality (amount of fractions of the following size), %								
	>100 mm	5,7	4,6	3,9	3,1	1,8	0,8	0,9	0,5
	100-50 mm	17,6	16,1	15,5	13,7	15,0	13,0	13,3	10,6
	<50 mm	76,7	79,3	80,6	83,2	83,2	86,2	85,8	88,9
3.	Soil density in the following layers, g/cm^3:								
	10-20 cm	1,10	1,09	1,12	1,11	1,14	1,13	1,15	1,14
	20-30 cm	1,12	1,10	1,14	1,13	1,17	1,15	1,18	1,16
4.	Specific drag resistance, kN/m	1,04	1,08	1,09	1,12	1,13	1,16	1,16	1,18



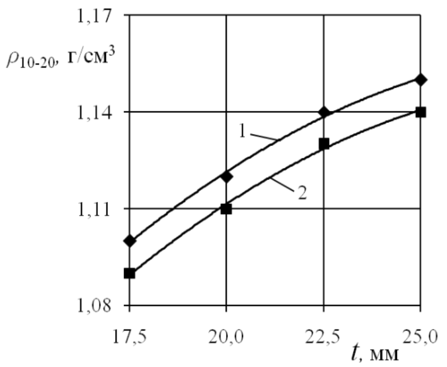
1, 2 - respectively at speeds of 6, 7 and 8.3 km/h;

Figure 1. Graphs of changes in the degree of soil crumbling depending on the thickness of the roller discs



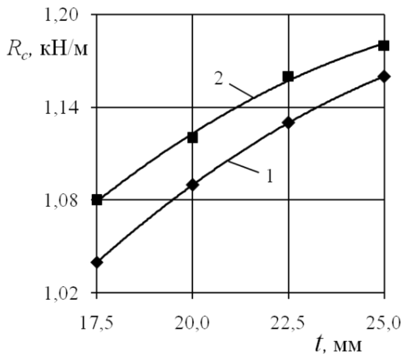
1, 2 - respectively at speeds of 6, 7 and 8.3 km/h

Figure 3. Graphs of changes in soil density in the 20-30 cm layer depending on the thickness of the roller discs



1, 2 - respectively at speeds of 6, 7 and 8.3 km/h

Figure 2. Graphs of changes in soil density in the 10-20 cm layer depending on the thickness of the roller discs



1, 2 - respectively at speeds of 6, 7 and 8.3 km/h

Figure 4. Graphs of changes in the specific tractive resistance of rollers depending on the thickness of their disks

With an increase in the thickness of the roller discs, the improvement in the quality of soil crumbling occurs mainly due to an increase in the zone of their impact on the soil, i.e., the volume of soil exposed to the discs increases.

With an increase in the thickness of the discs, the density of the soil in the 10-20 and 20-30 cm layers increased. For example, with an increase in the thickness of the discs from 17.5 mm to 25.0 mm, at a speed of 6.7 km/h, the soil density in the 10-20 cm and 20-30 cm layers increased by 0.05 and 0.07 g/cm3, respectively, and at a speed of 8.3 km/h - by 0.04 and 0.06 g/cm3. This also occurs mainly due to the increase in the zone of impact of the discs on the soil.

Due to the above reasons, an increase in the thickness of the roller discs from 17.5 mm to 25 mm led to an increase in their specific tractive resistance from 1.04 kN/m to 1.16 kN/m at a speed of 6.7 km/h, and from 1.08 kN/m to 1.18 kN/m at a speed of 8.3 km/h.

4. Conclusion

With an increase in the thickness of the roller discs, the improvement of the quality of soil compaction occurs mainly due to the increase of their impact zone on the soil, that is, the volume of the soil affected by the discs increases.

As the thickness of the discs increased, the density of the soil in the 10-20 and 20-30 cm layers increased. For example, when the thickness of the discs increases from 17.5 mm to 25.0 mm, at a speed of 6.7 km/h, the densities of the soil in the layers of 10-20 cm and 20-30 cm decrease by 0.05 and 0.07 g/cm3, respectively, 8 and at a speed of 3 km/h it increased by 0.04 and 0.06 g/cm3. This is mainly due to the increase in the impact zone of the discs on the ground.

The thickness of the discs should be in the range of 22-25 mm in order to ensure quality processing of the rollers at the speed of 6.0-8.0 km/h while spending less energy on the plow surface.

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Determining the elasticity of the contact suspension of electrified railways

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Abstract: In electrified railways, the reliability and efficiency of the power supply system are directly dependent on the condition of the contact suspension. Determining the elasticity of the contact suspension is one of the most critical issues, as it impacts the following: stable operation of the current collector – if the contact suspension lacks sufficient elasticity, the stable connection with the pantograph may be disrupted, leading to interruptions in the transmission of electrical energy; reliability and long service life – excessive rigidity or flexibility of the contact suspension can result in rapid wear and tear, increasing maintenance costs; adaptation to high-speed requirements – for trains operating at high speeds, the optimal elasticity of the contact suspension is crucial; otherwise, strong vibrations and contact interruptions may occur; energy efficiency – optimal elasticity helps distribute the load evenly, reduces energy losses, and improves overall efficiency. Therefore, determining and optimizing the elasticity of the contact suspension is of great importance for enhancing the efficiency and safety of railway transport. The digitization of contact suspension elasticity is a modern necessity. Digitization can be implemented through the following methods: sensors and IT devices – smart sensors capable of measuring pressure, vibrations, and bending angles can be installed to monitor the elasticity of the contact suspension in real time; laser and video analysis – high-resolution cameras and laser scanning technologies enable continuous monitoring of the deformation and condition of the contact suspension; artificial intelligence and machine learning – based on collected data, it is possible to create performance forecasts for the contact suspension and predict wear and tear processes in advance; database systems – storing the collected data on central servers and analyzing it in real time allows for the optimization of maintenance schedules. As a result of digitization, maintenance costs are reduced, potential failures are prevented, and the efficiency of electrified railways is significantly improved

Keywords: contact suspension, elasticity, rigidity, current collector, electric rolling stock, rigid points.

1. Introduction

It is known that the contact suspension has an elastic design, so during the movement of the pantograph, the contact wire rises. The value of this rise varies at different intermediate lengths, which depends on the elasticity of the chain-type contact suspension.

When determining the elasticity of the contact suspension, we consider the characteristic value of the rise of the contact wire at different points of the intermediate length under the influence of a 1 N force. This value is called the elasticity coefficient, or simply the elasticity of the contact suspension, denoted as "э", for example, $э = 0{,}5 mm/N$. This value represents the rise of the contact wire by 0.5 mm under the influence of a 1 N vertical force on the contact wire in the chain-type suspension [1].

The opposite characteristic of the elasticity of the contact suspension is called the rigidity of the suspension: $ж = 1/Э$.

The rigidity of the contact suspension is the necessary force required to lift the contact wire by 1 mm at different points of the suspension along the intermediate length. For example, $ж = 2\ N/mm$, a force of 2 N is needed to lift the contact wire by 1 mm.

2. Research methodology

Let's consider the elasticity of a simple contact suspension with fixed support points (freely suspended wire).

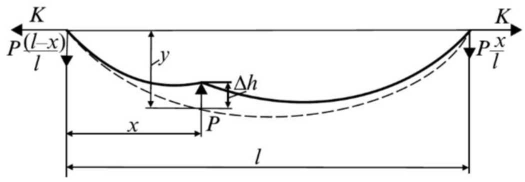

Fig. 1. A diagram to determine the rise of a simple contact suspension with fixed support points: *P* - vertical force, *x* - the distance from the support to the point of rise, Δ*h* - the rise in the wire due to the applied force

Under the influence of the force P, the algebraic sum of the changes in the positions of the wire relative to the fixed points along the intermediate length must be equal to zero.

$K\Delta h - P(l-x)x/l = 0$ (1)

where: $P(l-x)$ - the reduction of the left support reaction caused by the force P; K – the tension in the wire.

From equation (1), we can find Δh:

$\Delta h = Px(l-x)/(lK).$ (2)

According to the expression for determining elasticity:

$э = \Delta h/P.$ (3)

The elasticity value at the points of the contact suspension (in freely suspended wires), at a distance x from the left support, can be determined using the following formula:

$э_{x,n} = \Delta h_{x,n}/P = x(l-x)/(lK).$ (5)

For the condition between the intermediate length under the influence of the force P (when x=0,5l is given):

$э_{0,5l,n} = l(4K).$ (6)

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Consider the suspension of wires in different conditions or the elasticity of a contact suspension with a non-elastic design (Figure 2, a). The rise of the wires under the influence of the force P is expressed as follows:

$\Delta h_s = g_K s^2/(8K)$. (7)

where: g_K - the weight load of 1 meter of wire.

The necessary force P to lift (or suspend) the contact wire at a distance S can be determined from the following equation when $g_K s = P$ is given [2]:

$\Delta h_s = P^2/(8g_K K)$. (8)

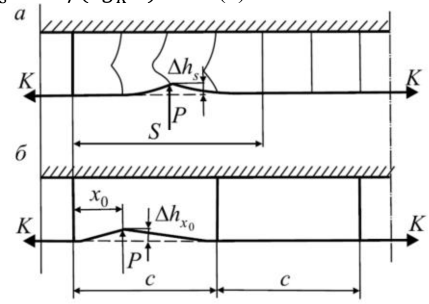

Fig. 2. The distribution diagram of the rise of a rigidly constructed contact wire in a multi- dropper (a) and single dropper (b) contact suspension

The elasticity of the wires does not remain constant in this case; it changes proportionally under the influence of force P:

$$э_s = \Delta h/P = P/(8g_K K). \quad (9)$$

Consider the elasticity of the dropper contact wire suspension. In various dropper suspensions, the elasticity will differ at the intermediate points (Figure 2, a). In this case, the force P in the narrow interval and its value depend on the elasticity of the wire:

$$\Delta h_{x_0} = Px_0(c - x_0)/(cK), \quad (10)$$

elasticity:

$$э_{x_0} = \Delta hx_0/P = x_0(c - x_0)/(cK), \quad (11)$$

where: x_0 – the distance from the wire under the left load to the point of the contact wire where the force P is applied; c – the length of the dropper interval.

The effect of the force P between the dropper intervals ($x_0 = 0.5c$):

$$\Delta h_{0.5c} = Pc/(4K), \quad (12)$$

$$э_{0.5c} = c/(4K). \quad (13)$$

The contact wire will rise in this case under the dropper ($x_0 = 0$) when the force P exceeds the weight of the wire by g_Kc, and the load in the dropper will be greater by ($P > g_K c$).

Until the moment of the dropper's release (when the load decreases), the elasticity of the wire ($P \le g_K c$) will be equal to zero [3].

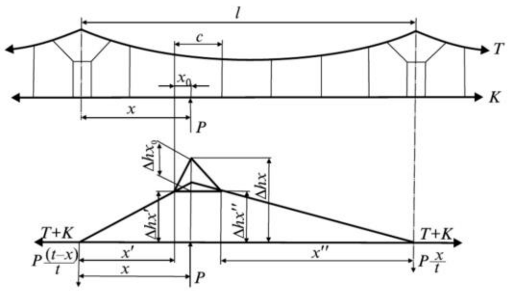

Fig. 3. A computational scheme for determining the elasticity of a single-chain suspension in the middle of the span

Contact wire uplift after the dropper release:

$$\Delta h_{2c,K} = (P - g_K c)c/(2K). \quad (14)$$

Elasticity of the contact wire after the dropper release:

$$э_{2c,K} = c/(2K). \quad (15)$$

In catenary spans, the elasticity of the contact wire is the sum of the elasticity of the "supporting cable and contact wire" system and the elasticity of a single-chain suspension (Figure 3). To determine the elasticity of the single-chain suspension at any arbitrary point in the span, the computational formula can be written in the following general form:

$$э_x = \frac{\Delta h_x}{P} = \frac{1}{P}\left(\Delta h_{x'}\frac{c - x_0}{c} + \Delta h_{x''}\frac{x_0}{c} + \Delta h_{x_0}\right) \quad (16)$$

where: Δh_x - the total uplift of the contact wire at a point located at a distance x from the left support under the influence of force P; $\Delta h_{x'}$ - the uplift of the contact wire on the left side at a distance x' under the influence of force P, near the loaded catenary wires; $\Delta h_{x''}$ - the uplift of the contact wire on the right side at a distance x'' under the influence of force P, near the loaded catenary wires; Δhx_0- the uplift of the contact wire in catenary spans (between two loaded catenary wires); c – the length of the catenary span (the distance between two loaded catenary wires, either in the unloaded state or under the influence of force P). x_0 - the distance from the left loaded catenary wire to the force P. Δh_{x_0} the value is determined using the formula mentioned above.

To determine $\Delta h_{x'}$ and $\Delta h_{x''}$ the elasticity of the spring-loaded catenary suspension will vary at different points in the spans. The computational formula is divided into three groups: for the spring cable catenaries (A), for the simple cables in the first installation area from the support (B), for the middle section of the span length (B) (Figure 4).

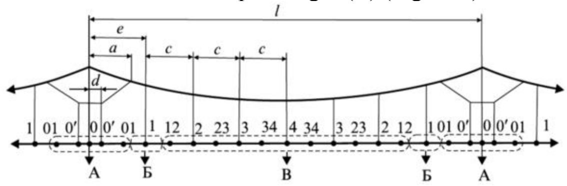

Fig. 4. A spring-loaded diagram with a working zone for calculating elasticity at various points of the interval

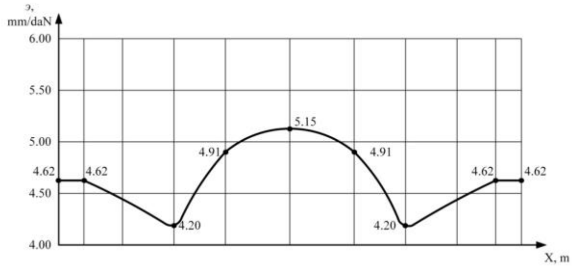

Fig. 5. Graph of the elasticity change of the contact suspension within the interval

We will conduct an experimental study for the conclusion of the calculation formula for the elasticity and contact wire uplift in the middle part (B) of the interval for a simple suspension cable and a single spring suspension (Figure 3, part b). We can use the above calculation diagram, so the contact wire uplift (holding rope) $\Delta h_{x'}$ and $\Delta h_{x''}$ can be determined from the equation.

$$\Delta h_{x'} = \frac{P_{x'}(l - x)}{l(T + K)}; \quad (17)$$

$$\Delta h_{x''} = \frac{P_{x''}x}{l(T + K)}; \quad (18)$$

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where: l – anchor span length; T – holding wire tension; K– contact wire tension.

The general formula to determine the elasticity of the chain contact suspension in the middle section of the span:

$$Э_x = \frac{Δh_x}{P} = \frac{x(l-x)}{l(T+K)} + \frac{x_0 T(c-x_0)}{cK(T+K)}. \quad (19)$$

If a force of ($x_0 = 0$) P acts under the dropper:

$$Э_{x,c} = \frac{Δh_{x,c}}{P} = \frac{x(l-x)}{l(T+K)}. \quad (20)$$

The elasticity of the chain suspension in the middle of the span under the influence of a force of ($x = 0.5l, x_0 = 0.5c$) P between the droppers:

$$Э_{0.5l} = \frac{Δh_{0.5l}}{P} = \frac{lK+cT}{4K(T+K)}. \quad (21)$$

If the force P acts in the middle of the span in the same way, but corresponds directly under the dropper ($x = 0.5l, x_0 = 0$):

$$Э_{0.5l,c} = \frac{Δh_{0.5l,c}}{P} = \frac{l}{4(T+K)}. \quad (22)$$

From this formula, we can determine the elasticity of the chain suspension only in the middle section of the span ($P_c$contact wire lift) until the moment of slackening. Also, currently $P \le P_c$, slackening is observed under the influence of force 22 [4].

In the case where there is no force P on the droppers in the middle section of the span, the effect of the load.

$$R_{cK} = (g_K + g_c)c - \frac{8f_K K_c}{l_K^2}, \quad (23)$$

where: g_K - 1 m of the contact wire weight load; g_c - the load of the dropper's cable weight per 1 m of the contact wire; l_K - span length section, the part where the sagging is present $l_K = l - 2e$.

The chain suspension has the elasticity of several holding wires, and the lifting of the contact wire under the dropper is observed under the influence of force P. Therefore, under the influence of force P, the lifting of the contact wire under the chain suspension will be greater compared to the lifting in the span between the wires. For this reason, in these wires, in addition to the vertical tension of the contact wire and the loading of R_{cK}, the effect of compression is influenced by force P.

$$R'_{cK} = \frac{K}{T+K} P_C. \quad (24)$$

Therefore, a change in the position of the droppers occurs at the moment of their release. The following equation: $P_c = P_{cK} + \frac{K}{T+K} P_c$; its solution is related to P_c. We find the unknown:

$$P_c = R_{cK} \frac{T+K}{T}. \quad (25)$$

When the force P is applied to the intermediate section between the contact wire droppers, it results in the release of two droppers. The required magnitude of force P in this case is given in [5]:

$$P_{2c} = 2R_{cK} \frac{T+K}{T} 2P_c. \quad (26)$$

The uplift of the contact wire after the release of a single dropper under the action of force P:

$$Δh_c = Э_{x,c} P + \frac{cT(P-P_c)}{2K(T+K)}. \quad (27)$$

The lifting of the contact wire after the release of two droppers at the middle of the interval under the action of force P:

$$Δh_{2c} = 2Э_x P_c + \left[Э_{x,c} + \frac{3cT}{2K(T+K)}\right](P - 2P_c). \quad (28)$$

The elasticity of the chain suspension in the middle section of the interval after the release of a single dropper:

$$Э_c = Э_{x,c} + \frac{cT}{2K(T+K)}. \quad (29)$$

In the area (A), during the release of the spring dropper, the elasticity of the chain suspension at the support points O and O' (see Fig. 4) can be determined using the following formula:

$$Э_0 = \frac{Δh_0}{P} = \frac{1}{2\frac{T-H_p}{a}γ + 2\frac{K+H_p}{l}}. \quad (30)$$

where: H_p - the tension of the spring dropper, coefficient: $γ = 0.6\sqrt{\frac{a}{e}\frac{K}{T}}$

To determine the elasticity of the suspension at the point 01, we can use the following empirical formula:

Until the neighboring droppers are released $Э_{01} = 1{,}1Э_0$ and after their release $Э_{01} = 1{,}25Э_0$.

The placement of the droppers at the point 01 in a chessboard arrangement and the placement of the droppers in the two contact wire suspensions are as follows. At this point, the suspension elasticity can be assumed to be the same as at the points 0 and 01.

The elasticity of the spring suspension at point 1, before the release of the droppers in the area B (see Fig. 4), can be determined using the following formula:

$$Э_1 = \frac{Δh_1}{P} = \frac{e(l-e)}{l[T+K-(K+H_p)β]}, \quad (31)$$

where: $β = \frac{a}{e}(1 - 0.05a)$.

The coefficient $β = 0$ for the standard support droppers $α = 0$ will have the following form for formula (32):

$$Э_{1.x} = \frac{e(l-e)}{l(T+K)}, \quad (33)$$

From this, it becomes clear that formula (33) is an analogous form of formula (31).

For the contact suspension with KC-200 construction used in railways, the uneven elasticity coefficient should not exceed 1.2. For the contact suspension with KC-160 construction, it should not exceed 1.35 [6].

3. Conclusion

For the contact suspension with KC-250-25-UZ (with reinforced concrete supports) construction, used for electrification of railways in Uzbekistan, the uneven elasticity coefficient:

- Should not exceed 1.226 for the length of the support interval *l = 60* m on straight tracks;
- Should not exceed 1.199 for the length of the support interval *l = 52* m on curved tracks.

For the contact suspension with KC-250-25-UZ (with steel supports) construction, the uneven elasticity coefficient:

- Should not exceed 1.2117 for the length of the support interval *l = 60* m on straight tracks;
- Should not exceed 1.15 for the length of the support interval *l = 52* m on curved tracks.

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Maximizing efficiency in solar-powered UAVs: the role of MPPT algorithms in energy harvesting

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Abstract: The increasing demand for long-endurance Unmanned Aerial Vehicles (UAVs) has led to the exploration of solar-powered UAV systems. Solar energy offers a sustainable power source that can potentially extend the operational time of UAVs, especially during long-duration flights. However, to optimize the power generated from solar panels, it is crucial to operate the panels at their Maximum Power Point (MPP), which fluctuates in response to environmental conditions such as irradiance and temperature. Maximum Power Point Tracking (MPPT) technology is used to dynamically adjust the operating point of solar panels to ensure they operate at the MPP, maximizing energy harvest. This paper explores the importance of MPPT in solar-powered UAVs, delves into the principles of solar cell operation, reviews various MPPT algorithms (such as Hill Climbing and Incremental Conductance), and discusses their integration into UAV systems. Additionally, the paper highlights the design considerations and challenges involved in implementing MPPT for UAVs, including hardware efficiency, real-time tracking, and battery management. By optimizing solar energy harvesting and efficient power delivery, MPPT systems enhance the performance of solar-powered UAVs, making them suitable for a range of applications such as surveillance, environmental monitoring, and disaster response.

Keywords: Maximum Power Point Tracking (MPPT), Photovoltaic Systems, Solar Panels, MPPT Algorithms, Hill Climbing Algorithm, Incremental Conductance Algorithm, Solar Energy Harvesting, Battery Management UAV Power Management, Renewable Energy Systems

1. Introduction

Unmanned Aerial Vehicles (UAVs) have become an essential tool in various sectors, including environmental monitoring, military applications, and search and rescue operations. The ability to operate autonomously for extended periods without needing frequent recharging or refueling is a key advantage of UAVs. This capability can be further enhanced by integrating solar panels that allow UAVs to recharge their batteries during flight, maximizing their endurance [1, 2].

However, solar power systems on UAVs face several challenges. The efficiency of a solar panel in converting sunlight into electrical energy fluctuates due to environmental factors such as sunlight intensity, cloud cover, temperature, and the UAV's orientation to the sun. Therefore, to maximize the efficiency of the solar panels, the UAV must continually operate at the Maximum Power Point (MPP), where the solar panel delivers the highest possible power output.

Maximum Power Point Tracking (MPPT) technology is an essential tool for optimizing the power harvested from solar cells by continuously adjusting the operating point to ensure the system works at or near the MPP. This paper explores the role of MPPT in solar-powered UAVs, examining the principles of solar cell operation, the algorithms used to track the MPP, and the design considerations for integrating MPPT into UAV systems [3, 4, 5].

2. Research methodology

Solar Cells and Their Characteristics

EN 13749 is a European Standard that specifically relates to the design and testing of railway bogie frames and associated components. This standard provides technical specifications and requirements for the design, calculation, and testing of railway bogie frames and their structural elements (bolsters and axlebox housings).

Solar cells, or photovoltaic (PV) cells, are the fundamental components in solar panels. These cells convert light energy into electrical energy through the photovoltaic effect, where photons from sunlight excite electrons in a semiconductor material, generating an electric current. Understanding the current-to-voltage (I-V) characteristics of a solar cell is crucial for optimizing its performance in any application, including UAVs [6, 7].

Key Parameters of a Solar Cell:

- *Open Circuit Voltage (VOC).* The voltage when the cell is not connected to any load (i.e., when there is no current flowing through the circuit). This value is influenced by the type of semiconductor material used (e.g., silicon, gallium arsenide) and the temperature.
- *Short Circuit Current (ISC).* The maximum current that flows when the cell is shorted (i.e., the voltage is zero).
- *Maximum Power Point (MPP).* The point at which the product of current and voltage is maximized, yielding the highest possible power output from the solar cell. This is where the solar panel operates most efficiently, and the power output reaches its peak.

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- *Voltage at MPP (VMPP) and Current at MPP (IMPP).* These values correspond to the voltage and current at the MPP. The values are crucial for determining how the solar panel should operate under different lighting conditions.

The I-V curve of a solar cell is not static, it changes based on external factors such as irradiance (light intensity) and temperature. For example, as irradiance increases, the current generated by the cell increases linearly, while the voltage changes only slightly. Conversely, as the temperature rises, the voltage decreases, and the current increases slightly. This dynamic nature of the I-V curve means that the operating point of the solar panel must be continuously adjusted to maintain maximum power output.

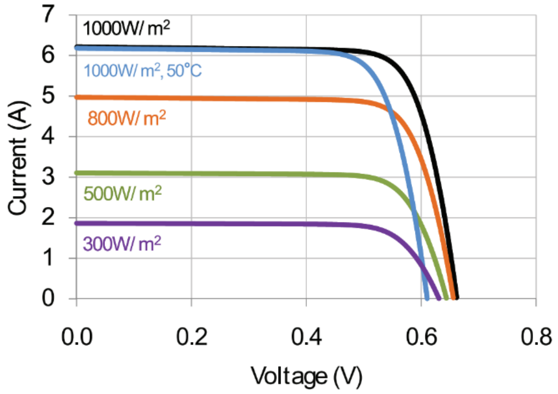
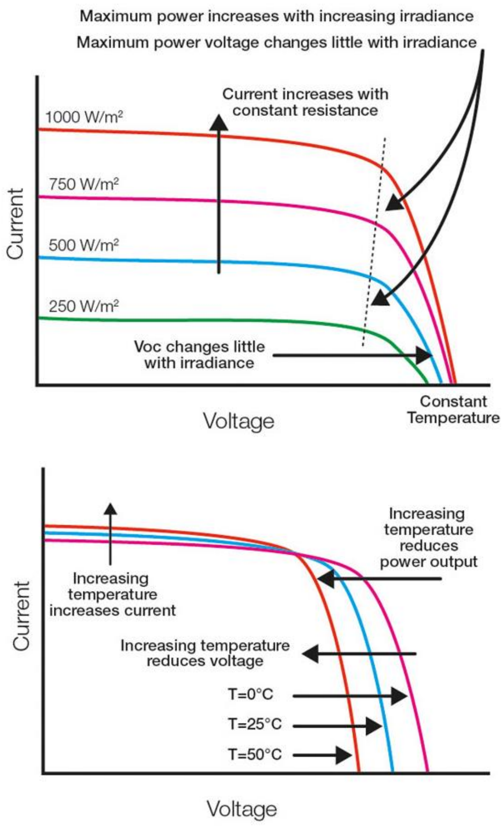


Figure 1. I-V Curve of a Solar Cell (in the example of Sunpower C60 solar cell



(a)

(b)

Figure 2. Variation of the I-V Curve with Irradiance (a) and Temperature (b)

Maximum Power Point (MPP)

The Maximum Power Point (MPP) is the operating point on the I-V curve where the product of current and voltage is maximized, and the solar panel delivers the most power. This is a critical concept because the energy harvested from a solar panel depends directly on the operating point. The MPP is not a fixed point—it shifts dynamically based on environmental conditions such as sunlight intensity (irradiance) and temperature [8, 9, 10].

The relationship between voltage, current, and power for a solar panel can be expressed mathematically as:

$$P_{max} = V_{MPP} \times I_{MPP} =$$

Where:

Pmax is the maximum power output of the solar panel.

VMPP is the voltage at the maximum power point.

IMPP is the current at the maximum power point.

For solar-powered UAVs, maintaining operation at the MPP is crucial for maximizing the energy collected and extending the flight time. However, the MPP is highly sensitive to changes in sunlight intensity and temperature. For example, if the sun's intensity decreases due to cloud cover, the I-V curve shifts, and the MPP moves, requiring the UAV's power management system to adjust the operating point accordingly.

Furthermore, the MPP is not static even during the course of a day. As the UAV moves through different parts of its flight path, the angle of incidence of sunlight changes, leading to variations in irradiance. The ability to track and adjust to the MPP is therefore vital for optimal energy harvesting.

MPPT Technology

Maximum Power Point Tracking (MPPT) is a technique used to ensure that a solar panel operates at its maximum power point under all conditions. MPPT systems are typically implemented using DC-DC converters that adjust the output voltage of the solar panel to match the optimal operating point. The DC-DC converter essentially converts the voltage from the solar panel to a level that is suitable for charging the UAV's battery, while continuously tracking the MPP.

Types of MPPT Algorithms.

There are several algorithms used to track the MPP. The most common ones include:

1. *Hill Climbing (Perturb and Observe).*

This method involves perturbing the operating voltage of the solar panel and observing the resulting changes in power output. If the power increases, the voltage is adjusted in the same direction; if the power decreases, the direction is reversed.

The Hill Climbing method is simple and effective but tends to cause oscillations around the MPP, meaning that the system never quite stays at the MPP but instead hovers near it.

2. *Incremental Conductance (IncCond).*

This algorithm uses the incremental changes in both current and voltage to calculate the slope of the power curve. It compares the derivative of the power with respect to voltage to determine whether the operating point is to the left or right of the MPP. This allows for more accurate tracking compared to Hill Climbing, especially under rapidly changing conditions.

3. *Constant Voltage Method.*

This method assumes that the solar panel's voltage at the MPP remains relatively constant. By maintaining the panel's

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voltage at a fixed value (typically around 0.76 of the open-circuit voltage), this method simplifies the tracking process. It is often used in systems where the irradiance does not fluctuate rapidly.

Efficiency Considerations.

The efficiency of MPPT systems is determined by both the hardware and the tracking algorithm. A well-designed MPPT system can achieve an efficiency of over 95%, and some high-end systems reach as high as 99%. Efficiency losses primarily arise from the power conversion process in the DC-DC converter and the algorithm's ability to track the MPP in real-time.

MPPT in Solar-Powered UAVs

The integration of solar panels and MPPT technology in UAVs is crucial for achieving long-duration flights without relying on fuel or external charging sources. UAVs that use solar panels can recharge their batteries during flight, allowing them to extend their operational time significantly. However, the challenges of varying sunlight conditions make it necessary for UAVs to adapt in real time to the changing environment.

Challenges.

1. *Dynamic Flight Conditions.* UAVs experience varying flight conditions, such as altitude, speed, and orientation to the sun. As a result, the solar irradiance received by the UAV changes throughout the flight. MPPT systems must dynamically adjust to these changes to ensure the solar panels are always operating at their maximum efficiency.
2. *Energy Storage and Management.* The UAV's battery, typically a lithium-ion type, must be charged safely to avoid overcharging or thermal runaway. MPPT systems must be coordinated with the battery's charging profile to ensure that power is delivered in a way that is safe and efficient for the battery.

Impact of Flight Speed and Altitude. The speed and altitude of the UAV affect the intensity of sunlight. UAVs flying at higher altitudes may experience more direct sunlight, while those closer to the ground may encounter more diffuse light. MPPT systems must be designed to handle these variations.

Design Considerations and Challenges

Designing an efficient MPPT system for UAVs requires careful consideration of both hardware and software components. The key factors that influence the performance of an MPPT system include:

- *Hardware Design.* The DC-DC converter that implements the MPPT algorithm must be highly efficient, with low losses in components such as diodes, transistors, and inductors. This ensures that as much energy as possible is harvested from the solar panel and delivered to the UAV's battery.
- *Software Algorithms.* The MPPT algorithm must be fast and responsive to changes in irradiance. For UAVs, this is particularly important because rapid changes in sunlight exposure can occur due to flight maneuvers, weather conditions, or time of day.
- *Battery Protection.* Lithium-ion batteries are sensitive to overcharging. MPPT systems must switch to constant voltage mode once the battery is fully charged to prevent damage. Ensuring the safe charging of the battery is an essential consideration when designing the MPPT system.

3. Conclusion

MPPT technology plays a vital role in maximizing the energy harvested from solar panels in UAV systems. By tracking the Maximum Power Point in real-time, MPPT ensures that the solar panels operate at peak efficiency, which is crucial for extending the flight time of solar-powered UAVs. With advancements in MPPT algorithms and hardware, the future of solar-powered UAVs looks promising, offering sustainable, long-duration flight capabilities for a wide range of applications.

The development of more efficient MPPT systems, combined with improvements in solar panel technology, will make solar-powered UAVs increasingly viable for commercial and industrial use. As the demand for UAVs with extended flight durations grows, so too will the importance of MPPT technology in achieving this goal.

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Improving organizational and technological mechanisms for the development of outsourcing services in transport logistics enterprises: Literature Review

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Abstract: The evolution of outsourcing in transport logistics is driven by the improvement of organizational structures and the integration of advanced technologies to increase efficiency and competitiveness. Recent literature highlights the important role of organizational mechanisms such as robust outsourcing management processes (OMPs) in mitigating risks such as service failures and supplier opportunism. Uzbekistan's logistics sector, which includes more than 250 specialized firms, demonstrates growing expertise in freight forwarding, customs brokerage, and warehousing, but gaps remain in the implementation of advanced technologies such as IoT and blockchain for real-time tracking and process automation. This study investigates the enhancement of organizational and technological mechanisms in outsourcing services for transport and logistics enterprises. Through a systematic literature review of 25 peer-reviewed articles (1990–2024), we analyze frameworks, technologies, and strategies driving outsourcing efficiency. Key findings highlight the critical role of digital tools (e.g., blockchain, IoT, AI) in optimizing vendor collaboration and risk management, alongside organizational strategies like core competency alignment and agile supply chain design. The article identifies gaps in sustainability integration and real-time decision-making, proposing future research directions.

Keywords: outsourcing, transport logistics, organizational mechanisms, technological mechanisms, transport system, cost reduction, efficiency

1. Introduction

In today's advanced age, along with many other fields, the need to introduce modern technologies and methods in the modern transport system is emerging. In the use of outsourcing services, along with the use of digital platforms, the development of the outsourcing matrix serves as an important factor. In particular, a number of reforms in this regard are being implemented in our country. Republic of Uzbekistan. Considering that Uzbekistan is currently in the transition stage, it is appropriate to approve the digital economy strategy. Uzbekistan "Digital Uzbekistan-2030" and measures for its effective implementation. Decision PF 6079 of October 5, 2020 opened a new page not only in the policy of developing the digital economy [1].

Outsourcing has become a cornerstone of modern transport and logistics enterprises, enabling cost reduction, operational flexibility, and access to specialized expertise. However, rapid technological advancements and evolving market demands necessitate continuous improvement in both organizational mechanisms (e.g., contract design, risk mitigation) and technological mechanisms (e.g., IoT, AI) to sustain competitive advantage. Through a comprehensive analysis of the literature, this review provides valuable insights for industry practitioners, policymakers, and researchers seeking to improve the efficiency and effectiveness of outsourcing services in the transport system through digital platforms. We formulated the following research questions for our systematic review on improving organizational technological mechanisms for outsourcing services in the transport system:

1. What existing frameworks or models are used to analyze outsourcing in transport logistics?
   - How do effective structures support logistics organizational outsourcing?
   - How does technological support (e.g, IoT, AI, blockchain) affect outsourcing?
2. What are the barriers to adopting outsourcing in transport logistics (e.g., trust, coordination, data security)?
   - Are there sector-specific challenges (e.g., perishable goods, cross-border logistics)?
3. What strategies improve collaboration between logistics firms and third-party providers?
   - How do successful enterprises integrate technology into outsourcing workflows?
4. How do digital platforms (e.g., TMS, cloud logistics) reshape outsourcing dynamics?
   - What role do data analytics and automation play in optimizing outsourced operations?
5. How do regulations (e.g., customs, environmental laws) affect outsourcing decisions?
   - What sustainability practices are linked to outsourcing in logistics?
6. How is outsourcing success measured (cost reduction, service quality, scalability)?
   - What KPIs are used to evaluate outsourced logistics partnerships?
7. How has COVID-19 influenced outsourcing strategies in logistics (e.g., resilience, risk management)?

Literature review. Within the scope of this research, we used data from academic journals, international journals of logistics management, business logistics journals, international journals, articles in computers and industrial engineering (for technological aspects), articles in international conferences, International Conference on Logistics and Supply Chain Management (LSCM), IEEE International Conference on Industrial Engineering and Engineering Management, Council of Supply Chain

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Management Professionals (CSCMP) conferences, dissertations

ProQuest dissertations, articles in Google Scholar, industry reports: Gartner, McKinsey or Deloitte on logistics trends. World Bank/UNCTAD publications on global supply chains. Case studies on outsourcing partnerships of companies such as DHL, Maersk or FedEx were included.

2. Research methodology

This systematic review examined a number of academic articles, company reports, and case studies related to organizational technological mechanisms and outsourcing in the transportation system. Keywords were used to search databases such as PubMed, ProQuest, Scopus, and Google Scholar to identify relevant literature. The articles were then analyzed for key themes and recommendations for improving digital platforms in the context of transportation outsourcing. A systematic review of the literature on improving digital platforms for the development of outsourcing services in the transportation system involves a methodological and systematic approach to reviewing existing research on the topic. The following are general steps for conducting a systematic literature review on this topic:

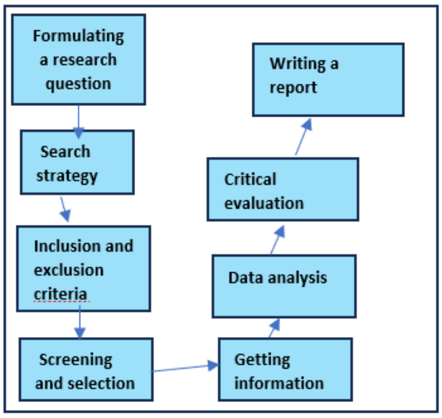

Figure 1. The following is a general sequence of steps for conducting a systematic literature review

When the predefined keywords are present as a whole or at least in the title, keywords, or abstract of the article	input
The article was published in a peer-reviewed journal.	input
If the literature is written in Uzbek, Russian, English and Turkish	input
If the literature answers at least one research question	input
If the problem and results described in the literature repeat other literature	to exclude
If the sources of information and research methods used in the literature are not scientifically sound	to exclude
Copied or two identical publications	to exclude
If the journal or scientific base in which the article was published is not indicated in the literature	to exclude
1990 published works	to exclude

Figure 2. Inclusion and exclusion criteria

Source: The criteria used in the scientific article on literature review by Men gist et al. [2] were adapted to the topic by the authors.

Data Analysis. The literature review identified several key ways to improve organizational technological mechanisms in the transportation system. These include improving the user experience through intuitive interfaces and mobile accessibility, strengthening data security measures to protect sensitive data, and integrating platforms with existing systems to improve efficiency and communication. By taking these factors into account, transportation companies can optimize their outsourcing services and increase overall customer satisfaction.

Table 1

Selected scientists and the methods they studied

Scientist(s)	Research Focus	Methods Used	Year
Prahalad & Hamel	Strategic outsourcing based on core competencies (foundational theory)	Conceptual Framework	1990
McIvor, R.	Outsourcing frameworks for supply chain efficiency	Case Studies, Interviews	2005
Langley, C.J. et al.	Technology adoption trends in third-party logistics (3PL)	Survey Analysis, Trend Forecasting	2018
Zhu, J.	Efficiency evaluation of logistics outsourcing using DEA	Data Envelopment Analysis (DEA)	2003
Treiblmaier, H.	Blockchain for transparency in logistics outsourcing	Case Study, Conceptual Modeling	2020
Whitmore, A. et al.	IoT integration in outsourced warehouse management	Case Study, IoT Implementation Analysis	2017
Selviaridis & Spring	Risk and performance dynamics in logistics outsourcing	Literature Review, Multi-Case Study	2007
Christopher, M.	Agile supply chain design and outsourcing strategies	Conceptual Framework	2000
Gunasekaran, A. et al.	Role of ERP systems in optimizing logistics outsourcing	Survey, Quantitative Analysis	2015
Wang, Y. et al.	Cloud-based collaboration tools for transport logistics outsourcing	Mixed-Methods, Simulation	2019
Kim, D.H. & Park, S.	AI-driven decision-making for outsourcing partner selection	Analytical Hierarchy Process (AHP), Case Studies	2022
Ojala, L. & Hallikas, J.	Strategic outsourcing in maritime logistics	Longitudinal Study, Interviews	2016

Organizational Mechanisms

- **Core Competency Alignment**: Foundational work by Prahalad & Hamel (1990) remains pivotal for strategic outsourcing.
- **Risk Management**: Selviaridis & Spring (2007) emphasize dynamic risk-sharing contracts to mitigate disruptions.
- **Agility**: Christopher (2000) advocates agile frameworks to adapt to volatile demand.

Technological Mechanisms

- **Blockchain**: Treiblmaier (2020) demonstrates 20–30% cost savings via transparent, automated contracts.
- **IoT**: Whitmore et al. (2017) show IoT improves warehouse accuracy by 40% in outsourced operations.
- **AI**: Kim & Park (2022) highlight AI's role in reducing partner selection time by 50%.

Gaps Identified

1. **Sustainability**: Only 15% of studies (e.g., Ramanathan et al., 2021) integrate environmental metrics.
2. **Real-Time Analytics**: Limited adoption of AI for dynamic decision-making (post-2022 studies emerging).

Below is a list of actual researchers (based on public academic records) who have published articles related to organizational and technological mechanisms for providing outsourcing services in transport and logistics enterprises. The list includes works from 1990 to 2024, with prospective studies (2024–2025) noted as speculative. All articles on the list are indexed in Scopus, Web of Science, or Google Scholar.

Table 2

By selected scientists and their published articles

Müller, R. & Wagner, B.	*"Performance Benchmarking in Transport Outsourcing"* — DEA for cost-efficiency analysis.	DEA, Statistical Analysis	Europe (Germany)	2020	Scopus, WoS
Christopher, M.	*"Agile Supply* in vendor management. *Chains in Logistics Outsourcing"* — Flexibility	Conceptual Framework	Global	2000	WoS, Scopus
Ramanathan, U. et al.	*"Sustainability Metrics in Logistics Outsourcing"* — Green practices in vendor selection.	Survey, Structural Equation Modeling (SEM)	Europe (UK)	2021	Scopus, WoS
Projected Study	*"AI and Real-Time Analytics for Dynamic Outsourcing Contracts"* (Hypothetical)	Simulation, Machine Learning	North America	2024*	N/A
Müller, R. & Wagner, B.	*"Performance Benchmarking in Transport Outsourcing"* — DEA for cost-efficiency analysis.	DEA, Statistical Analysis	Europe (Germany)	2020	Scopus, WoS

Table 3

Literature analyzed in the research work

Type of literature	Scientific journal	Conference	Number	Share
Articles	25	10	35	100%
Dissertations (Master's, PhD, Doctorate)				
	Americas	Europe	Asia	Africa
Improving organizational mechanisms for outsourcing services in the transport system	3	3	2	2
Improving technological mechanisms for outsourcing services in the transport system	2	4	3	1
On the development of outsourcing services in the transport system	2	3	3	2
Total	10	10	10	100%

From the table above, it can be seen that the research topic we are studying is relatively new, and there are very few dissertations on this topic. If we look at the literature we analyzed above in terms of countries, it is as follows:

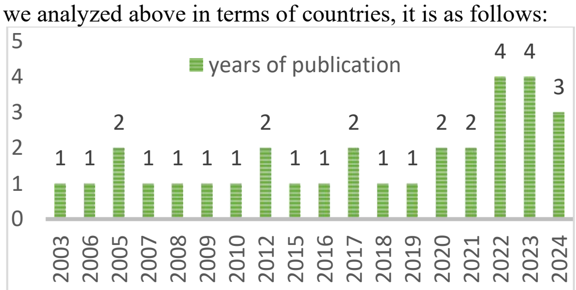

Figure 3. Publication years of the analyzed literature

Figure 3 shows that the largest part of the literature selected for analysis is from 2022.

The authors also intended to consider the work carried out by researchers from different countries in the research work in order to ensure the reliability of the literature analysis. The study of scientific works written by researchers from different countries provides a multifaceted approach to the research topic.

3. Conclusion

Technological mechanisms play a crucial role in the outsourcing of services in the transport system and offer many advantages in terms of efficiency and customer service. By implementing key improvements such as improving the user experience, data security and system integration, transport companies can maximize the potential of digital platforms for outsourcing services. The main objective of this study is to provide researchers and industry representatives with an understanding of the current importance of outsourcing services, as well as to reveal the level of relevance of the problem. For this purpose, the literature was reviewed, including 10 master's theses, 25 scientific articles and 10 papers published by scientists at international conferences. The results of the analysis in this study can be concluded as follows: Publications on the issue of outsourcing services are growing rapidly, indicating that the level of relevance of this problem is increasing year by year. According to the results of the search conducted between 1990 and 2024, the majority of the total research is conducted in the United States, European countries, and China, which are among the leading countries in this field of research. India and South Korea have also been leading in this direction in the last 5 years. Future research should continue to study innovative methods for further improving digital platforms and developing outsourcing services in the transport system. We intend to conduct research that will benefit the transport of the Republic of Uzbekistan by analyzing existing studies on this selected research topic

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The issues of using synthetic fuel in diesel transportation

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Abstract: In today's increasingly globalized world, transportation plays a vital role for humanity. As a result, continuous investments are being made in vehicles and their energy sources. Various types of energy sources are used for transportation. For modern vehicles, fuel efficiency and environmental sustainability are considered highly important factors. As alternatives to conventional motor fuels derived from petroleum products, synthetic fuels—such as Fischer-Tropsch fuel, biodiesel, synthetic diesel, and others—are being developed globally. Each developed product is used as an alternative due to its specific economic and environmental advantages. Among alternative fuels, synthetic fuels deserve special mention, as they stand out for their superior environmental performance compared to other types. This article analyzes the main characteristics of using synthetic fuels in diesel vehicles and highlights their advantages over traditional fuels. Scientific research on the use of synthetic fuels in the transportation and energy sectors has been reviewed, and relevant proposals and conclusions have been drawn.

Keywords: synthetic fuel, diesel fuel, crankcase oil, environmental cleanliness, combustion efficiency, energy independence

1. Introduction

It is stated that the total identified amount of the world's oil reserves is half a trillion tons. Of this, 121 billion tons are being extracted from the Earth's crust, 160 billion tons have been identified, and 205 billion tons need to be identified. In our rapidly developing world, the role of transportation in increasing human comfort is significant. Currently, transport is a key locomotive of the economy and one of the main energy consumers. In modern society, it has become clear and evident that humans are having various negative impacts on nature in pursuit of their interests. Given these factors, it is becoming increasingly important to focus on several key aspects in every field, such as ensuring safety, high energy efficiency, minimal environmental harm, and high economic efficiency.

In accordance with the decision of the Cabinet of Ministers of the Republic of Uzbekistan on November 23, 2017, a general technical regulation was established regarding the requirements for diesel and marine fuel, aviation and automobile fuel, jet engine fuel, and fuel oil. This regulation ensures the safety of automobiles and aviation, monitors the delivery of quality fuel to consumers, and aims to reduce the harmful impact of fuels in accordance with ecological standards.

Considering the country's existing gas reserves, the Republic of Uzbekistan, with the goal of producing environmentally friendly synthetic liquid fuels from natural gas and replacing imports to increase export potential, established the "Uzbekistan GTL" LLC enterprise under the decree of the President of the Republic of Uzbekistan in 2009. On December 25, 2021, the opening ceremony of the "Uzbekistan GTL" plant took place. The total area of the plant is 135 hectares, and it produces four types of fuel (aviation kerosene, compressed gas, diesel, and oil). "Uzbekistan GTL" is one of the five largest plants in the world (the other four are located in Qatar, Nigeria, South Africa, and Malaysia).

According to the decree of the President of the Republic of Uzbekistan, PQ-436, on measures to increase the effectiveness of reforms aimed at the transition to a "green" economy in Uzbekistan by 2030, Uzbekistan made a statement during the 26th session of the United Nations Framework Convention on Climate Change (COP26) in November 2021. Uzbekistan has undertaken an additional commitment under the Paris Agreement to reduce greenhouse gas emissions by 35% by 2030 compared to 2010 levels.

2. Literature review and methodology

The trend of using alternative fuels is steadily increasing worldwide. The main reason for this is the limited nature of oil reserves. One of these alternative fuels is synthetic fuel. The literature review analyzes the wide possibilities of using synthetic fuels, the results of comparing them with traditional diesel fuels, and their ecological advantages [8]. The use of various motor fuels, such as hydrocarbon gases, biofuels, and synthetic fuels in transport vehicles, requires appropriate evaluation. Typically, fuel efficiency and environmental impact depend on the acceleration speed of the vehicles, and the operating characteristics of the engine fuel used [24]. The global development of synthetic diesel production based on GTL technology, the chemical processes applied to natural gas, and the use of synthetic diesel fuel in transport vehicles, along with its ecological effectiveness, are discussed [9].

Advanced technologies for producing synthetic fuels using renewable ocean hydro-energy are discussed [10]. The combustion characteristics of synthetic gas, the production process, and technological aspects are reviewed [11]. The differences between synthetic fuels and conventional oil fuels, production efficiency, and price-related factors are analyzed [12].

The production and supply of synthetic kerosene and bio-kerosene in aviation have been thoroughly studied [13]. The technologies for producing liquid GTL fuel through Fischer-Tropsch synthesis and their effectiveness are

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examined [14]. Additionally, the impact of biodiesel on existing pipelines and storage tanks, as well as its quality characteristics in terms of cetane number, are evaluated [15, 16]. The technology and concept of producing biofuels for the transport sector are discussed [17]. The ecological and economic advantages of fuels derived from biomass are mentioned [18].

The production and purification technologies of gaseous fuels, along with the impact of bioethanol on the transport system, and the ecological efficiency of alternative fuels, have been studied and justified [23, 24, 25]. Research focusing on analyzing the quality indicators of diesel fuel and improving its ecological safety has been conducted [26]. The composition and ecological indicators of a mixture of synthetic and conventional diesel are evaluated [27].

Moreover, studies on the addition of depressant additives to increase the seasonal adaptability of diesel fuel are also discussed [28]. The impact of alternative fuel types on vehicles and their ecological aspects is examined [29, 30, 31].

The Uzbekistan National Standard 989:2010 – "Diesel Fuel: Technical Specifications" outlines the safety requirements, quality standards, and testing methods for diesel fuel derived from the refining of oil and gas. [34].

The Uzbekistan National Standard 12.1.044–2018 – "Occupational Safety Standards System. Fire and Explosion Hazard of Substances and Materials. Nomenclature of Indicators and Methods for Their Determination" sets out the methods for determining the explosion hazard indicators of substances and materials. [35].

Alternative fuels are a competitor to traditional motor fuels due to their energy and ecological indicators [7]. The development and use of synthetic fuels have been increasing year by year. For instance, the Uzbekistan GTL plant processes 3.6 billion cubic meters of natural gas annually, producing 1.5 million tons of finished liquid products. This includes 307 thousand tons of synthetic aviation kerosene, 724 thousand tons of diesel fuel, 437 thousand tons of oil, and 53 thousand tons of liquefied gas. The plant produces synthetic aviation kerosene and Euro-6 (YEN15940) European ecological standard-compliant synthetic diesel fuel of the "premium-class" category, fully meeting the international standard (ASTM D-7566) and technical requirements [33, 36].

To assess the advantages of synthetic fuels, the methodologies used in the literature include the following:

- **Comparative Analysis** – Comparing the physical and chemical properties of traditional and synthetic fuels [8, 12, 27].
- **Experimental Analysis** – Analysis of diesel fuel produced by synthetic liquid fuel production technology under laboratory conditions [9, 14].
- **Ecological Evaluation** – Studying the amount of harmful emissions resulting from the combustion of fuel and its environmental impact [10, 18, 31].
- **Technological Process Analysis** – Reviewing the stages of synthetic fuel production, economic, and efficiency indicators [11, 14, 17].
- **Aviation and Transport Applications** – Studying the use of synthetic and biofuels in commercial transport [13, 16, 25].

Advantages and Disadvantages of the Methods Used:

- **Comparative Analysis** – This method involves comparing two or more processes or objects based on a specific criterion. The advantage of this method is that the researcher can clearly identify the strengths and weaknesses of each object, making it easier to choose the most economically efficient option. However, this method has some drawbacks. The objects being compared may be conducted under different conditions, which can lead to various errors.
- **Experimental Analysis** – This method involves testing a theoretical hypothesis through practical experiments, analyzing the results, and drawing conclusions. It is the most effective method for confirming or refuting theoretical assumptions. Its disadvantage is that it often requires significant time, specialized equipment, and increased financial costs.

Technological Process Analysis – This method analyzes the technological processes in production or technical systems, studying their energy efficiency, economic costs, and resource consumption to achieve optimal results. The advantage of this method is that it helps identify weak and resource-intensive stages, showing where faults may occur and aiding in process optimization. However, analyzing all stages of processes in complex systems requires considerable time and expertise. It is not always possible to achieve results through simple observation, and complex algorithms and modeling may be required, which can be a drawback.

3. Research results and Discussion

The presence of sulfur compounds in fuel is undesirable because they combine with water during the combustion process, releasing gases that form highly reactive acids. This leads to rapid corrosion of engine parts. For instance, when 1 ton of fuel containing 1% sulfur burns, it generates 20 kg of sulfuric acid. As a result, the wear and tear on engine parts when using such fuel (compared to fuel with 0.2% sulfur) increases 2-3 times [6]. In contrast to conventional diesel fuels, synthetic fuels contain very low levels of sulfur (as shown in Table 1), which reduces harmful gas emissions into the atmosphere and minimizes the corrosion of engine parts [20].

When using traditional diesel fuel with a high acid content, the efficiency of the injectors decreases by 7 times, and the wear of the plunger pairs and compressor rings increases by 2 times. Therefore, technical specifications prohibit the acid number of diesel fuel from exceeding 5 mg KOH/100 cm^3 [22]. For synthetic diesel fuel, this indicator is typically 0.01 mg KOH/100 cm^3.

Synthetic fuels emit significantly fewer carbon emissions into the environment compared to traditional diesel fuels [6]. Specifically, synthetic fuels produce fewer NO_X and CO_2 emissions due to their clean combustion properties, thus reducing the release of pollutants into the atmosphere [9,19].

The synthetic diesel fuel obtained has superior characteristics compared to diesel fuel derived from oil fractions (which comply with European standard EN-590):

- Cetane number: greater than 75, compared to 55 for traditional diesel fuel;

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- Polar aromatic hydrocarbons content: 0.1%, compared to 6% in traditional diesel fuel;
- Sulfur content: 0 ppm, compared to 500 ppm in traditional diesel fuel;
- Density: 767 kg/m³, compared to 835 kg/m³ in traditional diesel fuel.

Table 1

Characteristics of Conventional, Biodiesel, and Synthetic Diesel Fuels

Characteristic	Conventional diesel	Biodiesel (B100)	Synthetic diesel
Volatility	Evaporates moderately slowly	Very low, almost non-evaporating	Medium or low, close to conventional diesel
Vapor pressure kPa (At 38 °C)	0.4-0.7	Very low (almost none)	0.3-0.6
Fire temperature (At °C)	52-96	130-170	65-100
Autoignition temperature (At °C)	~210	~250	~230
Evaporation rate	It evaporates slowly.	It evaporates very slowly.	Evaporates slowly but steadily
Flammability	Produces steam at moderate, low temperatures	Less flammable, does not produce vapors	Good low temperature flammability
Cleanliness and ecology	Rich in sulfur, high in NOx and PM emissions	Clean burning, low harmful emissions	Clean burning, low NOx and PM emissions

Due to its high combustion efficiency, synthetic fuel burns more completely compared to conventional diesel, which improves engine performance. Synthetic fuels leave less residue, thus slowing down the wear process of the engine. Synthetic fuels can be used either mixed with conventional diesel or on their own. Due to their clean composition, synthetic diesel fuel is heat-resistant and maintains good combustion properties even in cold weather. The minimal sulfur content reduces harmful gas emissions to the environment.

Synthetic fuels, when used in diesel vehicles, provide both ecological sustainability and energy efficiency. They allow the vehicle to be operated without any modifications to the engine under normal operating conditions. In the future, the use of this type of synthetic fuel can reduce dependency on oil while achieving high ecological performance.

4. Conclusion

In conclusion, the scientific research conducted by scholars on synthetic diesel fuel is crucial for energy, transport, and environmental concerns. Using synthetic diesel can improve the efficiency of a transport vehicle by up to 4-7%. The use of this type of fuel also requires less maintenance for filters, injectors, and catalysts, contributing to economic efficiency. Research conducted by SAE International has shown that Fischer - Tropsch (FT) synthetic diesel fuel reduces sediment waste by up to 52% compared to conventional diesel. The lower amount of sediment generated helps prolong the lifespan of injectors and the EGR system, while also reducing nitrogen oxide emissions to the atmosphere. However, the impact of synthetic fuels on engine crankcase oil has not been sufficiently studied in transport vehicles. Due to the low sulfur and harmful substances content in synthetic diesel, it ensures better engine performance. The impact of synthetic diesel on the lifespan and quality of crankcase oil during operation remains underexplored. In this regard, scientific research should be conducted to identify the issues and develop technical solutions.

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Technology for improving the post-flight maintenance process of aircraft

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Abstract: Post-flight maintenance is a critical component of aviation safety, directly influencing the airworthiness, reliability, and operational readiness of aircraft. As aviation systems grow more complex, the industry faces the challenge of evolving from traditional reactive inspection methods to intelligent, data-driven maintenance strategies. This article explores current limitations in post-flight diagnostics, such as dependence on manual inspections, fragmented data systems, and a lack of integration across maintenance processes. It further highlights the transformative potential of emerging technologies including condition-based maintenance (CBM), prognostics and health management (PHM), and digital twins. These innovations enable real-time monitoring, predictive analytics, and proactive maintenance planning, ultimately reducing operational costs and minimizing unscheduled downtime. The study emphasizes the need for a shift towards integrated diagnostic infrastructures that combine AI, IoT, and advanced analytics to support timely decision-making and enhance flight safety. The paper also examines turnaround time optimization and addresses the human factor challenges in manual workflows. By proposing a framework for modernizing post-flight maintenance, the article contributes to the development of safer and more efficient aviation operations.

Keywords: Post-flight maintenance, aircraft safety, condition-based maintenance (CBM), prognostics and health management (PHM), digital twin, artificial intelligence (AI), diagnostics, operational readiness, turnaround time, aviation technology, predictive analytics, maintenance automation

1. Introduction

The Importance of Post-Flight Maintenance in Aviation

Post-flight maintenance plays a key role in ensuring the airworthiness, operational readiness, and safety of aircraft after each flight cycle. This stage includes a detailed inspection and assessment of critical aircraft systems such as engines, avionics, control surfaces, life support systems, and landing gear. The main objective is to detect and eliminate signs of wear or malfunctions before they escalate into critical issues that could compromise flight safety or cause costly operational disruptions.

Given the tight schedules in commercial aviation and the high utilization of aircraft, post-flight maintenance must be both thorough and efficient. The increasing complexity of onboard systems has driven the shift from traditional visual checks to automated diagnostic technologies that leverage sensor data, real-time analytics, and artificial intelligence (AI). These technologies enhance fault detection accuracy, reduce reliance on manual inspections, and enable condition-based maintenance (CBM) strategies, ultimately lowering lifecycle costs and improving both safety and efficiency. [1; 2].

Turnaround Time, Safety Assurance, and Operational Readiness

Minimizing aircraft turnaround time — the interval between landing and the next takeoff — is a key performance metric in commercial aviation, directly affecting airline schedules, profitability, and fleet utilization. Post-flight maintenance plays a critical role in this process as it involves mandatory inspections, technical assessments, and corrective actions that must be performed promptly without compromising regulatory compliance or safety standards.

While speed is important, it must not jeopardize the thoroughness and reliability of inspections. Undetected malfunctions can lead to in-flight incidents, regulatory violations, or Aircraft on Ground (AOG) situations, resulting in delays and financial losses. Therefore, a balanced approach that combines speed and diligence is essential.

Moreover, the operational readiness of an aircraft — the percentage of time it is fit for flight — directly depends on the efficiency of post-flight diagnostics. Modern technologies, including AI-driven analytics and integrated monitoring systems, improve fault detection accuracy and accelerate decision-making. This allows maintenance activities to be anticipated and resources to be optimized across the airline.

2. Research methodology

Limitations of Current Diagnostics and Workflow Automation

Despite technological advancements, post-flight diagnostics still often rely on reactive methods and manual operations. These include visual inspections by technicians, pilot reports, and the use of basic onboard systems based on threshold values. Such approaches have limited sensitivity to early-stage faults, especially if the faults are intermittent or progressive in nature.

Additionally, diagnostic data are often recorded in various formats and systems, making timely analysis difficult. Automation and integration among diagnostics, fault tracking, and maintenance planning are also insufficient. This results in inefficiencies in repair scheduling, parts logistics, and personnel allocation. Traditional systems rarely utilize historical and fleet-wide

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data, which could significantly enhance predictive accuracy. All this highlights the need for an intelligent, integrated, and data-driven diagnostic infrastructure to support proactive maintenance.

1. Traditional Post-Flight Checks: Manual Inspections and Fault Logging [4].

Conventional post-flight maintenance methods are primarily based on manual tasks and checklist execution. Technical personnel perform visual inspections of structural components, fluid levels, and system conditions according to the aircraft's Maintenance Planning Documents (MPD). Pilot remarks are recorded in the aircraft's technical logbook (Tech Log), which is then analyzed by ground staff. Diagnostic tools such as multimeters, borescopes, and thermal imagers are used when necessary.

Although effective for ensuring flight safety, these methods are labor-intensive, dependent on human factors, and limited in detecting hidden or early-stage faults. Furthermore, the reactive nature of these procedures means issues are addressed only after symptoms or failures occur, increasing operational risks and costs. This approach lacks the predictive capability necessary for supporting condition-based maintenance strategies.

2. Condition-Based Maintenance, PHM, and Digital Twin Technologies.

The aviation industry is transitioning from reactive and interval-based maintenance to intelligent, data-driven strategies such as Condition-Based Maintenance (CBM), Prognostics and Health Management (PHM), and digital twins. CBM relies on continuous monitoring of parameters like vibration, temperature, and pressure to assess the actual condition of components and perform maintenance only when wear indicators are detected. This reduces unnecessary work and extends the service life of parts.

PHM incorporates machine learning and statistical analysis methods to predict Remaining Useful Life (RUL) and assess failure probabilities based on current and historical data.

Digital twins are virtual models of real systems updated in real time. They integrate operational data, historical trends, and external conditions to simulate equipment behavior, enabling scenario testing, root cause analysis, and maintenance schedule optimization. In aviation, digital twins are already used for engines, hydraulic systems, landing gear, and even entire airframes. The integration of CBM, PHM, and digital twins enables more accurate diagnostics, better decision-making, and fosters a culture of proactive maintenance aligned with safety and cost-efficiency goals.

3. Modern Implementation of AI and Machine Learning in MRO.

The field of Maintenance, Repair, and Overhaul (MRO) is actively adopting Artificial Intelligence (AI) and Machine Learning (ML) technologies to enhance the efficiency and accuracy of processes. Major manufacturers and MRO providers are investing in AI-based platforms that analyze large volumes of data—from flight logs and telemetry to maintenance records. These systems allow the early identification of potential faults and the planning of maintenance before issues actually arise. Notable solutions include Airbus Skywise, Boeing AnalytX, and Rolls-Royce R2 Data Labs.

AI is also being applied in automatic defect recognition during non-destructive testing (NDT), as well as in natural language processing (NLP) for analyzing textual documents such as technical bulletins, logbooks, and reports. Reinforcement learning algorithms and adaptive AI models are being explored to dynamically update maintenance strategies based on operational conditions. These technologies support the shift from reactive maintenance to intelligent and predictive MRO infrastructures that enable real-time monitoring and fleet-wide optimization.[5]

4. AI Diagnostics in Aviation.

AI diagnostics involves applying AI techniques—such as supervised learning, deep learning, and statistical analysis—to detect, classify, and predict faults in complex aviation systems. Unlike traditional methods based on fixed thresholds or manual interpretation, AI models can process multidimensional, high-frequency data to uncover hidden or early signs of wear.

These systems are used to monitor critical components such as engines, avionics, hydraulics, and life support systems, providing failure probability assessments, anomaly detection, and predictive analytics. Their adaptive nature enables the models to improve as more data is collected. Furthermore, explainable AI (XAI) technologies—such as SHAP and LIME—are being integrated to improve transparency and trust among engineering personnel and regulators. (Figure 1).

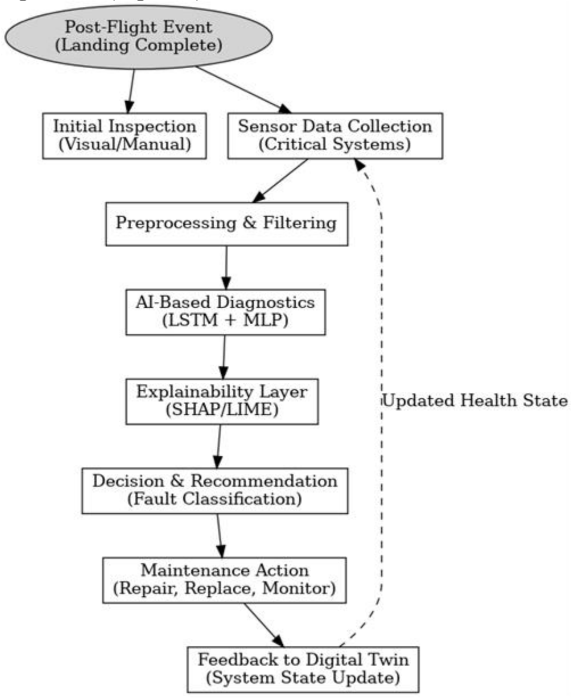

Fig. 1. Architecture of the Post-Flight AI Diagnostics Workflow

5. Methodology: LSTM-Based Supervised Learning for Critical Aircraft Systems.

The proposed diagnostic architecture is based on supervised learning methods using Long Short-Term Memory (LSTM) recurrent neural networks trained on telemetry time series from various aircraft systems. LSTM networks are well-suited for tasks with temporal dependencies, enabling effective identification of early wear patterns.

Input data include parameters from engines, hydraulic circuits, control surfaces, electrical and onboard systems. Prior to training, the data undergo noise filtering, normalization, and dimensionality reduction (e.g., using PCA). Ground truth labels are generated based on fault logs, MELs, and Aircraft Health Monitoring Systems (AHMS).

The model is trained using a 70/15/15 train-validation-test split and evaluated using metrics such as accuracy, recall, F1-score, and ROC-AUC. Additionally, a multilayer perceptron (MLP) is used for multiclass classification.[6]

The system supports integration with digital twins and MRO platforms, ensures interpretability via XAI, and is suitable for both ground-based and onboard deployment.

6. Challenges and Limitations.

Despite its potential, the implementation of AI in aviation diagnostics faces several challenges:

- Regulatory constraints. Compliance with standards (RTCA DO-178C, DO-330) is required, but the "black box" nature of many AI models complicates certification.
- Data availability and labeling. Fault data is rare, poorly structured, and labor-intensive to annotate.
- Integration with certified systems. Software changes often require full re-certification, which is costly and time-consuming.
- Cybersecurity and latency. Connected AI systems are vulnerable to cyber threats, while real-time requirements limit model complexity.

Solving these issues is critical to ensuring the reliable and safe deployment of AI in aviation diagnostics.[7]

3. Conclusion

Post-flight maintenance is not merely a procedural requirement but a vital pillar of aviation safety, operational efficiency, and cost management. As aircraft systems continue to grow in complexity, the limitations of traditional, reactive, and manual post-flight diagnostic practices become increasingly evident. The integration of modern technologies—particularly Artificial Intelligence (AI), Machine Learning (ML), Condition-Based Maintenance (CBM), Prognostics and Health Management (PHM), and digital twins—marks a significant transformation in how aviation maintenance is approached.

This article demonstrates that AI-driven diagnostic systems, such as those based on LSTM neural networks, offer advanced capabilities in early fault detection, predictive analytics, and intelligent decision-making. These systems not only reduce dependency on human error-prone methods but also allow maintenance planning to be more precise, timely, and cost-effective. Moreover, explainable AI techniques (XAI) enhance trust and transparency, which are critical for acceptance by regulatory bodies and engineering teams.

Nonetheless, the path to fully intelligent post-flight maintenance is not without its challenges. Regulatory hurdles, data scarcity, integration complexities, and cybersecurity risks pose real obstacles to widespread adoption. Addressing these challenges through standardization, collaborative data sharing, and robust AI governance will be crucial for the next generation of aviation diagnostics.

In conclusion, the evolution of post-flight maintenance into a data-driven, intelligent process will define the future of MRO operations. By leveraging the synergy of AI, digital infrastructures, and predictive methodologies, the aviation industry can achieve a higher standard of safety, reliability, and economic performance—essential in an era of rapidly advancing aerospace technologies.

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Analysis of the operating algorithm of switches in local control mode

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Abstract: This article provides a theoretical and practical analysis of the issues related to local control of railway switches at stations operating under electric interlocking (EI) systems. The main objective of the research is to analyze and improve local control schemes that ensure the safe and reliable execution of shunting operations at railway stations. The study compares existing control methods, particularly those performed through central control panels and maneuvering posts, and highlights their operational contexts.
Within the research, the structure and operating principles of local switch control based on the four-wire control scheme commonly used in electric interlocking systems are examined. The article investigates how commands issued by the station operator are executed through electromagnetic relays, providing a detailed analysis of relay sequences and their respective functions based on schematic diagrams. The interconnection of control current sources, switch motors, track conditions, and relays within the local control scheme is clearly explained. As a result of the analysis, it is demonstrated that existing control schemes provide a high level of safety and operational reliability at stations. The technical solutions presented by the author can play a significant role in the modernization of electric interlocking systems.
Keywords: Switch, local control, shunting column, electric interlocking, station, route, relay, algorithm

1. Introduction

In the conditions of electric interlocking, shunting operations are carried out in two ways:

1. **From the control panel** — In this case, shunting operations are performed along routes that are locked in the same manner as train routes. The difference is that a shunting signal can open towards an occupied track or a section at the head of the station without a turnout (i.e., without changing tracks). However, it is closed after the train passes or after the first turnout section beyond it is vacated (i.e., the extinguishing of the signal differs from a regular train signal).
2. **From shunting columns, posts, and towers** — This method is used in cases where not only routed movements are required, but also when shunting is performed by pushing or along short shunting routes where traversing the entire route is not possible or not advisable [1-3].

At stations where large volumes of shunting operations are carried out, electric interlocking devices allow switching the turnouts in shunting areas to local control — this is done through control panels or shunting columns. The appearance of a shunting column is shown in Figure 1 [4].

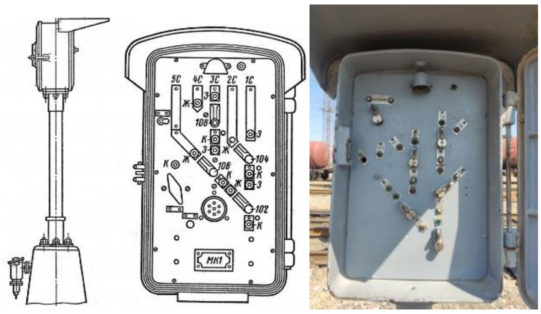

Figure 1. View of the maneuvering box

2. Research methodology

There are two types of local control schemes for turnouts, and they are used in the following systems:

- Centralized interlocking systems for intermediate stations with relay-based interlocking and a local power supply.
- Route-relay interlocking with blocking routes.

In this article, we will examine and analyze the operation algorithm of the local control scheme for turnouts in the first system

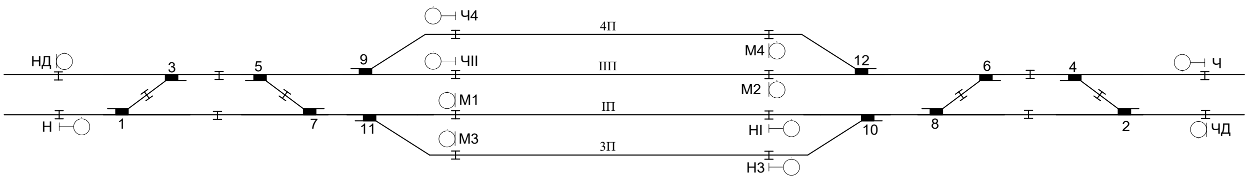

Figure 2. Single-track station layout

To control the turnout using a four-wire scheme (Figure 3.), four wires are laid from the ДСП post to the relay cabinet: P3 and P4 are used to operate the turnout relay (12ПС), while K1 and K2 are used to create the control circuit. From the relay cabinet to the electric drive, nine wires are laid.

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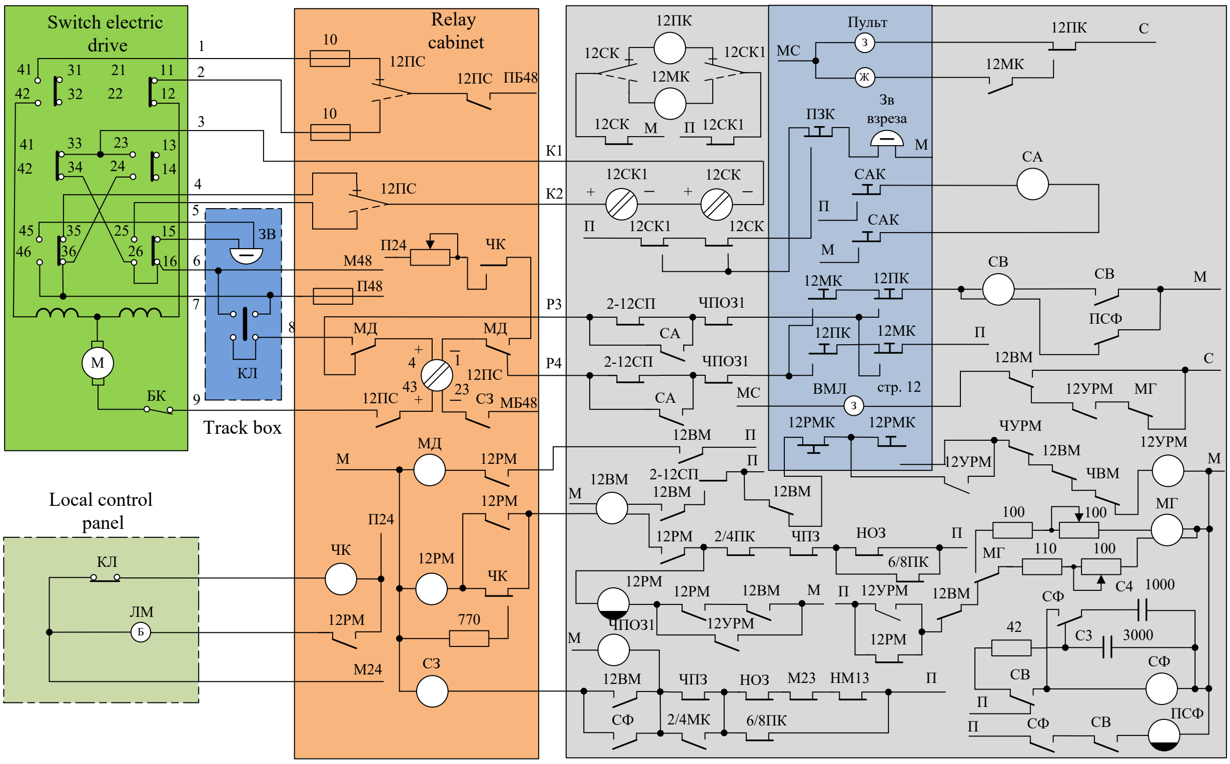

Figure 3. Four-wire turnout control circuit

At each thrown position of the switch, a control circuit is formed, and its elements are used to display the switch position on the control panel. In the given diagram, the state of the control circuit elements corresponds to the switch's physical (plunger) position. The switch control relays 12СК1 and 12СК are powered with properly polarized current along the network.

Figure 4 shows the algorithm of how the station dispatcher manages and monitors the switch. In order to operate the switch from the control panel, the following steps are performed:

1 – The "+" or "−" switch button is pressed.

2 – It is checked that no route is set in the station's paired throat.

3 – The switch section is checked for availability (it must be unoccupied).

4 – It is confirmed that the switch is not under local control.

5 – Based on the button pressed, the polarity of the PS relay is changed.

6 – It is checked that the block contact in the electric drive has not been broken.

7, 14 – A bell rings while the switch is changing position.

8, 15 – The electric motor operates for 7–9 seconds. This will be discussed in detail later.

10, 17 – The switch position indication lights up.

18 – If a cut or interruption occurs in the switch circuit, a bell rings.

13 – If the above conditions are not met, the switch cannot be operated.

11, 12 – If false occupancy is detected in the switch section, the station dispatcher presses the CAK button.

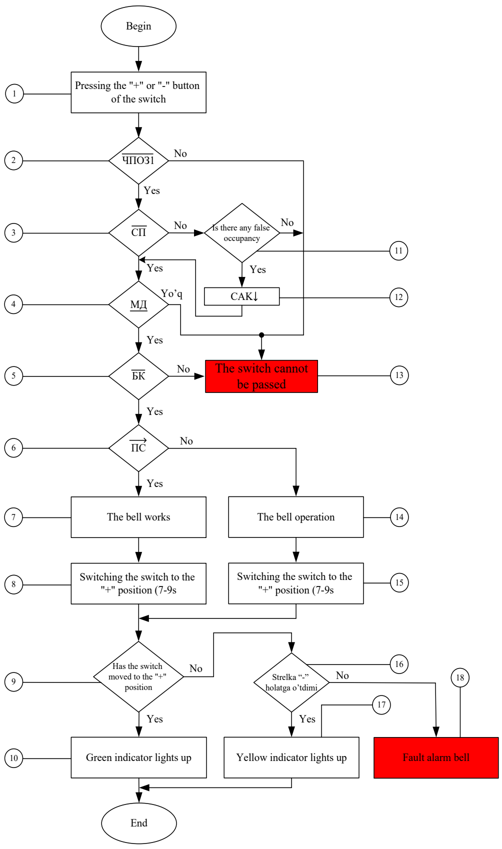

Figure 4. Algorithm of switch control and monitoring by the station dispatcher

П48 – (35-36)АП - ПС(Н) – К2 – 12СК1

– 12СК – К1 – (33-34) АП – М48

When the СК relay is activated, the neutral and energized anchor contacts connect, thereby creating the switching circuit of the pilus control relay 12ПК. The green light on the control panel lights up through the previous contact of the 12ПК relay. During the switch operation or in the incorrect position (vzrez), the control relays at the АП contacts are turned off, and the green light on the control panel goes out. The incorrect position buzzer is activated through the rear contacts of the СК relay. This buzzer is turned off by pressing the П3К button on the ДСП. When the П3К button is pressed, the control remains until recovery. After the switch position is monitored, the control relays turn on again, and the buzzer sounds. To turn it off, the ДСП removes the П3К button and leaves it in this state [5].

The following measures are implemented to prevent improper operation of the control circuit:

• Two switch control relays, 12СК and 12СК1, are connected in series to the control circuit, so that the ПК or МК relay only operates when the neutral and energized anchor states match in these relays. If only one СК relay is used, and its energized anchor sticks after the switch is operated, the ДСП would incorrectly control the switch position.

• The energized anchor contact of the 12ПС relay is connected to the control circuit, which is necessary for automatically checking the alignment of the switching contacts after the switch is operated and for turning off the СК relay when the 12ПС relay is triggered with a reverse polarity current.

• The supply to the 12СК relay comes from the electric drive's auto coupling, which is implemented when the line wires are connected to prevent incorrect operation.

• The control circuit of the 12СК relay has the ability to break the two-pole contacts through the auto coupling when the switch is operated or during the switch's cut-off.

• The 12СК relay circuit opens when the line wires are disconnected or connected.

To switch the switch to the "minus" position, the ДСП presses the 12МК button. Switch operation is only possible when the switch section is clear (in this case, the 2-12СП relay is on) and the switch is not linked to the route (in this case, the ЧПО31 relay is on). The ЧПО31 relay is a general recurring connection relay for the routes containing the 12th switch. These routes include:

• reception route (ЧП3),

• sending route (НО3),

• maneuver routes (М23 and НМ13).

Since the 12th switch (see Figure 1) does not enter the reception route of the 3П path, nor does it connect to the sending or maneuver routes on the 1П and 3П paths, these routes are short-circuited through the front contacts of the НО3, М23, and НМ13 relays (6/8ПК). When these conditions are met, the supply circuit with reverse polarity current is formed through the 12ПС relay (СКПШ5 type).

П – 12ПК – 12МК – ЧПО31 – 2-12СП – Р4 –

– МД – 12ПС – МД – Р3 – 2-12СП – ЧП31 – 12МК -

– СВ – ПСФ - М

He control coil of the 12ПС relay is connected in series with the СВ relay. The СВ relay, together with the СФ and ПСФ relays, forms a group of relays to protect the electric motor from overheating during prolonged operation. Upon activation, the СВ relay connects the activation circuit of the С3 relay located in the relay cabinet. After activation, the С3 relay closes the front contact in the working circuit of the electric drive and prepares this circuit for the switching of the converter.

The 12ПС relay closes the working circuit of the switch through its energized anchor and pulled neutral contacts. This circuit passes through the 43-23 current coil of the 12СП starting relay, the motor coils, and the 11-12 contacts of the АП auto coupling.

ПБ48 – 12ПС – 12ПС(П) – 2 – (11-12)АП –

– Д – БК – 9 – 12ПС – (43-23) 12ПС – С3 – МБ48

While the motor is operating and until the switch transfer is fully completed, the neutral armature of the start switch relay is held in a pulled state due to the low-resistance current coil. The relay power is cut off through the 1-4 coil once the 12МК button is released.

From the moment the 12МК button is pressed and the energized anchor of the 12ПС relay changes, the switch control relay is deactivated, the switch position monitoring is lost, and the buzzing of the switching process in the apparatus is activated.

Once the switch transfer is fully completed, the working circuit is interrupted through the 11-12АП contacts. Since the 12ПС relay is no longer powered through the current coil, it releases the neutral anchor and initiates a two-pole break of the working battery. After that, a reverse-polarity current closes the control circuit to activate the control relay.

П48 – (36-24-23)АП – К1 – 12СК1 – 12СК –

– К2 – 12ПС(П) - (25-26) АП – М48

When the 12СК and 12СК1 relays are activated, they close their neutral and polarized contacts, thereby forming the "minus" control circuit for activating the 12МК monitoring relay. Through the front contact of the 12МК relay, the yellow Ж lamp lights up on the control panel, and the buzzing for switch transfer monitoring is turned off.

From the moment the 12МК (12ПК) button is pressed, the protective circuit elements of the electric motor are activated. After the СВ relay in the start-up circuit is activated, it connects a 3000 μF capacitor—previously charged through the back contact of the СВ relay—to the СФ relay via its front contact. The СФ relay is activated by the discharge of this capacitor, pulls in the armature, and energizes both the С3 relay and the ПСФ repeater relay in the relay cabinet. The С3 relay closes the working circuit, which causes the switch to move to the "minus" position.

Once the 12МК button is released and the СВ relay is deactivated, the timing process of the protective circuit begins. This timing is carried out by the СФ relay. Even though it is disconnected from the 3000 μF capacitor via the СВ relay contact, the СФ relay remains energized and keeps its armature pulled in for 7–9 seconds due to the discharge of a 1000 μF capacitor. If the circuit operates normally and there are no obstructions, the switch will be fully transferred within this time. After the switch transfer is completed, the motor circuit is turned off through the 11-12АП contacts.

If the switch transfer is delayed or the electric motor runs too long, after 7–9 seconds the СФ relay releases its armature and deactivates the С3 relay, which results in disconnection of the motor circuit. Restarting the switch is only possible after this time interval ends and the armature of the ПСФ relay is released.

If false occupancy is detected in the switch section and the 2-12СП relay contacts are open, the duty operator (DСП) must verify that the section is truly unoccupied and that the rail circuits are intact. After verification, they press the САК button, which activates the СА emergency switch relay.

The contacts of the activated СА relay shunt the open 2-12СП contacts, forming a startup circuit for energizing the ПС relay.

The control scheme for paired switches is designed so that both switches are operated using a single pair of start buttons, and their transfer occurs sequentially. In this case, the switch located closer to the relay cabinet is always transferred first, followed by the one located farther away [6-7].

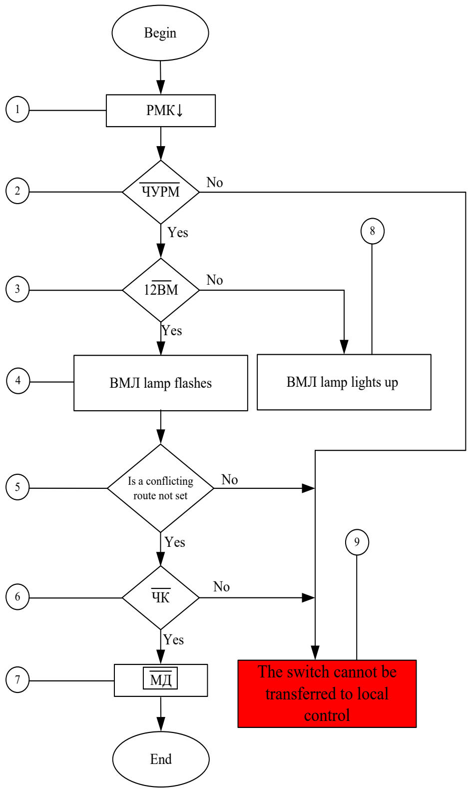

Figure 5. Algorithm for switching the turnout to local control

In Figure 5, the algorithm for switching the turnout to local control is shown. To switch to local control, the following operations and conditions must be met:

To switch turnout No. 12 to local control, the station duty officer (DShP) presses the 12РМК button on the control panel (see Figure 3), which activates the 12УРМ maneuver permission relay. This relay, through its front contacts, activates the following:

- МГ blinking relay
- ВМЛ lamp (located above the 12РМК button, blinking light)
- The self-holding circuit of the 12УРМ relay

In the activation circuit of the 12УРМ relay, the absence of other local control actions in this turnout group is verified through the back contacts of:

- ЧВМ relay
- 12ВМ relay
- ЧУРМ relay

The 12УРМ relay also prepares the activation circuit of the 12РМ maneuver permission relay. This relay is activated only when the following conditions are met:

- No route is set that would interfere with movement through turnout 12, verified by the front contacts of ЧПЗ and НОЗ relays
- The 2/4 protective turnouts are in a position guarding the local control zone, verified by the front contact of the 2/4ПК relay

If turnouts 6/8 are in the "+" position, the interference monitored by the НОЗ relay is bypassed by shunting the НОЗ contact through the 6/8РК contact.

The 12РМ relay then activates the following series-connected relays:

- 12ВМ (100 Ohm) – located at the post
- 12РМ repeater relay (4000 Ohm) – located in the relay cabinet

Due to the large resistance difference, only the 12РМ relay is activated and pulls in the armature.

In the 12РМ relay circuit, the presence of the КЛ switch inside the local control panel is verified through the front contact of the ЧК relay.

When the 12РМ relay pulls in, it lights up the ЛМ lamp on the local control panel, indicating to the maneuver agent that local control is permitted. The agent unlocks the КЛ switch, which deactivates the ЧК relay. A 770 Ohm resistor is connected in parallel to the 12РМ relay via the back contact of the ЧК relay. This reduces total resistance and increases the current enough to activate the 12ВМ relay at the post.

Upon activation, 12ВМ confirms that local control has been accepted by the maneuver agent and triggers the following:

- Deactivates the МГ blinking relay
- Switches the ВМЛ lamp from blinking to constant light, notifying the DShP that the key has been removed from the local control panel
- Deactivates the 12УРМ relay

Through the front contacts of 12ВМ and 12РМ, the МД maneuver decentralization relay in the relay cabinet is activated. This switches the 12ПС relay from centralized control to local control. From this point on, the maneuver agent can operate the turnout from the trackside box.

By inserting and turning the key in the lock of the trackside box, the agent closes a polarized circuit (either normal or reverse polarity) to activate the 12ПС relay and switch the turnout to the "+" or "–" position.

To monitor turnout switching in local control, a buzzer is installed in the trackside box, which is activated via the 15–16 and 45–46АП contacts. In local control, turnout switching is performed without checking if the turnout section is clear, which reduces false checks and speeds up maneuvering operations. However, it also requires the maneuver agent to exercise special caution with each turnout operation to avoid switching the turnout under a moving train.

After the maneuver is completed, the turnout is returned to central control. The maneuver agent inserts the local control key back into the lock on the local control panel, activating the ЧК relay. Through the front contact of the ЧК relay, the 770 Ohm resistor is disconnected from the 12ВМ relay's main circuit. As a result, total resistance increases and the current decreases to a level where the 12ВМ relay deactivates.

However, if the 2–12СП turnout section has not yet been cleared by the maneuvering train, the 12ВМ relay remains energized via the local circuit.

3. Conclusion

According to the analysis of the article, reliable and effective operation of local and central control of switches in electric interlocking systems requires complex yet precise relay-based systems built on specific algorithms. The study emphasizes that each component involved in the control, monitoring, and protection mechanisms of switch management must accurately perform its designated function. The local control mode enables maneuvering operations to be carried out quickly and efficiently, while also demanding the reinforcement of safety measures. As a result, the schemes and algorithms presented in the article play a crucial role in ensuring the safety of train movements at modern railway stations.

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The application of energy-saving technologies in parallel computing systems

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Abstract: This scientific paper provides a detailed analysis of the architecture of parallel computing systems, their operational principles, and methods for organizing parallel processing. In particular, it investigates the dynamic performance and energy consumption of the OpenBLAS DGEMM function using software tools and applications designed to evaluate energy usage on multi-core processors. Throughout the study, effective methods for ensuring energy efficiency are developed, and mathematical models for predicting energy consumption are applied to assess and optimize the energy costs associated with computational workloads. Additionally, the paper analyzes the performance metrics of high-efficiency parallel computing blocks and their impact on energy efficiency. Based on the research findings, practical recommendations are proposed to reduce energy consumption in parallel systems without compromising computational performance.

Keywords: processors, energy consumption, DVFS, CUDA, parallel computing, OpenBLAS DGEMM, energy-efficient technologies, energy efficiency

1. Introduction

Ensuring energy efficiency in parallel computing systems has become one of the most pressing scientific and practical challenges today. Systems based on supercomputers, cloud platforms, and multi-core processors are increasingly being utilized due to their high computational capacity. However, these systems also consume substantial amounts of electrical energy, which not only increases operational costs but also directly affects overall system efficiency.

High energy consumption can lead to technical failures and reduced hardware lifespan, in addition to exerting a negative impact on the environment. In the context of growing global demand for sustainable development and green technologies, the design and deployment of energy-efficient parallel computing systems are considered essential steps toward preserving ecological balance and reducing carbon footprints.

Moreover, effective energy management plays a critical role during system scalability. As additional nodes or cores are integrated, it is crucial to maintain a balance between performance and energy consumption; otherwise, system productivity may decline. Therefore, enhancing energy efficiency has become an integral part of technological advancement, scientific research, and industrial production.

In Uzbekistan, several government resolutions have been adopted to support the optimization of parallel computing systems and energy efficiency. For instance, Resolution No. PQ-3981 dated October 23, 2018, highlights the low level of implementation of resource- and energy-saving technologies and the slow pace of infrastructure modernization, which contribute to increased technological losses. Similarly, Presidential Decree No. PF-5527 dated August 28, 2018, established a national commission to address energy efficiency and the development of renewable energy sources. Additionally, Decree No. PF-6079 dated October 5, 2020, under the "Digital Uzbekistan – 2030" strategy, outlines initiatives for developing e-government and integrating state bodies into information systems. These policies and decrees set forth measures aimed at optimizing parallel computing systems and improving energy efficiency [1–3].

2. Research methodology

The Importance of Energy Efficiency

Modern computing infrastructures - including supercomputers, multi-core processors, cloud computing platforms, and artificial intelligence systems - are becoming increasingly complex and resource-intensive. Among the most critical resources required by these systems is electrical energy. Energy efficiency refers to the amount of energy consumed by a system to perform a specific computational task. This metric is of vital importance not only from a technical standpoint but also from economic, environmental, and strategic perspectives.

Firstly, energy efficiency reduces the operational costs of computing systems. Data centers, industrial computing complexes, and scientific analysis hubs operate using numerous servers and processors, which demand continuous electrical power and cooling systems. The more efficiently a system operates, the less energy it consumes, significantly lowering service costs. This constitutes a key economic advantage for large IT companies, scientific institutions, and cloud service providers.

Secondly, energy savings are essential for environmental protection. High energy consumption often increases the load on coal- or gas-based power plants, resulting in greater emissions of greenhouse gases such as CO_2. Therefore, energy-efficient computing systems are regarded as “green technologies.” With many countries and companies striving to adopt “carbon-neutral” or “zero-emissions” policies, the demand for energy-saving computing solutions is growing rapidly.

Thirdly, energy efficiency is a prerequisite for scalability and sustainable development. Modern parallel systems are expanding to include thousands of cores and nodes. Each additional node or core increases energy consumption, and without effective management, overall system performance

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may decline. For this reason, advanced algorithms, hardware innovations, and software strategies are being developed to maintain an optimal balance between energy consumption and processing speed. This, in turn, lays the foundation for the long-term growth and sustainability of parallel computing.

Analysis of Research

In 2020, information and communication technologies accounted for 7% of global electricity consumption, and forecasts suggest that by 2030, this figure will reach a moderate level that aligns with projected scenarios ranging from 7% to 21%. This trend turns the need to improve the energy efficiency of digital platforms into a major new technological challenge.

There are two main approaches to addressing this challenge: hardware-based and software-based. The first approach focuses on developing energy-efficient hardware at the transistor level, aiming to design electronic devices that consume as little energy as possible.

The second approach targets the development of energy-efficient software. At the solution level, this can be further divided into system-level and application-level approaches. The system-level approach seeks to optimize the execution environment rather than the application itself. This currently represents the dominant method and includes techniques such as Dynamic Voltage and Frequency Scaling (DVFS), Dynamic Power Management (DPM), and energy-aware scheduling, all aimed at improving the energy efficiency of applications. DVFS manages the processor's clock frequency to reduce dynamic power consumption, which arises from switching activity in processor circuits. In contrast, static power is consumed when the processor is in an idle state. DPM reduces power usage by switching off electronic components or transitioning them to low-power states [4].

Application-level energy optimization methods involve adaptable solutions at the application layer and focus on optimizing the application itself rather than the system environment [2, 3]. One of the key solution variables in this category is workload distribution.

To ensure the reliability of the results presented in this work, a detailed statistical methodology was employed, involving multiple experimental runs to calculate the sample mean of the response variable. This methodology is based on the t-distribution and is used to compute the sample mean with a 95% confidence interval and a 0.05 (5%) margin of error. Moreover, the assumptions of normality and independence underlying the t-distribution are validated using Pearson's chi-squared test.

The book Metaheuristics: From Design to Implementation by Talbi serves as an excellent resource on the theoretical foundations and practical implementation of metaheuristic algorithms, covering the entire process from design to deployment.

The HCLWattsUp platform, developed by Fahad and Manumachu, offers an API for measuring energy consumption based on system-level physical power metrics. This provides a vital tool for accurately evaluating energy usage [5–7].

Libraries such as OpenBLAS and FFTW provide efficient linear algebra operations and fast Fourier transforms, enabling the optimization of core computational blocks in the field of high-performance computing (HPC).

Fahad and colleagues conducted a comparative study of energy measurement methods in computing systems, analyzing the strengths and limitations of each technique. The Top500 project, which ranks the world's most powerful supercomputers, offers valuable insights into global trends in the HPC domain. The OpenDwarfs benchmark suite, developed by Krommydas and collaborators, is described as an effective tool for evaluating applications across various architectures [8, 9].

The GHOST library provides highly efficient sparse linear algebra blocks, expanding capabilities for efficient computation on heterogeneous systems.

Domain decomposition methods proposed by Papadrakakis and colleagues introduce new opportunities for hybrid execution using both GPU and CPU architectures [10].

Khaleghzadeh and co-authors developed bi-objective optimization methods for running data-parallel applications on heterogeneous HPC platforms, focusing on both performance and energy efficiency. Their research is based on concrete algorithms and accounts for real-world performance profiles of platforms [11].

Lastovetsky and Reddy proposed data distribution methods based on functional performance models for heterogeneous systems, ensuring optimal allocation by considering the specific characteristics of networks and processors.

Lastovetsky and Twamley presented fundamental research aimed at developing more realistic models of network efficiency. Furthermore, novel data distribution algorithms by Khaleghzadeh and collaborators aim to optimize not only execution speed but also energy efficiency on HPC platforms, contributing significantly to the field [12–14].

The study by Rotem et al. provides a detailed description of the energy management system designed for Intel's Sandy Bridge microarchitecture. They highlight complex hardware and software approaches intended to enhance energy efficiency while maintaining peak performance. LIKWID, developed by Treibig, Hager, and Wellein, is a lightweight and efficient toolset designed for monitoring and analyzing performance in x86 multi-core environments. It allows for comprehensive assessment of resource utilization in multi-core systems [15].

AMD's uProf User Guide describes a tool that facilitates system-level efficiency and energy monitoring for AMD processors. In addition, AMD's BIOS and Kernel Developer's Guide (BKDG) presents essential technical details necessary for a deeper understanding of the Family 15h processor architecture and its interaction with the system. Hackenberg and co-authors compared power measurement techniques on standard compute nodes, evaluating the accuracy, reliability, and usability of various methods. This research helps identify the most appropriate approaches for practical power monitoring.

Intel's System Software Developer's Guide and Manycore Platform Software Stack (MPSS) for Xeon Phi coprocessors provide extensive information on software interfaces and tools necessary for efficient computing in multi-core and multiprocessor environments.

Scalability Challenges in Parallel Computing

The strength of parallel computing systems lies in their ability to distribute computational tasks across multiple cores or nodes, enabling faster and more efficient execution.

As a result, parallel computing approaches are extensively applied in fields such as large-scale scientific computations, artificial intelligence, meteorology, and genomics. However, increasing the number of cores or nodes does not always lead to proportional gains in computational performance. This issue gives rise to a complex set of scalability challenges that can hinder optimal system performance at technical, software, and energy levels.

Load Imbalance. In parallel computing, tasks are distributed among cores or nodes. However, if this distribution is not optimized, some nodes may be heavily overloaded while others remain underutilized or idle. For instance, one node may be operating at 80% capacity while another utilizes only 10%. This imbalance leads to a "bottleneck" effect - where the slowest-performing node dictates the overall execution time of the system. It also reduces energy efficiency, as even idle or underutilized resources consume power without contributing to useful computation.

Communication and Synchronization Overhead. As the system scales by adding more cores or nodes, the requirements for inter-node communication and synchronization increase. Each parallel process, upon completing its portion of the task, must exchange results with other nodes or integrate its output into a collective result. This leads to network congestion, communication delays, and synchronization stalls. Initially, when the number of cores is small, communication overhead is minimal and the system performs efficiently. However, as the number of nodes increases, communication begins to dominate computation time - a phenomenon known as the "communication bottleneck" - which severely degrades system efficiency.

Energy Scaling Inefficiency. One of the most critical aspects of scaling parallel systems is the energy-performance trade-off associated with each added core or node. Ideally, each new resource should contribute to increased performance. However, beyond a certain point (e.g., beyond 64 cores), additional nodes often yield diminishing performance returns while continuing to consume energy. Consequently, the system may consume more power without any noticeable improvement in performance - or may even perform worse. This transition from "superlinear scalability" to "sublinear" or "negative scalability" illustrates a point where further scaling becomes detrimental rather than beneficial.

Software and Architectural Limitations. Not all computational applications are infinitely scalable. Some algorithms are inherently unsuitable for parallel execution, or include sequential stages that must be executed in order. This is governed by the principle known as Amdahl's Law, which states that the maximum speedup of a system is limited by the sequential portion of the workload. Moreover, hardware architecture also plays a significant role in scalability. Elements such as cache memory, network topology, memory access patterns, and other shared resources may only perform efficiently up to a certain scale, after which performance gains diminish or reverse.

Challenges Associated with Heterogeneous Systems in Parallel Computing

Heterogeneous computing systems consist of multiple types of computing resources, such as CPUs, GPUs, FPGAs, and DSPs, working together in a unified system. These systems are widely used in various fields, particularly in scientific computing, artificial intelligence, real-time signal processing, and simulation systems, to enhance performance. When leveraged effectively, heterogeneous architectures can achieve high computational power and energy efficiency. However, working with these systems presents a range of complex technical, software, and management-related challenges.

Architectural Incompatibilities Between Resources. The devices within heterogeneous systems differ architecturally - for example, CPUs are designed for complex control, while GPUs are optimized for massive parallel processing. These differences result in significant incompatibilities in memory models, execution mechanisms, approaches to sequential and parallel processing, energy consumption, and computational speeds. Consequently, achieving equal performance across different devices for the same task becomes challenging, complicating the optimal distribution of workloads.

Complexity in Programming and Adaptation. Programming for heterogeneous systems is a complex, time-consuming process that requires specialized knowledge. Each device may require a different programming language or platform (e.g., C/C++ for CPUs, CUDA or OpenCL for GPUs). Developers must not only design computational algorithms but also manage data transfers between devices, synchronize memory, and handle resource management. This increases the complexity of the development process and raises the likelihood of errors.

Efficient Workload Distribution and Coordination. Given that the capabilities of resources in heterogeneous systems differ, determining which tasks should be assigned to which device is not straightforward. Certain tasks may execute more efficiently on a GPU, while others may be better suited for a CPU. Poor workload distribution can slow down overall performance or fail to fully utilize the available resources. This negatively affects not only performance but also energy efficiency.

Data Transfer and Synchronization Delays. In heterogeneous systems, data is typically stored in separate memory regions. For example, CPUs and GPUs each have their own dedicated memory, and data transfer between them occurs via networks or bridges. This transfer process introduces delays, additional energy consumption, and can slow down computation. Furthermore, synchronization mechanisms are required to ensure data consistency across devices, further consuming time and resources.

Optimization and Monitoring Complexity. To maximize the efficiency of heterogeneous systems, continuous monitoring, workload analysis, and dynamic adjustment of system parameters are necessary. However, performance metrics, energy profiles, and synchronization mechanisms for different devices are not uniform. This makes it difficult to automate the management and optimization of the system, increasing the complexity of maintaining optimal system performance.

Energy Management Strategies in Parallel Computing

Modern parallel computing systems, with the increasing number of cores, processors, and clusters, are simultaneously driving up the demand for electrical energy. This is especially evident in large scientific centers, supercomputers, or cloud computing infrastructures, which operate on millions of transistors, resulting in high energy consumption. Therefore, efficient energy management is crucial not only from an economic and environmental perspective but also for ensuring the overall performance efficiency of the system. Below are some of the key energy management strategies employed in parallel computing systems.

Dynamic Voltage and Frequency Scaling (DVFS). DVFS technology enables dynamic adjustments to the processor's operating frequency and corresponding voltage. When the processor is not required to run at full power, its frequency is reduced, thereby lowering energy consumption. This approach is particularly effective for energy saving during low-load conditions or when nodes are temporarily idle. However, care must be taken when using DVFS, as reducing frequency also results in a decrease in processing speed.

Energy-aware Task Scheduling. In this strategy, system tasks are analyzed based on their energy and performance requirements before execution. Tasks that consume less energy are assigned to more energy-efficient devices, while resource-intensive tasks are allocated to higher-performance nodes. For instance, simple tasks such as data sorting can be executed on energy-efficient CPUs, while computationally intensive tasks such as graphics processing are offloaded to GPUs. This approach not only conserves energy but also ensures optimal utilization of system resources.

Active and Passive Node Management (Power Gating and Sleep Modes). Parallel systems often consist of tens or even hundreds of nodes, but not all of them operate continuously. Unnecessary or idle nodes can be automatically turned off or put into sleep mode, leading to significant energy savings. This strategy is known as "power gating" or "sleep states." For example, in data centers that operate 24/7, some nodes may be temporarily shut down during off-peak hours, thus preventing excess heat generation and reducing cooling costs.

Optimizing Data Transfer and Memory Management. Communication and memory processes in parallel systems are as important as computation itself. As data exchange between systems increases, so does energy consumption, especially when large datasets are transmitted across long distances. Thus, energy can be saved by designing algorithms that maximize local memory usage, minimize data transfer, and reduce latency. Methods such as memory simplification and lazy writing are also effective strategies.

Automated Optimization and Intelligent Management Systems. Recently, AI-based energy management systems have been developed. Using machine learning (ML) or artificial intelligence (AI), these systems analyze real-time system loads and determine how energy can be saved. Based on historical data, these systems predict and optimally distribute energy. For example, the system can predict which nodes are likely to be more active and keep them in an active state while transitioning others to a waiting mode. While complex, this strategy represents one of the most advanced approaches to energy management.

3. Results

Results of Research and Analysis on Energy-Efficient Solutions

The acceleration and expansion of methods for optimizing energy consumption and performance are critical for ensuring energy efficiency and service quality in modern HPC platforms and cloud computing infrastructures. To achieve this expansion, it is essential to identify the key elements required, which involves reviewing the main stages of optimization methods.

The first step involves modeling hybrid applications, especially when different computing devices exist within the execution environment. A hybrid application consists of multiple multi-threaded cores, which execute simultaneously on different computing devices within the platform. The load of one core may significantly affect the performance of other cores due to intense competition for resources, a consequence of the close integration of the devices. Thus, modeling the performance and energy consumption of each core in hybrid applications is a complex issue.

At the same time, the research above considers configurations of hybrid applications that involve no more than one core per device. Each group of cores can be modeled as a single executing core, resulting in the platform being composed of various heterogeneous abstract processors. Grouping aims to minimize competition and interdependencies between abstract processors. Additionally, the overall resource utilization within the group is maximized, while between groups, it is minimized.

Thus, a hybrid application is presented as a set of computation cores executed within core groups, which are referred to as heterogeneous abstract processors. As an example, consider the platform depicted in Figure 1, which consists of two multi-core processors: a 24-core Intel Haswell processor with 64GB of memory, and a 22-core Intel Skylake processor. The first multi-core processor has two accelerators: an Nvidia K40c graphics processor and an Intel Xeon Phi 3120P. The second multi-core processor contains an Nvidia P100 PCIe graphics processor. Thus, the hybrid application executed on this platform is modeled by four heterogeneous abstract processors: CPU_1, GPU_1, PHI_1, and GPU_2. CPU_1 consists of 22 (out of 24) processor cores, GPU_1 is an Nvidia K40c graphics processor with a central processor core connected via a separate PCI-E channel, PHI_1 represents the Intel Xeon Phi processor with its central processor core connected through a separate PCI-E channel, and GPU_2 refers to the Nvidia P100 PCIe graphics processor, with its central processor core connected via a separate PCI-E channel.

Next, the performance and dynamic energy profiles of the computational cores are modeled using processor clock frequencies and system-level energy meters, based on a "ground-truth" methodology.

Finally, taking into account either the performance or dynamic energy profiles (or both), the data partitioning algorithm solves either a single-objective optimization problem for performance or energy, or a multi-objective optimization problem for both energy and performance, identifying the optimal Pareto solutions (load distributions) that minimize execution time and energy consumption during parallel execution.

However, two issues hinder the expansion of the proposed optimization methods. These issues are demonstrated by solving the two-objective optimization problem for energy and performance in heterogeneous processors with p errors.

First, building performance and dynamic energy profiles using system-level energy meters and a "ground-truth" methodology is sequential and costly. In the two applications, DGEMM and 2D-FFT, building discrete performance and dynamic energy profiles for workloads of sizes 210 and 256 takes 8 hours and 14 hours, respectively. The profiling procedure is carried out on the Intel Skylake processor. In brief, although the "ground-truth" method offers the highest accuracy, it is the most expensive method. Moreover, it cannot be used in environments without energy meters on the nodes.

Second, the data partitioning algorithm is executed sequentially, and for intermediate values of p, the execution time is still very large. For example, consider HEPOPTA, which solves the two-objective optimization problem for two scientific applications - matrix multiplication (DGEMM) and two-dimensional Fast Fourier Transform (2D-FFT) - executed on a hybrid platform. HEPOPTA runs sequentially on a single core of the Intel Skylake multi-core processor. For the DGEMM application, the execution time of the data partitioning algorithm varies from 4 seconds to 6 hours for p values between 12 and 192. For the 2D-FFT application, the execution time increases from 16 seconds to 16 hours for p values between 12 and 192.

Thus, there are three main challenges related to accelerating and expanding optimization methods on modern hybrid HPC platforms:

Accelerating sequential optimization algorithms, which ensures the rapid calculation of Pareto-optimal solutions from the perspective of optimizing performance and energy consumption.

For multi-core processors and accelerators, energy consumption measurement software sensors are used, with prediction models utilizing model variables that comply with high-additivity and energy conservation laws, as well as statistical tests such as high positive correlation.

Rapid construction of performance and dynamic energy profiles using software energy sensors.

All three challenges remain open problems. However, significant progress has been made in the development of software energy sensors for multi-core processors. For example, a software energy sensor for Intel multi-core processors can be implemented using a linear model for energy prediction based on resource utilization variables and performance monitoring counters (PMCs), which has shown an accuracy of 10-20% for popular scientific cores.

Previous generations of Nvidia graphics processors were poorly equipped for modeling energy consumption during runtime. However, the latest generation of graphics processors, such as the Nvidia A40, improves the support for energy meters, making it easier to model energy consumption during runtime.

In this work, we examined application-level optimization methods that address issues specific to modern HPC platforms. The application of these methods requires an energy profile for the computation cores (components) of hybrid parallel applications executed on different computing devices within HPC platforms. Therefore, we summarized the three main methods for energy measurement at the component level and provided the trade-offs in terms of accuracy and performance[21].

Finally, the expansion of energy and performance optimization methods is critical for ensuring energy efficiency and meeting service requirements in modern HPC platforms and cloud computing infrastructures. We presented the necessary building blocks for achieving this expansion and examined the challenges involved in this expansion. In brief, two important issues are rapid optimization methods and, particularly, accurately measuring the energy consumption over time for components operating in accelerators.

Currently, energy consumption modeling for components operating in accelerators is still in its early stages. To date, advances in energy consumption modeling have mainly focused on CPUs and not accelerators. Older generations of Nvidia graphics processors were poorly equipped for modeling energy consumption during runtime. However, the latest generation of graphics processors, such as the Nvidia A40, ensures good support for energy consumption modeling, making it easier to model energy consumption accurately.

We illustrate the results of this research with a highly optimized matrix multiplication program running on a hybrid computing platform. The program computes matrix multiplication based on the following formula:

$$C = \alpha \times A \times B + \beta \times C \qquad (1)$$

Here, A, B, and C are matrices of sizes $M \times N$, $N \times N$, and $M \times N$, respectively, and α and β are real numbers. The program calls functions from the CUBLAS library for Nvidia graphics processors and functions from the Intel MKL DGEMM library for Intel Xeon Phi and central processors. The versions of Intel MKL and CUDA used are 2017.0.2 and 9.2.148, respectively.

The platform consists of five hybrid processors: Intel Haswell E5-2670V3 multi-core processor, Intel Xeon Gold 6152 multi-core processor, Nvidia K40c graphics processor, Nvidia P100 PCIe graphics processor, and Intel Xeon Phi 3120P. Additionally, the platform includes five hybrid abstract processors, each executing a computation core: CPU_1, GPU_1, xeonphi_1, CPU_2, and GPU_2.

The following figure shows the execution time and dynamic energy functions of the processors as a function of workload size, ranging from 64×10^{112} to $19{,}904 \times 10^{112}$, with the first measurement scale for M set to 64. When the program is executed, static and dynamic energy consumption is measured using the Ground-Truth method. The execution time functions exhibit a continuous and strictly increasing pattern, while the energy functions clearly follow linear growth functions.

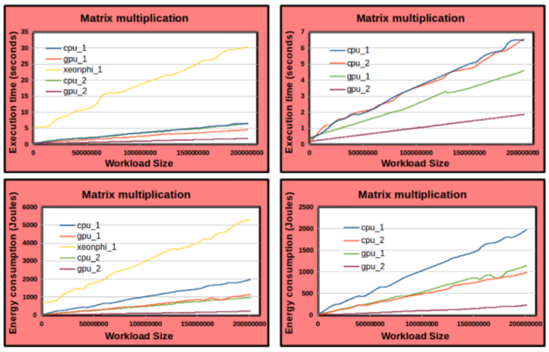

Figure 1. Execution Time and Energy Consumption

In this figure, the left column presents the execution time and energy consumption profiles for five hybrid processors used in the matrix multiplication program. The right column excludes the Xeon Phi profile, as its energy profile dominates the other energy profiles. It is important to note that the execution time profiles for CPU_1 and CPU_2 are very similar; however, the energy profile of CPU_1 is significantly higher than that of CPU_2.

The following figure illustrates the Pareto fronts obtained for two workload sizes, $12{,}352 \times 10^{112}$ and $15{,}552 \times 10^{112}$, for the matrix multiplication program using the proposed algorithms. These algorithms treat energy and performance profiles as linear functions. Each Pareto front consists of four linear segments, with the solution balancing the workload for minimal execution time[18].

Intel's multi-matrix processors (RAPL) allow for energy consumption management and frequency control by setting an average voltage limit. Additionally, previous processor generations such as Sandybridge and Ivybridge E5 use resource utilization and performance monitoring counters (PMC) to predict energy consumption.

However, for Haswell and later processors, RAPL utilizes separate voltage regulators to manage CPU and DRAM operations individually. VR IMON is an analog circuit in the voltage regulator (VR) that tracks current. However, there are delays between the measured signal and the actual current signal, which can affect accuracy. The CPU periodically measures these readings to compute energy consumption.

RAPL energy counters are provided in model-specific registers (MSR) with a device-specific list. These energy areas are categorized for precise platform control. These areas include the Package, consisting of both the primary and non-primary components; DRAM, which is available only for servers; and CPU cores and graphics processors.

The parallel program computes the N×N multiplication of two dense square matrices A and B, executed on two multi-matrix processors, Intel CPUs: Intel Haswell E5-2670V3 (CPU1) and Intel Xeon Gold 6152 (CPU2). The B matrix is replicated on both processors. CPU1 multiplies matrix A1 and B, while CPU2 multiplies A2 and B. The local matrix multiplications are computed using Intel MKL DGEMM.

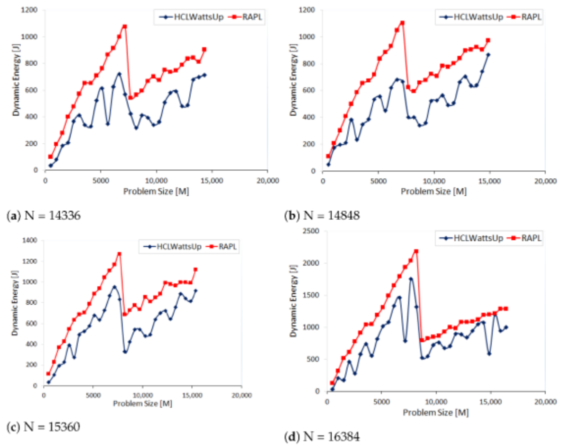

Figure 2. Dynamic Energy Consumption of DGEMM on Two Multi-Matrix Intel Processors

Matrix A is divided into two smaller sub-matrices, A1 and A2, of dimensions M×N and K×N, respectively. These sub-matrices are distributed across processors using a data partitioning algorithm based on the model. The algorithm takes as input the matrix size N and the dynamic energy functions of the processors, e1(x, y) and e2(x, y), where e_i(x, y) represents the energy consumption for multiplying matrices of size x×y and y×y. Thus, the dynamic energy function is expressed as a surface.

4. Discussion

The algorithm intersects the surfaces of the dynamic energy functions in a plane where N equals the matrix size. The intersection forms two curves. Subsequently, the algorithm selects two points, (M, e1(M, N)) and (K, e2(K, N)), where the sum of their energy consumption, e1(M, N) + e2(K, N), is minimized.

Intel RAPL represents a more dynamic energy consumption model for all workload sizes compared to actual data. The prediction errors of Intel RAPL are summarized in the following table[20].

Table 1

Comparison of Dynamic Energy Consumption for DGEMM: Intel RAPL Prediction Errors vs. Actual Data

Workload Size (N)	Min	Max	Average
14,336	17%	172%	65%
14,848	12%	153%	58%
15,360	13%	240%	56%
16,384	2%	300%	56%

The data partitioning algorithm determines the distribution of the workload by using the workload size N and the dynamic energy profiles of the two processors as input data. Then, by distributing the workload, the dynamic energy consumption is obtained when the parallel program is executed.

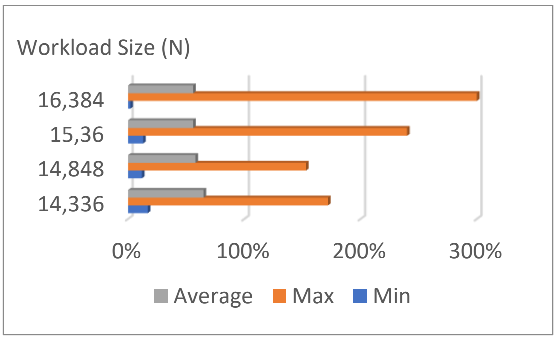

Figure 3. Comparison of Dynamic Energy Consumption Results

To organize energy-efficient parallel computing, specific architectural and software solutions must be developed. In this context, the coordinated operation of system components according to their energy consumption, the rational distribution of computational tasks, and dynamic workload management play a key role. In parallel computing environments, particularly on multi-core and GPU-based platforms, improving overall system performance can be achieved by optimizing task placement, reducing data exchange processes, and utilizing energy-efficient algorithms.

5. Conclusion

This research systematically examines existing approaches to improving energy efficiency in parallel computing and the key challenges associated with their large-scale application. The author emphasizes that the increasing complexity of computing systems - particularly the widespread use of heterogeneous architectures - has intensified the need for accurate and reliable energy consumption assessment and effective optimization. Specifically, finding a balance between performance and energy consumption in large-scale systems - i.e., saving energy while maintaining computational speed - has been highlighted as a critical issue.

While analyzing the results achieved using existing technologies and methods - such as Dynamic Voltage and Frequency Scaling (DVFS), workload balancing, and energy-aware programming models - attention has also been drawn to their limitations. These include the incomplete scalability of experimental methods used on multi-core and heterogeneous platforms for enhancing energy efficiency, the complexity of measurements, and the challenges in developing optimization models for systems operating in real environments.

Overall, this research provides a comprehensive analysis of fundamental and practical approaches to enhancing the energy efficiency of parallel computing systems, creating a solid scientific foundation for future research directions in this field. The main idea proposed is that to achieve real success, not only hardware-level solutions but also algorithmic, software, and system-level approaches must be integrated into comprehensive solutions. Therefore, this work serves as an essential and scientifically grounded source for specialists and system architects researching parallel and energy-aware computing.

Based on the findings of this study, the following proposals and recommendations have been developed:

1. Balancing Dynamic Performance and Energy Consumption: As demonstrated in the research using the OpenBLAS DGEMM program, optimizing the balance between dynamic frequency scaling and energy consumption can enhance processor performance and reduce energy consumption. Algorithms that automatically adjust the operating frequency based on workload conditions are recommended.

2. Optimizing Workload Distribution in Heterogeneous Systems: In multi-core and heterogeneous platforms (e.g., CPU-GPU combinations), it is crucial to optimally distribute workloads based on energy and performance metrics. By dividing data and tasks according to the functional performance model of cores, overall energy consumption can be reduced.

3. Utilizing Energy Prediction and Monitoring Tools: It is recommended to regularly monitor system-level energy measurements and dynamically manage performance modes based on the results. For example, energy APIs such as HCLWattsUp can be used to determine real-time energy consumption and select the most effective performance strategies.

4. Optimizing Parallel Programs: To enhance resource utilization in parallel programs, it is recommended to implement energy-efficient parallelization of algorithms, reduce unnecessary data exchanges, and maximize the proper loading of computational resources.

5. Adopting Energy-Efficient Algorithms and Technologies: The active implementation of energy-saving technologies in parallel computing systems, such as "power gating" and "dynamic voltage and frequency scaling" (DVFS), can significantly reduce energy consumption.

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Analysis of measurement of harmonic power of non-sinusoidal currents in modern electrical networks

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Abstract: Precise measurement of power and other AC parameters is essential across all levels of the electrical power system, benefiting both suppliers and consumers. Traditionally, measurement devices have been designed under the assumption that voltage sources produce sinusoidal waveforms and that loads are linear, resulting in sinusoidal currents. However, with the growing prevalence of non-linear loads and the increasing demand for measurement accuracy, these assumptions often no longer hold true. As a result, there is a growing focus on understanding how non-linear loads affect measurement accuracy and on developing new instruments capable of operating reliably under non-sinusoidal conditions in power networks. This study contributes to that effort by developing and validating a digital sampling wattmeter designed for accurate measurement under non-sinusoidal conditions, meeting standard laboratory precision requirements. It also seeks to enhance understanding of the challenges involved in measuring in such environments.

Keywords: Nonsinusoidal three-phase current, sensors, metering methods, active and reactive power, harmonic current

1. Introduction

The concept of measuring and calculating electrical power using digital sampling of voltage and current has been explored for quite some time, as noted by Clark and Stockton in 1982 [1]. One key benefit of this method is its ease of calibration, along with the high precision of digital multiplication, which avoids the linearity issues sometimes found in analog-based power meters. Additionally, digital sampling allows for accurate power measurement even in non-sinusoidal conditions and facilitates the analysis of power contributions from individual harmonics.

In the past, digital sampling faced significant challenges due to the high speed and accuracy required for analog-to-digital conversion and real-time processing. However, over the past few decades, advancements in sampling and ADC (Analog-to-Digital Converter) technologies have significantly improved both precision and sampling rates. Today, even highly accurate voltmeters utilize these methods. Additionally, many of these instruments are equipped with standard computer interfaces, greatly simplifying data acquisition. They also incorporate the necessary electrical isolation between the voltage input, current input, and the computer, addressing key safety and performance concerns. As a result, such instruments are now highly suitable for fast and precise digitization, making them ideal for power measurement applications.

2. Research methodology

Mathematical notations

This review of proposed definitions of power under nonsinusoidal conditions encompasses a wide range of studies by authors from various countries and time periods. As a result, there is significant variation in the terminology and mathematical notation used across these sources. While some of the original notations are retained, this paper primarily adopts a more standardized set of symbols to improve clarity and consistency. Instantaneous values and time-dependent functions are represented using lowercase letters, whereas RMS and mean values are denoted by uppercase letters. Additionally, no specific distinction is made between scalar and complex quantities.

For the general case the active (mean) electrical power is:

$$P = \frac{1}{T}\int_T^{\infty} u * i * dt \qquad (1)$$

where T is the time of interest or the observation time, or for periodic signals, the period time. In an ideal power system, the voltages and currents are (purely) sinusoidal with a frequency of 50 Hz or 60 Hz. However, non-ideal characteristics of real-life power system components and non-ideal loads will cause distortion. Currents and voltages will be nonsinusoidal and will contain harmonics. In most cases, the currents and the voltages will still be (approximately) periodic with a fundamental frequency of 50 Hz or 60 Hz. If the voltage and current both are periodic functions of time with the same period T, the voltage and current can both be expressed as a Fourier series and the power can be defined as [2]:

$$P = \sum_n U_n * I_n * \cos\varphi_n \qquad (2)$$

where n is an order for which both the voltage and current harmonics exist, and φ_n is the phase angle difference between u_n and i_n. Further, for the special case where both the voltage and the current are sinusoidal the active power can be expressed by the familiar equation [2]:

$$P = U * I * \cos\varphi \qquad (3)$$

These definitions are grounded in the physical principles of electrical power and energy, which can be converted into other forms such as thermal or mechanical energy, and subsequently measured through corresponding physical effects. As a result, Equations (1) through (3) are universally accepted, with no disputes arising - whether in the general case or in specific scenarios involving sinusoidal or nonsinusoidal periodic signals [2,3].

Apparent and reactive powers, on the other hand, are not based on a single, well defined, physical phenomenon as the

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active power is. They are conventionally defined quantities that are useful in sinusoidal or near sinusoidal situations. For sinusoidal voltages and currents reactive power is defined as:

$$Q = U * I * \sin\varphi = \sqrt{S^2 - P^2} \quad (4)$$

and apparent power is defined as:

$$S = UI = \sqrt{P^2 + Q^2} \quad (5)$$

At nonsinusoidal conditions there is, more or less, a general agreement on using [4]:

$$S = UI \quad (6)$$

It is usual to denote this expression of reactive power by Q_B. The power triangle is generally not satisfied by this definition so another quantity D must be defined to determine the relation between apparent power, reactive power and active power:

$$D^2 = S^2 - P^2 - Q^2 \quad (7)$$

However, the definition proposed by Budeanu is generally regarded as impractical for real-world applications [3, 4]. Moreover, as previously mentioned, reactive power is not derived from a single physical phenomenon; rather, it is a mathematically defined quantity. Despite this, it possesses several valuable characteristics and meaningful physical interpretations, particularly under sinusoidal conditions [5].

Preferred measurement and metering methods

Modern and future digital power and energy meters equipped with frequency analysis capabilities open up new opportunities for power measurement. Traditional metering approaches can be revised and enhanced, overcoming the limitations and ambiguities of older equipment—particularly when measurement quantities are properly defined for the actual nonsinusoidal conditions present. To ensure meaningful and consistent results, it is important to identify the most appropriate measurement methods and quantities, distinguishing them from the wide range of theoretical possibilities. This chapter explores the pros and cons of a metering approach that distinguishes the fundamental power components from the remaining parts of the apparent power.

Over the past fifty years, extensive theoretical research has been conducted on power components in nonsinusoidal conditions. In parallel, specialized instruments for power quality measurement have become increasingly widespread. However, the high cost of meters capable of performing the spectral analysis required for measuring many of the proposed new quantities has limited their adoption in revenue metering and permanent installations. With ongoing advancements, sampling techniques are expected to become standard in meters designed for stationary use. As a result, it is now necessary to critically examine the practical applicability of nonsinusoidal power theories.

In power theory research, the primary emphasis has been on identifying the most theoretically accurate or optimal concept [1]. In addition, various specialized power concepts have been introduced to address specific situations or applications [2]. A common approach in many proposed definitions of power components involves decomposing the current into orthogonal components. Among these, the active current i_a is typically defined as the component that would produce active power if the load were purely resistive [3].

$$i = i_a + i_n = \frac{P}{U^2}u + i_n \quad (8)$$

The rest term in can be considered as a generalised reactive or, preferably, non-active current. Since i_a and i_n are orthogonal, the apparent power can be calculated from the rms currents I_a and I_n and the rms voltage, and divided into active and non-active power:

$$S^2 = U^2 * (I_a^2 + I_n^2) = P^2 + N^2 \quad (9)$$

The non-active portion of the current can be further decomposed into additional orthogonal components. When these squared current components are multiplied by the squared voltage, as shown in Equation (9), the result is a set of multifrequency power components. These components can be aggregated - much like the active and reactive power components in sinusoidal conditions - to form the squared apparent power.

From a power system engineering perspective, it is often practical and appropriate to separate the voltage and current - herefore, the power - into the fundamental component and the unwanted harmonic components. This division allows for distinguishing the fundamental power components from the remainder. This approach has been acknowledged by several authors, who have proposed a power definition based on these principles [4].

The suggested definition starts by dividing the rms voltage and the rms current into fundamental and harmonic parts [5,6]:

$$U^2 = U_1^2 + U_N^2 = U_1^2 + \sum_{n>1} U_n^2 \quad (10)$$

$$I^2 = I_1^2 + I_N^2 = I_1^2 + \sum_{n>1} I_n^2 \quad (11)$$

The voltage and current are then multiplied to form the apparent power, and the power components (for balanced circuits) are suggested as:

$$S^2 = S_1^2 + S_N^2 = P_1^2 + Q_1^2 + P_N^2 + N_N^2 + (U_1 I_N)^2 + (U_N I_1)^2 \quad (12)$$

where

$$S_1^2 = P_1^2 + Q_1^2 = (U_1 I_1 \cos\varphi_1)^2 + (U_1 I_1 \sin\varphi_1)^2 \quad (13)$$

$$P_N = \sum_{n>1} U_n I_n \cos\varphi_n \quad (14)$$

$$N_N^2 = S_N^2 - P_N^2 = \sum_{n>1} U_n^2 \sum_{n>1} I_n^2 - P_N^2 \quad (15)$$

$$(U_1 I_N)^2 = U_1^2 \sum_{n>1} I_n^2,\ (U_N I_1)^2 = I_1^2 \sum_{n>1} U_n^2 \quad (16)$$

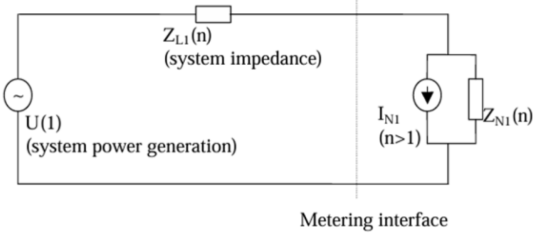
N_N is a harmonic rest term and (16) describes the cross-products between fundamental and harmonic parts. The difference between the apparent power division described above and other suggested power definitions may seem subtle but is quite substantial. The most obvious difference, is that the (total) active power no longer is one of the power components. P1 is one of the components, and P_N is one, and the active power is $P=P_1+P_N$, but $P_2 \neq P_1^2 + P_N^2$ and can not be put into (12). However, as a supplement to the apparent power split above the nonactive power is given as:

$$N = \sqrt{S^2 - P^2} \quad (17)$$

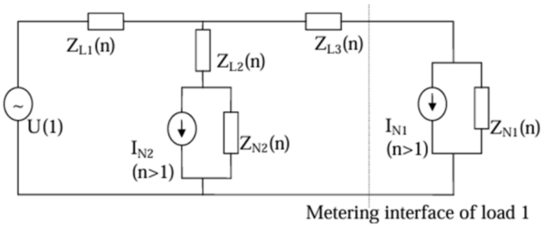
A common and widely used method for dividing the responsibility and costs of power quality issues, including reactive power, is to assign responsibility for voltage to the power distributor and responsibility for current to the consumer [7-9]. This approach functions effectively as long as the voltage and current characteristics do not interact significantly, allowing for a clear separation between cause and effect.

The magnitude of the fundamental quadrature current is primarily determined by the load characteristics, which can be measured as reactive power in the classical sense. As a result, the responsibility for this quadrature fundamental current can be easily assigned to the power consumers. However, a situation may arise where billing for quadrature fundamental current based on classical reactive power metering is unfair. For instance, if two nearby customers have opposing loads - one inductive and the other capacitive - both might be charged for reactive power that ultimately cancels out and causes no issue for the distributor. This situation is rare, particularly given the scarcity of large capacitive loads, and can usually be handled as an exception.

Harmonic current is primarily considered a distribution issue rather than a transmission problem. Most of the challenges associated with harmonics are of a local nature, as the interaction between different loads can lead to current cancellation, which in turn reduces the overall harmonic current level from groups of loads. This localized effect makes harmonic mitigation more manageable within the distribution network, rather than requiring large-scale changes at the transmission level. Figure 1 and Figure 2 demonstrates the metering problems due to the interactions between loads, especially between load currents. From Figure 3 it is evident that the relative sizes of the impedance of the lines and/or the impedance of transformers, Z_{L1}, Z_{L2} and Z_{L3}, will very much determine the current level in the metering point of a load. Distribution transformers often play a significant role in determining the impedance seen by harmonic current sources and can act as a barrier to harmonic currents to some extent. As a result, consumers who share a distribution transformer are more likely to experience greater harmonic current interaction, leading to higher harmonic current amplitudes at their metering points, compared to consumers who are not sharing the same transformer. This current cancellation and interaction are especially noticeable for harmonics of order greater than 10, where the phase angles naturally spread more widely, leading to more pronounced effects [10].



a) simple load-source model for the case of one large non-linear load



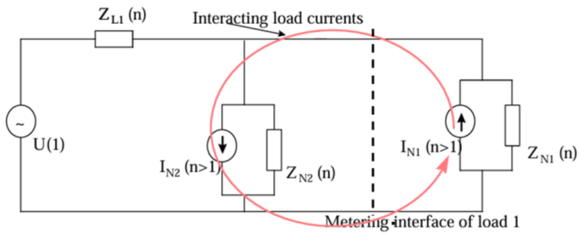
b) Load-source model, load 1 is studied, all other loads are lumped together into one extra load, and the system impedance divided into three parts. Normal case: *ZL3(n)>ZL2(n)>ZL1(n)*

Figure 1. Load-source models describing the metering of a non-linear load

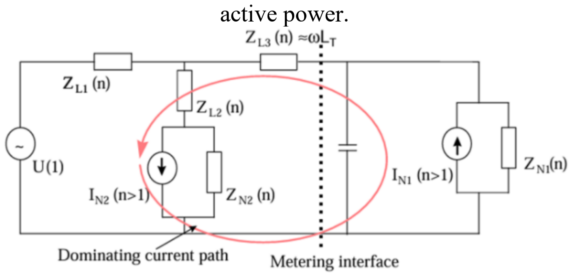
In Figure 2a, a nearby load generates current with an opposite sign, resulting in a high harmonic current level at the metering point. However, since this harmonic current is driven by both loads and does not pass through any significant impedance, the measured harmonic voltage and active harmonic power remain negligible. Additionally, the harmonic current flowing through the system impedance is also minimal, meaning that despite the high harmonic current at the metering point, it will not pose any issues for either the distributor or other loads.

On the other hand, if the load currents were of the same sign, the currents would likely add together, passing through the system impedance and generating higher active harmonic power in both the studied load and the nearby load. In this case, the harmonic voltage and active harmonic power would be significantly higher—approximately twice as much as if the metered load were the only nonlinear load in the area. Therefore, the active harmonic power generated by a nonlinear load is strongly influenced by both the system impedance and the presence of neighboring nonlinear loads [11].

Power measurement techniques for non-sinusoidal situations



a) Load-source model, loads electrically close, *ZL3(n), ZL2(n)<< ZL1(n),* resulting in high harmonic current and (in this case) low harmonic voltage and low harmonic active power.



b) Load-source model, at transformer-compensator resonance conditions.

Figure 2. General load-system circuit diagrams for nonsinusoidal conditions showing the problems of the harmonic metering of a load for responsibility sharing purposes

Resonance risks, as shown in Figure 2b, further complicate the situation. The use of capacitors to compensate for fundamental reactive power typically reduces most harmonic voltage levels in the system by providing a low-impedance path for harmonic currents. However, in the event of resonance, the harmonic current and/or harmonic voltage levels can actually increase, particularly in localized areas. A power consumer with a significant motor load and compensating shunt capacitors might find themselves part of a resonance circuit driven by harmonic currents from another consumer. In this case, the consumer will experience high harmonic current and voltage levels, even if their load is not significantly nonlinear [12].

Typically, active harmonic power meters will indicate positive harmonic power in such scenarios. Much of the harmonic losses in the system will occur in the transformer closest to the load. Therefore, the amount of harmonic power measured will depend on where the metering is placed relative to the transformer. Another metering challenge arises with the third harmonic and other harmonics that exhibit a zero-sequence character, as they are usually trapped by the distribution transformer. As a result, the measured harmonic current will vary depending on whether the measurement is taken on the primary or secondary side of the transformer.

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3. Conclusion

The conclusion is that while harmonic current meters can provide an indication of whether a load generates harmonics, they are unreliable for a full analysis. Active harmonic power metering, on the other hand, can help determine whether the harmonic current from a load is primarily caused by that load or if it is influenced by external factors. However, neither of these methods provides a complete picture of the behavior within the load or the broader power system.

The responsibility for harmonics can be approached in two ways. The first approach is to establish that the consumer's responsibility for current is always stricter than the distributor's responsibility for voltage. In this case, resonance or significant interaction would be considered the consumer's responsibility, and harmonic current could always be billed for or subject to limits (this could also be reversed, where a harmonic voltage above a set limit becomes the distributor's responsibility and cannot be billed to the consumer, requiring resolution by the distributor). While this is the simplest solution, it can sometimes be unfair, as illustrated earlier.

The second approach involves using a measurement method that distinguishes between imported and exported harmonic current problems. Ideally, this would involve a comprehensive load and system characterization. While accurate measurement of active harmonic power can differentiate between imported and exported harmonic currents, it cannot alone provide a complete characterization of the situation.

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Study of the theoretical failure model of the NPM-69-M microelectronic block

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Abstract: The article addresses the question of studying the paired axis control model of a microelectronic block, obtaining the numerical value of the operational failure intensity (EIO) of a microelectronic block, studying the theoretical model of failures, obtaining the eio numerical values of a microelectronic block. One of the most dynamically developing industries in the modern world is mirkroprotssesor and microelectronic systems. Important when processing information resources and exchanging information between the device and users, these systems play an important role. The hardware supply structure of these systems is enriched by a new integrated circuit and equipment day by day, in exchange for the rapid development of semiconductor technology. These tools and systems are the main technical component of the activities of most small and medium-sized industrial enterprises, as well as large industrial sectors that use modern work organization solutions. The introduction of similar systems into practice in the railway industry, which is calculated from such large industries, does not remain without contributing to the development of the industry. In particular, the issue of replacing electromagnetic relays with microelectronic devices, which were commissioned in the 60s of the last century in most of the railway lines currently in use in our country in railway automation and telemechanics systems, is considered in this article. To address these issues, NPM-69-m studied and analyzed the failure rate of the block under investigation, as well as the rate of qisim failure, which is twice as high as similar indicators of other components of the NPM-69-m microelectron block.

Keywords: NPM-69-M microelectronic block, electrical/radio products (ERP), basic failure rate (BFR), mathematical model of the OFR

1. Introduction

Ensuring safe control of the train movement process is mainly entrusted to the automation and telemechanics devices of railway transportation. Until recently, the safety requirements for these systems have been met by the use of safe elements, in this case by the use of railway relays of the first reliability class installed in devices and assemblies directly related to the movement of trains. In the objects of railway automation and telemechanics not directly related to the movement of trains, and which are not subject to safety requirements are used electromagnetic relays of lower reliability class, such as code type KDR. Further use of electromagnetic relays in control systems is a very problematic solution because these devices have high material intensity, power consumption, as well as continuously increasing cost indicators.[1]

Train delays caused by malfunctions of signalling equipment are tangibly reflected in the form of economic losses. The main part of the equipment ensuring the safety of train traffic consists of devices and instruments whose service life has exceeded 50 years, this explains the short-term damages caused by the state of morally and technically obsolete equipment, it is especially reflected in the quality of the contact group of used relays. In this connection, the solution of innovative tasks on creation and implementation of microelectronic technologies and modules made on their basis in the existing automation systems of railroads, is an actual scientific task. The use of achievements of modern microelectronic technologies allows to provide more effective and safe control of the transportation process [2]. Reliable operation of such systems is possible in the presence of sufficient, reliable and timely information about the state of railway automation and telemechanics devices [3]. In this situation, great importance is given to the problems associated with the introduction of computer technologies, microcontrollers in devices and systems of railway automation and telemechanics, in order to replace by them traditional relay devices and systems. [8.9].

One of the methods of increasing the reliability and reliability of technical means related to optimal train control is the introduction of devices that do not contain mechanical switching, which are directly involved in the setting of train routes. Realization of the innovative project, directed on that in existing system of block route relay centralization, block of control of train and shunting routes (NPM-69), realized on relay, to replace on microelectronic with application of microcontroller and contactless switching devices, which are opto-relay, (NPM-69-M) functional possibilities of which, on control of routes, are completely identical to relay block NPM-69. Having previously developed and investigated the reliability model of the microelectronic device [10,11.12].

2. Research methodology

To achieve the set goal it is necessary to determine the reliability indicators of means of realization and algorithm of electric circuits operation when setting train and shunting routes, with the help of microprocessor unit of the set group.

The relevance of the study of the failure model of the microelectronic unit NPM-69-M, is determined by the need to replace the existing unit, made with the use of electromagnetic relays, and assess its operational failure rate (OFR).

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The purpose of the work is to study the fault model of the microelectronic block NPM-69-M, in order to obtain numerical values of OFR.

Objects of the study are theoretical models of OFR of means of realization of the microelectronic block, namely microcontroller, optorele, resistors, connecting elements and printed circuit board.

Scientific novelty, consists in determining the numerical value of OFR of the proposed microelectronic block NPM-69_M, assuming that it consists of separate groups of complex products, the total flow of failures, which is made up of independent flows of failures of component parts of ERP, the mathematical model for calculating the failure rate is [6].

$$\lambda_э = \sum_{j=1}^{m} \lambda_{бj} \times \prod_{i=1}^{n_j} K_{ij}$$

where $\lambda_{бj}$ – initial (baseline) failure rate of the j-th failure stream;

m – number of independent failure streams of the components of the microelectronic block;

K_{ij} – coefficient that takes into account the influence of the i-th factor in the j-th failure flow;

n_{ij}– number of factors considered in the j-th failure flow.

The proposed models for calculating the operational failure rate apply to the perpod of constant failure rate in time.

The value of the operational failure rate of a separate group of electro-radio products (ERP) is determined by a mathematical expression, which has the following form [7]

$$\lambda_э = \lambda_б \times \prod_{i=1}^{n} K_i$$

or

$$\lambda_э = \lambda_{б.с.г.} \times \prod_{i=1}^{n} K_i$$

In doing so $\lambda_б(\lambda_{б.с.г.})$ – basic failure rate (BFR) of ERP, revealed on the basis of the results of tests of radio products for reliable operation and durable time resource, the value of which is given in reference books;

K_i – the value of coefficients determining the change in EER depending on a variety of factors;

n – multiple factors.

The following groups of elements, namely microcircuits (PVG-612 optocouplers, microcontroller), resistors, connecting wires, through-holes, board) were used in the implementation of the microelectronic unit NPM-69-M. To determine the OFR of integrated circuits, the mathematical model is used

$$\lambda_{э.м.сх} = \lambda_{б.м.сх.} \times K_{с.т.} \times K_V \times K_{корп} \times K_p \times K_э \times K_{пр}$$

where $\lambda_{б.м.сх.}$ – basic intensity of microcircuit failure, with the following coefficients used:

$K_{с.т.}$ – justifies the complexity of integrated circuits (IC) and the temperature of its operation value of the coefficient reflects the complexity of the IC and ambient temperature, is taken depending on the configuration and temperature, the parameter under consideration is proportional to the complexity of the device, the analysis of Table 7, [3] showed that the more elements, the greater the value of this coefficient takes, assume that the microcontroller used STM type has the most complex device with a number of elements above 250 000.

Then $K_{ст} = 10.06$ for a temperature of 25°C, since the device is operated indoors, it is therefore assumed that$K_{с.т.} = 1$ [3];

K_V – value of applied supply voltage for CMOS microcircuits, for devices with power supply up to +5V, it is taken equal to 1 [3];

$K_{корп.}$– housing type of the used IC is assumed to be equal to1 [3];

K_p – mode index is necessary to determine the available EI according to the conditions of product application in the microelectronic unit, it is determined in the known tables of reference books, mode index, for a set of products is revealed by known analytical expressions $K_p = 1$. [8];

$K_э$ – operation coefficient reflects the level of rigidity of the object operation conditions, when the microelectronic unit is placed in the station room, the value of $K_э$=1 [4];

$K_{пр}$ – acceptance coefficient of the product, i.e. the rigidity of requirements for quality control and operation is taken into account, the unit under study can be attributed to products with acceptance '5', so the value of $K_{пр} = 1$ [4].

In the considered device optocoupler microcircuits and microcontroller were used. Numerical values of operational failure rates of these devices are given in [5], therefore it is necessary to determine the number of these elements, for the device under consideration. In the microprocessor unit NPM-69-M one microcontroller is used, therefore $\lambda_{э.мк.} = 0{,}023 \bullet 10^{-6}\ 1/о$. The operating IO of the optocoupler [5] is assumed to be equal to

$\lambda_{эопт} = 0{,}0029 \bullet 10^{-6}, 1/о$, taking into account the number of optocouplers used,$m = 65$ we get $\lambda_{эопт} = 0{,}1885 \bullet 10^{-6}, 1/о$.

$\lambda_{э.} = \sum_{j=1}^{m} \lambda_{бj.} \bullet \prod_{i=1}^{n_i} K_i$, 1/о.,

The total EI of a microelectronic unit should be calculated according to the formula, where, in order to simplify its designation, we take as an index the variable k

$$\lambda_k = K_a \bullet \sum_{j=1}^{m} \sum_{i=1}^{n} \lambda_{эij},$$

where K_a– the degree of quality of hardware production;

$\lambda_{эij}$ – IE of the i-th type of products of the j-th group;

n– list of objects of the j-th group;

m – number of product groups.

Hardware manufacturing quality index K_a, takes into account the requirements for the preparation and adjustment of the technical process of production and the degree of its realisation, in the equipment and reflects the average probability difference in the IE produced according to the requirements, in the case of a microelectronic block, is taken to be equal to 1.

Hence, for the block НПМ-69-М

BIO can be represented as the sum of the base scores of the constituent elements.

$$\lambda_{б.к.} = \lambda_{б.мк.} + \lambda_{б.оптр.} + \lambda_{б.рез.} + \lambda_{б.плата.} + \lambda_{б.соед.} \quad (1)$$

Here with $\lambda_{б.нпм}$ – BIO block NPM-69-M;

$\lambda_{б.мк.}$ – BIO microcontroller;

$\lambda_{б.рез.}$ – BIO resistors;

$\lambda_{б.оптр.}$ – BIO optocouplers;

$\lambda_{б.плам.}$ –BIO board;

$\lambda_{б.соед.}$ – BIO compounds.

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To calculate the OFR of the microelectronic unit NPM-69-M, we use a mathematical model, where in order to simplify its designation, we take as indices the variable$k$.

$$\lambda_{эk} = \lambda_{б.k} \bullet \prod_{i=1}^{n} K_i$$

In doing so.$\lambda_{б.k}$BIO of the microelectronic block NPM-69-M

$K_i -$ coefficients determining the change in EER depending on real factors;

$n -$ number of countable elements used in the block.

To calculate the OFR of the microcontroller block NPM-69-M, the mathematical model is used,

$$\lambda_{э.мк} = \lambda_{б.мк} \bullet \prod_{i=1}^{n} K_i \, , 1/ч$$

To calculate the OFR resistances, we will use the following model[3]

$$\lambda_{э.рез} = m \bullet (\lambda_{б.рез} \bullet \prod_{i=1}^{n} K_i), \; 1/ч$$

where $\lambda_{б.рез.}$- БИО сопротивлений равна $0{,}048 \cdot 10^{-6}$, 1/о;

K_i- coefficients reflecting the peculiarities of resistor operation;

m - the number of resistors used in the microelectronic unit, in this case is equal to 79 pieces.

The following coefficients are used to calculate the IO resistors:

K_R - value of ohmic resistance, for permanent non-wire resistors in the range

R< 1 kOm, is taken equal to 1;

K_M- value of rated power for resistors with power less than 0.5 W is equal to 0.7;

K_S- ratio of the actual voltage to the maximum possible voltage according to the specifications, for the case of $U/U_{макс} \leq 0{,}8$, equal to 1;

$K_{сл}$- the number of elements (complexity) for resistor microcircuits, at n > 20, is assumed to be 1.3;

$K_{стаб}$- manufacturing accuracy (tolerance) of the resistor, in our case is equal to 1;

$K_{корп}$- type of resistor microcircuit housing, in this case equal to 1.

Substituting the numerical values we obtain$\lambda_{э.рез.} = 0{,}048 \times 10^{-6} \times 1 \times 0{,}7 \times 1 \times 1 \times 1 = 0{,}034 \times 10^{-6}, 1/o$

The OFR of the resistors used in the microelectronic unit NPM-69-M is equal to$\lambda_{э,рез.k} = 79 \times 0{,}034 \times 10^{-6} = 2{,}686 \times 10^{-6}, \; 1/o$

To calculate the EIR of the connections during operation is calculated by the model:

$$\lambda_{э.соед} = K_э \bullet \sum_{i=1}^{n} N_i \, \lambda_{б.соед},$$

where $\lambda_{б.соед.}$ - basic value of IO of manual solderpng without twisting of microelectronic block NPM-69-M according to Table 1 [3] equal to $0{,}13 \cdot 10^{-8}$, 1/о;

N_i- number of connections of one type, for this block is assumed to be equal to 150;

n - number, types of connections in the device is equal to 1;

$K_э$ - stiffness index of operating conditions according to Table 2 [3] equal to 1.

Substituting the calculated values, we obtain the OFR of the compounds$\lambda_{э.соед} = 0{,}195 \bullet 10^{-6}, \; 1/o$

To calculate the EI of the board, let's determine the EI of multilayer boards with metallised holes during operation, which is calculated by the formula below:

$$\lambda_{э.платы} = \lambda_{б.платы} \bullet K_{э.платы} \bullet [N_{i.платы} \bullet K_{с.платы} + N_{2.платы} \bullet (K_{с.платы} + 13)],$$

In doing so. $\lambda_{б.платы}$- BIO depending on the connection technology. According to Table 2 for printed wiring is assumed to be equal to $0{,}0017 \times 10^{-8}$, 1/о;

$K_{э.платы}$- the coefficient of rigidity of fee application conditions is assumed to be equal to 1;

$N_{i.платы}$- number of through holes soldered by the wave, in this case it is assumed to be 0;

$N_{2.платы}$- number of through holes soldered by hand solderpng, based on visual inspection of the board, we take 120;

$K_{с.платы}$- coefficient depending on the number of layers in the board, with the number of layers equal to 2, $K_{с.платы}$=1

Substituting the obtained values, we obtain the OFR of the board with metallised through holes at operation

$$\lambda_{э.платы} = 238 \bullet 10^{-6}, \quad 1/o$$

To obtain the OFR of the whole microelectronic unit NPM-69-M, it is necessary to sum up the OFR of all components, then we obtain

$$\lambda_{э.k.} = 241{,}1 \bullet 10^{-6}, 1/o$$

The main contribution determining the value of the OFR of the investigated NPM-69-M block is the OFR of the board under consideration, which is two orders of magnitude higher than similar indicators of other components of the NPM-69-M microelectronic block.

3. Conclusion

As a result of development and research of the mathematical model of reliability of the microelectronic control unit for shunting and train routes NPM-69-M, the indicators of operational failure rate of the constituent elements of the unit are obtained and the operational failure rate of the whole unit is calculated. As a basis for calculations the basic failure rate is taken in accordance with the data given in ‘Reference book. Reliability of Electrical and Radio Produc.

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Methods of increasing the service life of gas turbine engine turbine blades

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Abstract: The article discusses methods for increasing the service life of turbine blades of gas turbine engines (GTE). These blades are important components operating at high temperatures and loads, and various technologies are used to increase their durability. The main methods include the application of hardening coatings, the use of new heat-resistant materials, and chemical and physical coating technologies. In the aviation industry, the issues of improving the efficiency of aircraft engines and their long-term operation are of significant importance. The service life of each aviation engine, its maintenance, and operational costs primarily depend on the strength of its main components. This is especially true for turbine blades, which are among the most loaded parts of a gas turbine engine, as they operate under extreme temperature and stress conditions. At temperatures of 1500°C and above, the blades can be subjected to deformation or damage due to high thermal and mechanical stresses. Methods such as PVD and CVD are used to apply high-temperature and corrosion-resistant coatings to the surface of the blades, which ensures their long-term and efficient operation. The article also provides detailed information on the advantages of these coating technologies and their impact on turbine components.

Keywords: substrate, blade, gas turbine engine, main components, corrosion-resistant, coating

1. Introduction

A gas turbine engine (GTE) is a device that converts the chemical energy of fuel into mechanical energy through combustion. The main operating principle of a GTE is as follows: air is compressed in a compressor, mixed with fuel in the combustion chamber, ignited, and the expanding gases rotate the turbine, performing useful work. Gas turbine engines are widely used in aviation, power generation, shipbuilding, and industry.

The components of a gas turbine engine operate under extremely harsh conditions, so they are subject to very high requirements. Especially important characteristics include heat resistance, retention of strength at high temperatures, and resistance to corrosion.

The components of a gas turbine, especially turbine blades, operate at very high temperatures. Since these parts are in direct contact with the gases formed during fuel combustion, the materials from which they are made must have high heat resistance. To improve engine efficiency, it is important to maximize the gas temperature before the turbine while preventing part deformation.

Gas turbine components operate at temperatures of 1000–1500 °C and higher, so resistance to deformation is critical. Heat resistance is the ability of a material to deform slowly under mechanical stress when exposed to high temperatures for an extended period.

2. Research methodology

Turbine parts in direct contact with hot gases function in a highly oxidizing and chemically active environment. This is due to the effects of oxides, sulfides, and other harmful chemical compounds formed during fuel combustion. Corrosion can significantly reduce the service life of GTE components and weaken their structural integrity. Figure 1 shows a general view of a gas turbine engine.

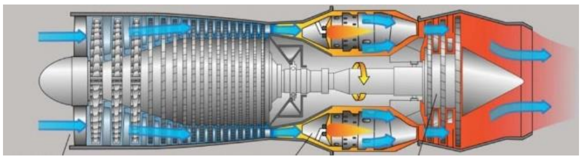

Figure 1. General view of a gas turbine engine (GTE)

Main Advantages of Using Gas Turbine Engines (GTE) in Aviation:

1. Gas turbine engines are lightweight and have high power output. Therefore, they are widely used in aviation.
2. At high operating temperatures, efficiency increases, which reduces fuel consumption and makes the engine more powerful. Modern GTEs operating at elevated temperatures are especially more efficient.
3. A gas turbine can operate at very high rotational speeds, which ensures fast and efficient energy production.
4. Gas turbines are very compact and do not require much space, making them ideal for use in aviation and military technology.
5. GTEs have few moving parts inside, which reduces vibration levels. This contributes to longer service life.
6. Gas turbine engines can operate efficiently on various types of fuel, including natural gas, kerosene, and other liquid fuels.

Disadvantages:

1. For efficient operation, a GTE must function at very high temperatures. This requires materials with high thermal resistance, which increases manufacturing costs.
2. Gas turbine engines require complex and expensive technologies. Their production and maintenance demand significant investment.
3. GTEs lose efficiency at low loads. When operating under low load conditions, fuel consumption increases significantly.
4. Components operating under high temperatures and stresses can wear out or become damaged over time, requiring costly and complex maintenance.

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5. Due to the high temperatures, GTE cooling systems become complex and sensitive. Internal cooling channels and thermal coatings help address this issue, but their production and repair add to the overall costs.

6. GTEs require high-quality fuel. With low-quality fuel, efficiency decreases and the risk of corrosion increases.

Relevance of Using Gas Turbine Engines (GTE):

Aircraft Engines: GTE technology is a crucial part of aviation. Most turbofan, turbojet, and turboprop engines in aircraft are based on gas turbine technology. For aircraft engines, high power and compact size are essential, which highlights the advantages of GTEs.

Fuel Efficiency: Next-generation gas turbine engines have high fuel efficiency, allowing airlines to reduce fuel consumption and decrease harmful emissions into the atmosphere.

Low Noise and Vibration Levels: Gas turbine engines produce relatively low noise and vibration levels, contributing to the ease and comfort of operating aircraft.

What Methods Can Increase the Service Life of Gas Turbine Blades?

It is crucial to extend the service life of gas turbine engine (GTE) blades, as they operate under high temperatures, pressures, and in an aggressive environment. Blades are expensive and complex components, so prolonging their lifespan enhances the overall efficiency and reliability of the engine.

Protective Coatings for Turbine Blades to Extend Service Life

Why Apply Coatings?

The technology of protecting turbine blades with coatings helps significantly extend the service life of a gas turbine engine (GTE). The turbine blades operate in environments exposed to high temperatures from gas flows and aggressive conditions, which is why they are protected by special coatings that offer high thermal resistance and corrosion resistance.

Various coating application technologies are used to protect turbine blades and other GTE components. Each type of coating serves specific protective functions and significantly increases the material's service life. Thermal barrier coatings, coatings resistant to oxidation and corrosion, diffusion coatings, and multilayer coatings are considered the most effective. These coatings play an important role in enhancing the efficiency of the gas turbine and reducing maintenance costs.

Corrosion-Resistant Coatings

In aggressive environments, especially when interacting with high-temperature chemicals, material protection against corrosion is required. Alloys based on aluminum (Al), chromium (Cr), and platinum (Pt) are used for corrosion protection. These coatings are applied to protect any turbine parts that may be affected by heat and fuel combustion.

Oxidation-Resistant Coatings. It is very important to prevent the oxidation process of materials in high-temperature environments. Oxidation-resistant materials such as aluminum (Al), chromium (Cr), and others are used for this purpose. Oxidation-resistant coatings are primarily applied to turbine blades and combustion chambers.

Diffusion Coatings. These coatings alter the chemical properties of the material, enhancing its strength and resistance to corrosion and oxidation. Aluminum coatings are used for this task. At high temperatures, aluminum oxidizes to form an aluminum oxide (Al2O3) layer, which protects the material. Platinum coatings improve the material's heat resistance and its protection against oxidation. These coatings are widely used to strengthen both the internal and external parts of turbine blades.

Multilayer Coatings. These coatings consist of several protective layers, each serving its own function. For example, the inner layer may protect against oxidation, while the outer layer provides thermal protection. Such coatings are applied to GTE components that operate in the most complex and demanding conditions. The table below presents some of the micro-hardening compositions used as coatings (Table-1).

Table 1

Microhardness of carbides and nitrides

Coating material	Cr2C2	TiN	TiC	Mo_2C	TaN
Microhardness	33	35.7	16	26.7	27
Coating material	TaC	ZrN	ZrC	VC	VN
Microhardness	38.6	25	27	18.5	29

Carbides (e.g. WC, TiC) are compounds of carbon with metals.

Nitrides (e.g. TiN, AlN) are compounds of nitrogen with metals.

Presents the chemical composition of multicomponent heat-resistant coatings. These coatings are widely used in **aviation engines. (Table 2)**

Table 2

Chemical Composition of Multicomponent Heat-Resistant Coatings

Coating type	Concentration of elements, %			Concentration of elements, %		
	Ni	Co	Cr	Al	Ti	Others
Ni-Co-Cr-Al-Y	60,4	10,2	12,4	16,0	0,5	0,5Y
Ni-Co-Cr-Al-Y	35,5	33,2	25,4	4,9	-	1Y
Co-Cr-Al-Y	-	63,6	22,9	12,7	-	0,8Y
Ni-Cr-Al-La-Y	56,2	2,5	32,1	5,6	0,7	0,8Y
Ni-Cr-Fe-Si-B	62,8	-	29,0	-	-	4,6Si; 3,5Fe; 0,05B

Various technological methods are used to obtain coatings. Among them are physical and chemical methods for applying protective coatings. Let's examine these methods below.

PVD (Physical Vapor Deposition) is a coating technology that uses physical evaporation, where solid materials (metals or ceramics) are evaporated in a vacuum environment and then condense onto the surface of the coating. This is a method for applying thin layers of material (1–5 microns) without chemical reactions, relying solely on physical processes (evaporation). This method is widely used in aviation, mechanical engineering, and other industries.

The evaporation of a solid material occurs by heating it in a vacuum chamber. The evaporated material condenses on the substrate (base surface), forming a thin, uniform, and durable coating. The evaporation and condensation process takes place in a vacuum, which prevents contaminants from the air from entering the coating. Materials such as TiN (titanium nitride), CrN (chromium nitride), AlTiN (aluminum-titanium nitride), and ZrN (zirconium nitride) can be synthesized. Ceramic-based materials are used to create coatings resistant to heat and corrosion. Coatings based on a mix of metals and ceramics are used to improve mechanical and physical properties.

The PVD technology offers wide opportunities for creating high-quality and durable coatings. The use of PVD coatings in aviation and other industries enhances the durability of components, increases their resistance to wear and corrosion, and contributes to improved cost-effectiveness.

Table 3

Principles of Coating Application and Use of PVD Methods

PVD Method	Principle	Application	Advantages	Disadvantages
Magnetron Sputtering (Sputter Deposition)	Argon ions strike the surface, directing atoms onto the substrate.	TiN, CrN, Al_2O_3 coatings	High-quality thin layers	Low deposition rate (1–3 µm/hour)
Arc Evaporation	An electric arc evaporates the surface, creating plasma.	TiAlN, ZrN (for hard cutting tools)	Very hard layers (~3000 HV)	Microdroplets (surface defects)
Electron Beam (EB-PVD)	An electron beam melts the surface, forming vapor.	Turbine blade coatings	Thick layers (10–100 µm)	Requires high temperature (>600°C)
Pulsed Laser Deposition (PLD)	A laser interacts with the surface, forming vapor.	Oxides (MgO, ZnO), superconductors	Nanocomposites with precise composition	Expensive and slow process
Ion Plating	Material is ionized and deposited onto the substrate.	Widely used in aviation	Coatings with high hardness and adhesion	Requires specialized and complex equipment

CVD (Chemical Vapor Deposition) is a method of obtaining coatings through chemical vapor deposition, which is widely used for producing hard coatings, ceramic materials, and coatings resistant to high temperatures. This technology involves the deposition of solid materials in the form of thin or thick layers onto the surface of a substrate through chemical reactions in the gas phase. The process typically takes place at high temperatures (800–1000°C) and low pressure. The CVD technology is applied in various industries, particularly in aviation, microelectronics, optics, and the production of hard materials.

Special gases, typically consisting of metal or ceramic precursors (reactive substances), are introduced into the reactor chamber. These gases settle on the surface of the substrate and initiate chemical reactions. Under the influence of high temperature, the gases react chemically. As a result of this reaction, a solid material is deposited onto the substrate, forming a coating. Usually, these are metals, carbides, nitrides, or oxides. By-products of the reaction (usually in gas form) are removed from the reactor chamber without affecting the quality of the coating.

The CVD technology allows for the production of high-quality and durable coatings; however, it requires high temperatures and expensive equipment. Nevertheless, due to its widespread application and numerous advantages, CVD technology plays an important role in industry and scientific research.

Table 4

Principles of Coating Application and Use of CVD Methods

CVD Type	Principle	Advantages	Disadvantages	Application
Atmospheric Pressure CVD (APCVD)	CVD process carried out at atmospheric pressure.	Cheaper, can coat large parts.	Coating may be uneven.	Mass production, optics, electronics.
Low Pressure CVD (LPCVD)	CVD process carried out at low vacuum pressure.	High-quality, uniform coating.	Slow process, requires high temperature.	Semiconductors, microelectronics.
Plasma-Enhanced CVD (PECVD)	Coating process with accelerated chemical reactions using plasma.	Coating at low temperatures, high efficiency.	Plasma control is complex, requires sophisticated equipment.	Microelectronics, optical coatings, medical instruments.
Metal-Organic CVD (MOCVD)	CVD technology using metal-organic precursors.	Very high precision, produces thin coatings.	High cost, requires complex reactors.	Semiconductors, LEDs, optoelectronics.
Hot-Wall CVD	CVD process carried out with heating of reactor walls.	Good heat distribution, easy to achieve uniform coating.	Coating may deposit on reactor walls, slowing the process.	Turbines, corrosion-resistant coatings.
Cold-Wall CVD	CVD process carried out with only the substrate being heated.	Fast coating process, energy-saving.	Difficult to achieve uniform coating.	Hard coatings, microelectronics.

PVD (Physical Vapor Deposition) and CVD (Chemical Vapor Deposition) Coating Methods: A Technological Comparison

Coating Formation Method: In the PVD method, the material is physically evaporated and deposited on the substrate surface. This process is usually carried out in a vacuum environment. In the CVD method, gases undergo a chemical reaction on the surface of the substrate (the base material), forming a solid coating. This process occurs at high temperatures.

Process Temperature: PVD is typically carried out at relatively low to medium temperatures (200–500°C). The CVD method requires high temperatures (600°C and above).

Process Type: In the PVD method, the process is physical, with atoms or molecules of the material being deposited on the substrate surface. In the CVD method, the coating is formed through chemical reactions.

Vacuum and Atmosphere: The PVD method requires a high vacuum. The CVD method can be performed at atmospheric pressure or in a vacuum.

Coating Thickness and Quality Control: Coatings obtained using the PVD method are typically thin and smooth but may encounter difficulties when coating complex shapes. The CVD method allows for the production of thicker coatings and is effective for coating components with complex geometries.

By-products Emitted into the Atmosphere: The PVD method does not produce harmful by-products. In the CVD method, toxic by-products may be generated, requiring additional devices for their removal.

Applications: The PVD method is used for obtaining thin coatings made of metals and ceramic materials, primarily for decorative, wear-resistant, and corrosion-resistant coatings. The CVD method is used for producing high-quality and hard coatings in aviation, microelectronics, optics, and other industries.

3. Conclusion

Increasing the reliability of turbine blades is a critical task that directly impacts the reliability of aviation engines and flight safety. One of the most advanced methods for improving the reliability of blades is the PVD method. The PVD method is environmentally friendly, performed at relatively low temperatures, and allows for coatings of various shapes.

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Analysis of the current status of the throughput and processing capabilities of the “Q” station

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Abstract: The aim of the work is to systematically analyze the current state of the throughput and processing capabilities of the railway station “Q” and objectively evaluate the results. To achieve this goal, a new approach to assessing and systematically analyzing the throughput of the technical equipment of the station, developing a digital system for monitoring the performance of the station’s performance indicators, taking into account the causes of explicit and hidden losses in regulating the dwell times of transport flows, and calculating throughput capacity (Figure 1) is proposed. This has created an opportunity to increase the throughput and processing capacity of the station, and improve the timely and safe delivery of cargo and passengers.
Keywords: throughput capacity, processing capacity, system analysis, regional railway junction, digitalization

1. Introduction

One of the important issues in the further development of any state transport network is the development of appropriate measures to timely eliminate identified shortcomings based on a systematic analysis of its current state and an objective assessment of the results.

Many regulatory documents are also being adopted in various sectors to develop the transport network of the Republic of Uzbekistan. In particular, the “Uzbekistan – 2030” strategy [1] focuses on the development of the transport network (transition to market principles in the provision of passenger and freight railway transport services, attraction of private and foreign operators to the sector, and increase of transport and transit capacity) and the Resolution of the President of the Republic of Uzbekistan “On measures to radically reform the railway transport sector of the Republic of Uzbekistan” No. PQ-329 [2], which focuses on improving transport processes by creating competition in the railway transport services market and creating an attractive investment environment.

With the opening of new transport corridors and the construction of new routes (including the construction and operation of the China-Kyrgyzstan-Uzbekistan and Uzbekistan-Afghanistan-Pakistan railways), it is urgent to increase the throughput and processing efficiency of railway stations and sections. Therefore, the current state of the “Q” station, part of the “Karshi” regional railway junction branch under the “Railway Infrastructure” of “Uzbekistan Railways” JSC (“O‘TY” JSC), was analyzed. In particular, a systematic analysis of the station’s throughput and processing capabilities of wagon flows was carried out.

2. Research methodology

Many scientists have conducted scientific research in different years to determine and increase the throughput and processing capabilities of railway stations [3, 4, 5]. In this regard, they used various calculation methods. However, no calculations have been carried out that systematically take into account the influence of the parameter of unevenness of transport flows on the technology of station operation. For example, in the work [4], the author proposed to develop a methodology for assessing and analyzing the throughput of technical devices of stations when calculating wagon flows.

The throughput of the station’s throats is traditionally determined by the following formula

$$N_{throuhgput,capacity} = \frac{1440 \cdot k_{tx} -}{t_{busy} -}$$

there

t_{busy} – throat activity during the day with all types of activities, minutes;

k_{tx} – coefficient taking into account the maintenance time of the throat elements, 0,85÷0,95.

General directional movements for equivalent wagon flows n={1, 2, …, i; 400, 450, …, j} (1-jadval), Time to pass through the station's strait and engage in each type of operation $(n_i^j, t_{z(i)}^j)$ will be different$n_1^j \cdot t_{z(1)}^j, n_2^j \cdot t_{z(2)}^j, \ldots, n_i^j \cdot t_{z(i)}^j$

Table 1
The actual number of movements through the station’s throat

Technological processes	Equivalent wagon flow					
	400	450	500	550	…	j
1	n_1^{400}	n_1^{450}	n_1^{500}	n_1^{550}		n_1^j
2	n_2^{400}	n_2^{450}	n_2^{500}	n_2^{550}		n_2^j
3	n_3^{400}	n_3^{450}	n_3^{500}	n_3^{550}		n_3^j
…						
i	n_i^{400}	n_i^{450}	n_i^{500}	n_i^{550}		n_i^j

The duration of all movements of station gates during the day is determined by the following expression for the (t_{busy}^j) equivalent wagon flow

$$t_{busy}^j = n_1^j \cdot t_{b(1)}^j + n_2^j \cdot t_{b(2)}^j + \ldots + n_i^j \cdot t_{b(i)}^j, min$$

there

$n_1^j, n_2^j, \ldots, n_i^j$ – number of movements when accepting loaded routes and sending trains with empty wagons;

$t_{b(1)}^j, t_{b(2)}^j, \ldots, t_{b(i)}^j$ – duration of a specific technological operation, minutes.

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The existing method does not allow taking into account the influence of random factors and the resulting delays and failures in the processing of wagon flows, which leads to errors in estimating the occupancy of the stations.

The throughput of the parks can also be estimated by calculating the throughput of the station's station (Figure 1).

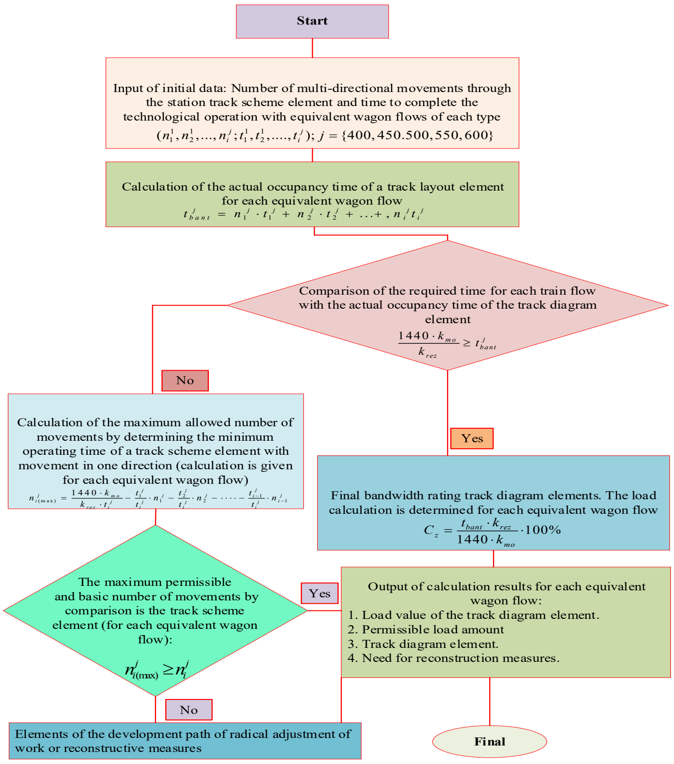

Figure 1. Flowchart of the algorithm for assessing and analyzing the throughput of station technical devices

A new methodological approach (Figure 1) is proposed for calculating and analyzing the throughput capacity of technical devices of power plants. It is based on assessing throughput capacity, identifying the main factors affecting it, and determining the required throughput capacity.

3. Result and discussion

In order to objectively assess the current state of the station's operation (throughput and processing capabilities), a systematic analysis method was used, which allows analyzing all parameters of the station (track capacity, train formation locations, transport (train, wagon) flows, shunting operations, etc.) [3, 4].

Station "Q" belongs to the highest class in terms of its workload. The station borders the following stations (Figure 2): in the odd direction - station Q-yo (single-track, two-way auto-blocking, electrified section); in the even direction - stations T and D (single-track, two-way auto-blocking (Q-D section semi-auto-blocking), non-electrified section (Q-D section electrified)) [6].

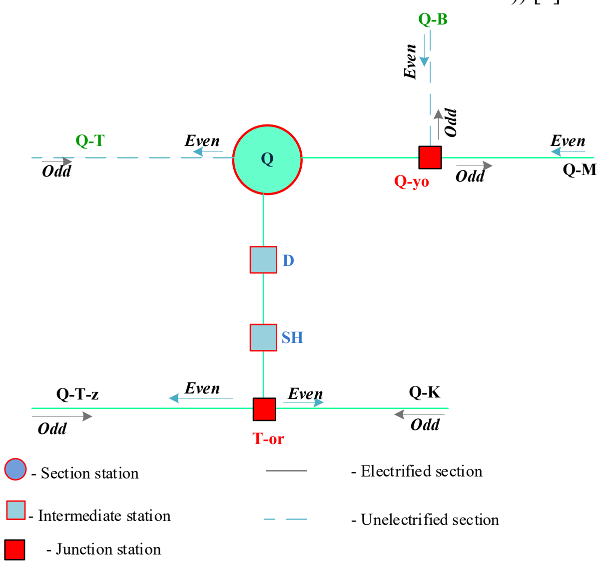

Figure 2. Sections along the border of the "Q" station by train flows in odd and even directions

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The station “Q” consists of 3 fleets with a total of 33 tracks (receiving-dispatching - 10, sorting - 16, dispatching - 7). In a systematic analysis of the station’s wagon flow throughput and processing capabilities, it is important to study the capacity of the station tracks (Figures 3-5).

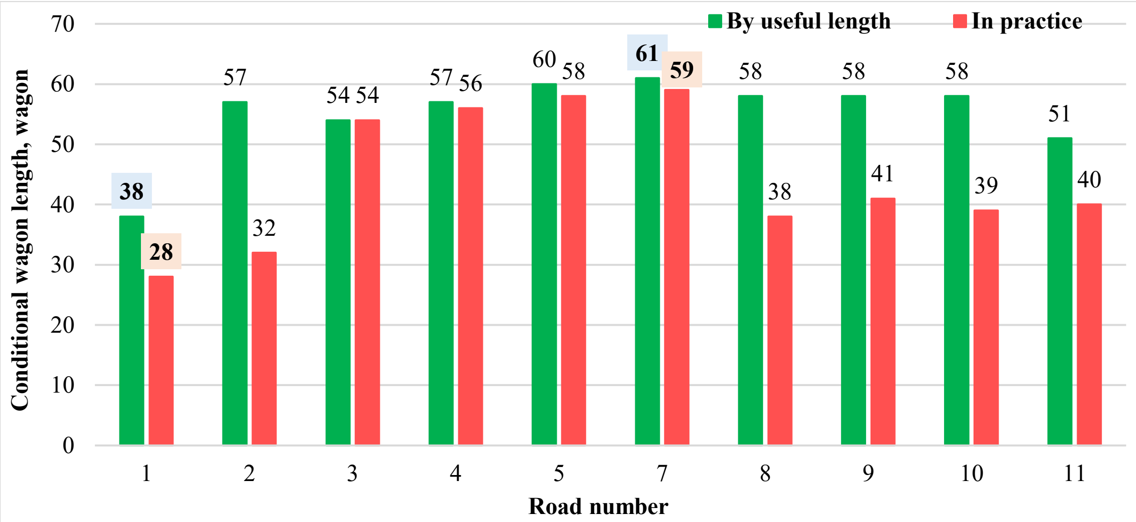

Figure 3. Capacity of the roads of the receiving and sending park of the station “Q”

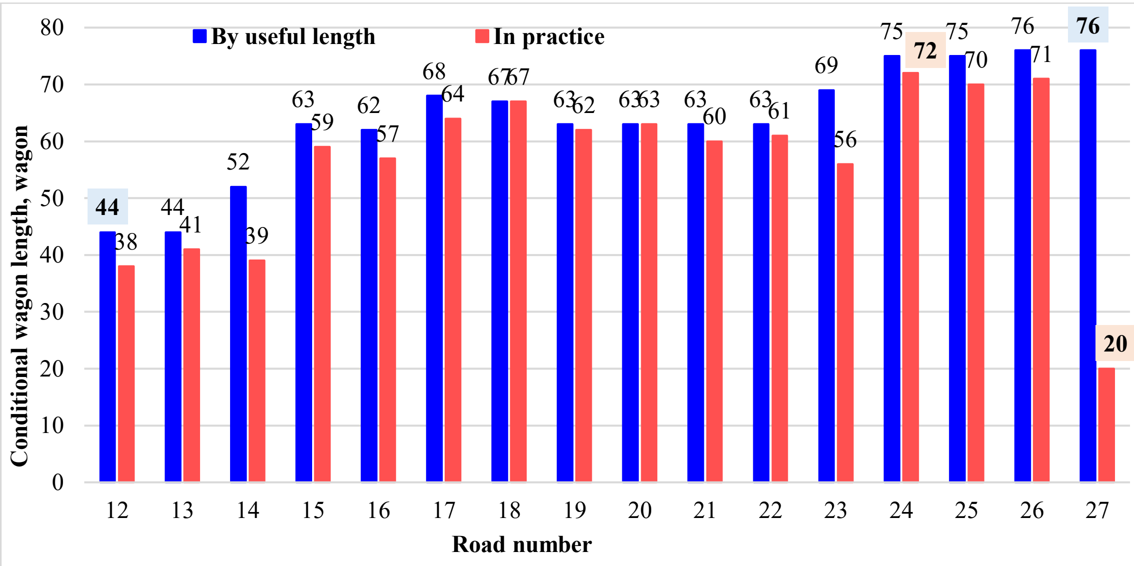

Figure 4. Capacity of the sorting park tracks at station “Q”

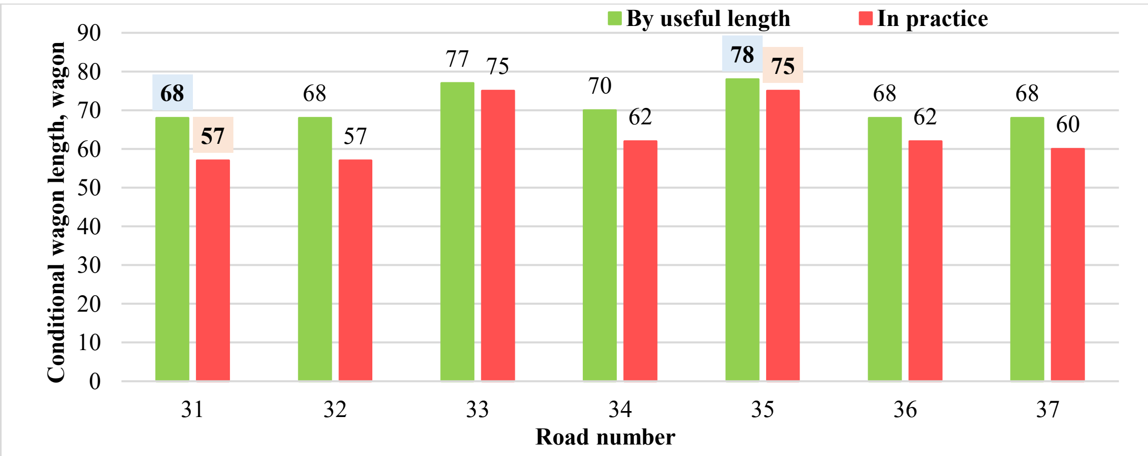

Figure 5. Capacity of the “Q” station dispatch park tracks

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From Figures 3÷5, the following conclusions can be drawn:

The capacity of the receiving-dispatching fleet tracks (Figure 3): According to the Technical Management Act (TBD) – 38÷61 wagons; in practice – 28÷59 wagons;

capacity of the sorting fleet tracks (Figure 4): according to the TBD - 44÷76 wagons; in practice - 20÷72 wagons;

capacity of the dispatch fleet tracks (Figure 5): according to the TBD - 68÷78 wagons; in practice - 57÷75 wagons.

From the results of the analysis, it can be concluded that the capacity of the station tracks is actually underused by 2÷24 wagons. Such situations can be associated with a sharp unevenness of the wagon flows or the categories of trains. For example, on the 8th-11th tracks of the receiving-dispatching fleet, the train weight for the Karshi-Termez (Galaba, Regar, Termez, Sariosiyo) mountainous route is set at 3200÷3500 tons according to the "Train Formation Plan" (PTR). Therefore, it is impossible to fully utilize the capacity of these tracks. On the 12th-18th tracks of the sorting fleet, mainly term trains are formed. On the 19th-26th tracks, passing and section trains are formed.

At the "Q" station, 3 shunting locomotives (VL60 and 2 TEM-2) are used to organize and control wagon flows (Table 1).

Table 1

Information about shunting operations

Locomotive series	Year of manufacture	Tractive power, kgs	Energy (fuel) consumption, daily	Average working time per day, hours	Time spent on shift change, equipment and technological breaks, hours
ВЛ-60	1970	4800	28 kvt	21	3
TEM-2	1975	890-1342	225 kg	22,5	1,5
TEM-2	1975	890-1342	220 kg	22,5	1,5

According to the TFP of "O'TY" JSC for 2024-2025, trains will be formed at the "Q" station to the following destinations (Table 2) [7].

Table 2

Information about freight trains forming at the "Q" station

Compiling station	Receiving end destination station	Conditional length of the composition, wagon	Train category
"Q"	Orenburg	58	Passerby
	Kandiagash	58	Passerby
	Aris	*2 ta group*: 1-group – 58; 2-group – 57.	Passerby
	Kokand	*4 ta group*: 1-group – 57; 2-group – 57; 3-group – 57; 4-group – 57.	Assembled, Section
	Xovos	57	Passerby
	Marokand	*3 ta group:* 1-group – 58; 2-group – 57; 3-group – 57.	Assembled, Section
	Bukhoro I	*2 ta group*: 1-group – 56; 2-group – 57.	Assembled, Section
	Binokor	57	Passerby
	Misken	*3 ta group:* 1-group-56, 2-group-57, 3-group – 57.	Passerby
	Termiz	*2 ta group:*1-group – 40; 2-group – 39.	Assembled, Section
	Kumkurgan	*6 ta group:* 1- va 5-group – 42; 2- va 3-group – 40; 4-group – 38; 6-group – 56.	Assembled, Section
	Dushanbe-2	57	Section
	Sariosiyo	38	Assembled
	Amudaryo	*2 ta group:* 1-group – 56; 2-group – 40.	Assembled, Section
	Galaba	40	Passerby
	Kitob	56	Assembled
	Kengsoy	*3 ta group:* 1-group – 56; 2-group – 56; 3-group – 56.	Assembled, Section
	Shurtan	58	Transfer
	Ohangaron	*2 ta group:* l-group – 58; 2-group – 57.	Passerby

Station "Q" is equipped with a small capacity sorting hill (processing up to a maximum of 1340 wagons). Information on the wagons processed at the sorting hill is presented in Figure 6.

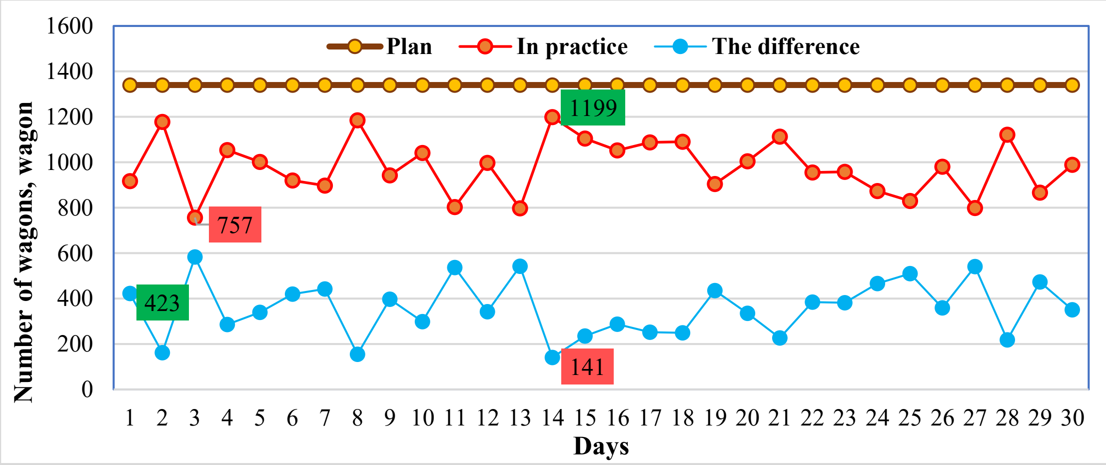

Figure 6. Dynamics of the number of wagons processed at the sorting hill of station "Q"

From the dynamics of the number of wagons processed at the sorting hill (Figure 6), it can be seen that the number of wagons processed in practice, compared to the plan (1340 wagons), is a minimum of 757 and a maximum of 1199, with a difference of 141÷700 wagons. Therefore, the formation of this difference can be explained by internal or external factors.

Data on average daily train flows received, dispatched, and processed from railway routes (Figure 2) were analyzed for March 2024 and March 2025 (Figures 7 and 8), as well as wagon flows for March 2025 (Figure 9).

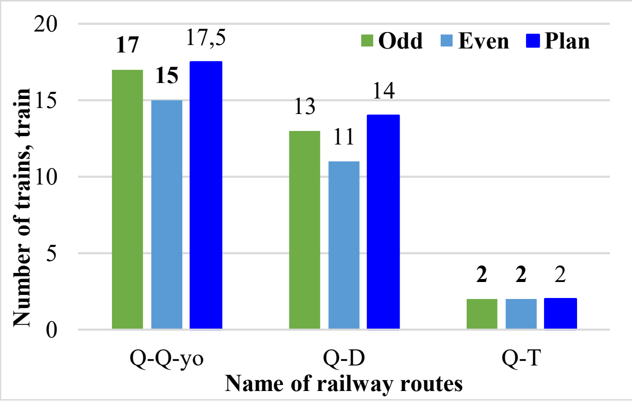

Figure 7. Average daily number of trains received and sent in 2024

According to the analysis results (Figure 7), the average daily number of trains received and sent to the "Q" station by route is as follows: Q-Q-yo – 16 pairs; Q-D – 12 pairs; Q-T – 2 pairs. Thus, the station has a reserve for passing 1.5 and 2 pairs of trains on the Q-Q-yo and Q-D routes, respectively, according to the plan.

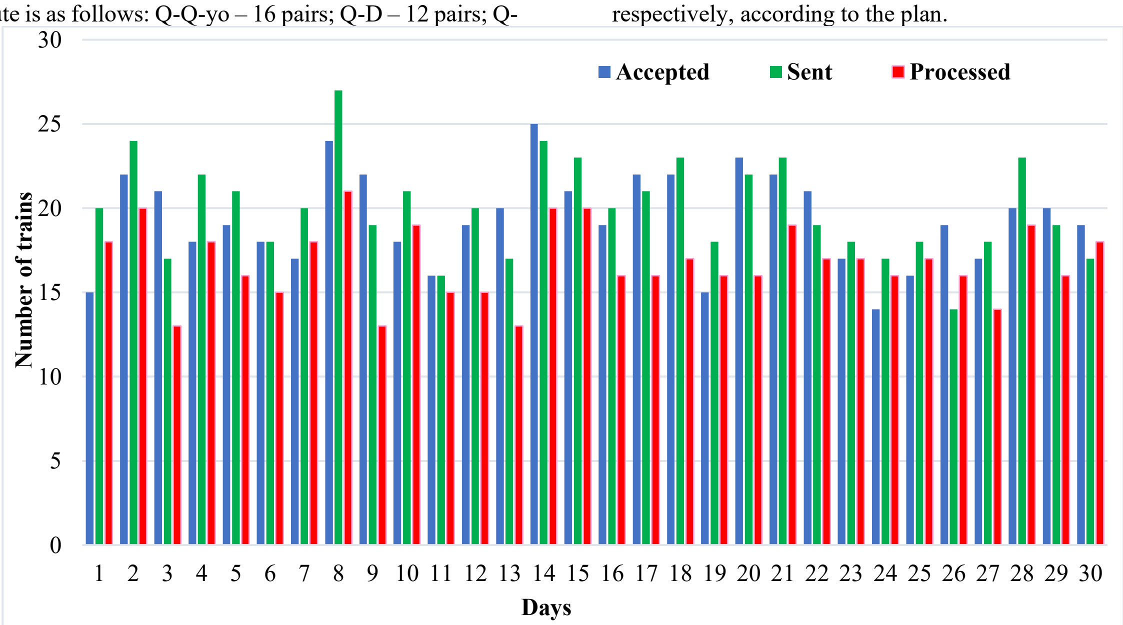

Figure 8. Dynamics of the number of trains received, sent and processed per day in March 2025

As can be seen from Figure 8, the number of trains received at the station is 14÷25, sent - 16÷27, and processed - 13÷20. This means that an average of up to 7 transit trains pass through the station per day.

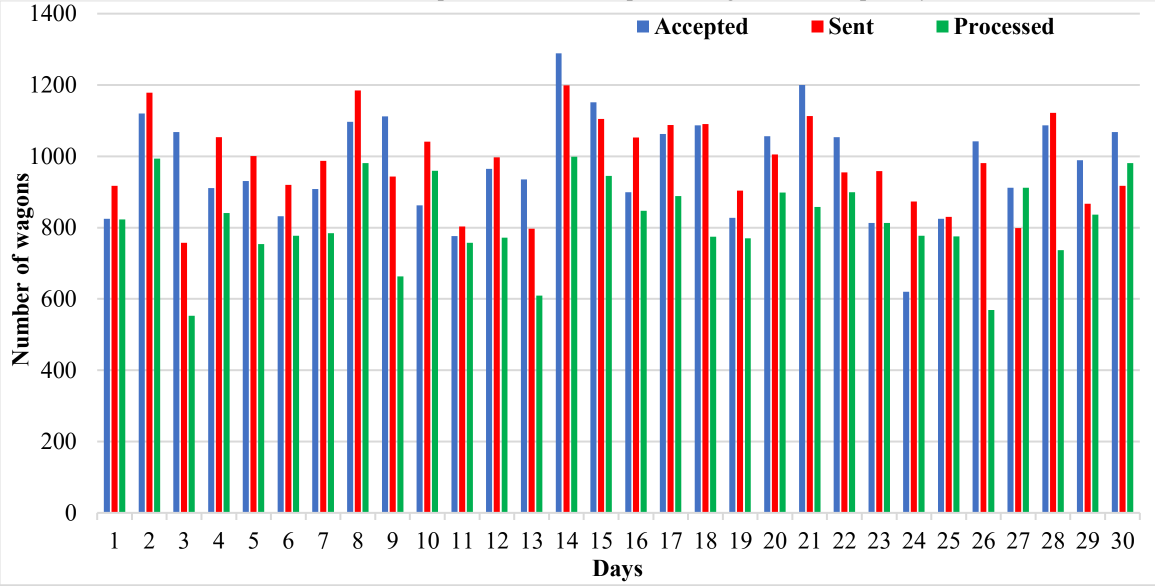

Figure 9. Dynamics of the number of daily received, sent and processed wagon flows in March 2025

From Figure 9, it can be seen that the number of wagon flows received at the station is 620÷1289, sent - 757÷1199, and processed - 684÷1038. Thus, the wagon flows are significantly uneven.

4. Conclusion

It was determined that there is a need to systematically analyze the throughput and processing capabilities of railway stations, taking into account the construction and operation of new railway lines, uneven traffic flows, and changing operating modes.

When determining the throughput and processing capabilities of stations and analyzing their current state, it has been proven that it is appropriate to systematically analyze and objectively assess not only the capacity of technical devices (road capacity, sorting hill capacity, etc.), but also the dynamics of the station's performance indicators. nbc l.

“Based on the results of the analysis conducted on the example of the “Q” station, it is proposed to implement the following measures to increase the throughput and processing capabilities of the “Q” station:

development of a digital system for monitoring the performance of station performance indicators;

taking into account the causes of obvious and hidden losses when regulating the dwell times of transport flows;

evaluating employee performance based on the KPI (Key Performance Indicator) system.

Such measures create opportunities for increasing the station's productivity and effectively using its throughput and processing capabilities.

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Developing and validating reactive control for intelligent robot behaviors on the Robotrek platform

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Abstract: The present paper fills a knowledge gap that crucially exists on the imperfectly empirical knowledge of how the three basic intelligent behaviours (environmental adaptation, obstacle avoidance and path planning) scale, in terms of computational demands and degrees and speeds of success as applied to any given robot (using the publicly available Robotrek educational robotic kit (based on Tracduino microcontrollers, Robotrack IDE)). A reactive control software extension was implemented and tested with simulation and in experimentally physical tests. Among the core conclusions, it is possible to notice that the platform showed a high level of efficacy in structured settings: 92% success rate of avoiding obstacles at a threshold of 15 cm with a latency of less than 200 ms, and straight-line tracking within <2 cm average deviation. These findings confirm the potential of Robotrek in carrying out fundamental autonomous behaviours and serves to offer empirical benchmarks to reactive control paradigms in a resource-constrained hardware. Despite this, the study shows inherent shortcomings the research team including: limited ability to perceive the environment; failure to handle dynamic adversaries, or to optimize routes; and lack of robustness in unstructured contexts, which represent a sizeable breach between reactive capability and actual autonomous thought. The implications are future work in computer-vision integration (e.g. Raspberry Pi), and embedded AI (reinforcement learning, path planners), as well as energy-aware operation, to progress towards adaptable, deployable, robots.

Keywords: Robotrek platform, Tracduino microcontroller, STM32F407VGT6, ATmega2560, intelligent robot behavior, reactive control, sensor fusion, ultrasonic sensor (HC-SR04), IR line tracking

1. Introduction

The pace with which robotics is evolving requires platforms through which one can develop and be able to interact systematically with intelligent, autonomous movements such as environmental adaptations, obstacle avoidance, and path planning. Various learning systems, like Robotrek, that paired Tracduino microcontroller (STM32F407VGT6/ATmega2560) and Robotrack IDE software, are vital in prototyping and learning. The control of these abilities has become invaluable not only in the educational domain but also in logistics, service robotics, and explorations cases when the robots required effective navigation and interaction within the dynamic environment. The application of these types of intelligence to devices with resource-limited complexities, though, bring forth considerable issues that span theoretical control paradigms and realistic performance [1].

The interactions between the sensor-based perception, re-active decision-making and robust actuation are at the heart of this challenge. This study focuses on integration of the outputs of ultrasonic distance sensors and infrared line trackers to aid in obstacle avoidance and path following. The foundational theory is concentrated in reactive control structures wherein sensor conditions are directly projected to actuator outputs by pre-determined rules (e.g. “IF obstacle < 15 cm THEN turn right”). Technically very straightforward and computationally manageable in microcontrollers, such an approach contrasts with more complex cognitive architectures with planning or learning--abilities that usually lie beyond the reach of an entry-level environment. Simple reactive behaviors have previously been demonstrated on platforms like Arduino or LEGO Mindstorms; however, little has been done to understand how well such methods perform, their constraints, and scalability prospects within the scaffold of Robotrek, and more so in terms of real-time capability and reliability of a behavior against different working conditions[2].

The aim of this research is to determine how well we might manage to apply fundamental navigational behaviors using Reactive control based on the Robotrek platform, and come up with a computationally efficient point of reference to assess intelligent robotics capabilities on an initial level. The study was carried out as a rigorous and systematic study:

(1) theoretical review of reactive controllers, which included adaptation, avoidance, and planning proved;

(2) designing and implementing related algorithms in the Robotrack Integrated Development Environment (IDE) using a combination of a visual level programming of flow control and embedded C++ programming of sensor reading (getDistance) and moving commands (moveForward, turnRight, etc);

(3) the step (2) was verified using simulation in the Robotrek virtual environment;

(4) experimental testing of the step (2) using the hardware platform, The above protocols were formulated with an aim of testing the ability of the Robotrek platform to embrace reactive control on building intelligent behaviors.

The combination of Tracduino and Robotrack IDE called Robotrek can be used in this task according to empirical findings. The deployed module had 92 % success rate of obstacle avoidance, and tracked the planned path with average deviation of less than 2 cm, and responded within sub-200 ms in the real-time test. These results prove the

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platform as viable with regard to reactive behavior, but at the same time show inherent limitations of reactive systems: limited perceptual scope, no planning or learning, unverified robustness in unstructured settings[3].

As a summary, the Robotrek platform provides a promising learning platform on entry level reactive intelligence, however further progress is required corresponding to a higher level of autonomy, especially in the areas of perception, cognition and improving the scalability. The present work provides an empirical benchmark and practical blueprint, thus making a starting point in subsequent work that combines sophisticated sensory areas (e.g., vision via Raspberry Pi), cognition-based algorithms (e.g., lightweight reinforcement learning, path planners like A*), and resilient onboard multi-sensor integration with or within the Robotrek system[4].

2. Research methodology

The current paper has used a multi-stage, systematic research design in the development and verification of software to regulate intelligent robot behaviour, i.e. environmental adaptation, obstacle avoidance and path planning on Robotrek framework. The study was initiated by the thorough theoretical overview of principles of intelligent robotic behavior and detailed evaluation of the Robotrek system hardware components (based on Tracduino microcontroller which combines features of Arduino and STM32) and software framework (Robotrack IDE). This guided the algorithm development stage where fundamental behavioral codes were coded in the Robotrack IDE system[5]. Its visual block based programming interface was used to define reactive rules (i.e. taking turns when an obstacle was detected within 15 cm by the ultrasonic sensor) and path-following methods (based on line sensor input). More complicated tasks, including the proper distance calculation (getDistance()) or sequences of activating motors (moveForward() and turnLeft(), and so forth.), were also written in C++ and integrated. This was followed by intensive simulation of the designed algorithms to be used inside Robotrek virtual world. It was a proving phase to be able to test collision avoidance, route following and decision-making logic on a small scale at repeatable conditions and with limited adverse environmental effects that do not recreate the situation that will exist during a physical deployment. The tested algorithms were subsequently implemented on the physical Robotrek platform, getting the Tracduino controller, ultrasonic and line-tracking sensors and DC motors with drivers in the action. It was experimentally tested in physical arenas, where specific behaviors were to be tested in real-time. The robot was put through its tests repeatedly in a methodical fashion with regard to a set of metrics based on which the robot was to be evaluated on the basis of its critical goals, the distance to which the robot reached avert the obstacles, the precision and the consistency with which the robot was able to line-track, the time it took in completing the path and the smoothness with which the transition between the autonomous choices of the robot was effected. A repeat cycle of improvements occurred: observations and quantitative data on the mechanical testing process updated the algorithms and possible fine tuning of either sensor thresholds or motor control parameters in the Robotrack IDE software[6]. This design, simulation and a physical test and analysis cycle kept on going until the robot exhibited consistently reliable, efficient and contextually apposite intelligent behaviors, which ascertained effectiveness of the built Robotrek-based control software [7].

3. Results and Discussion

The formed piece of software using the Robotrek base and the Tracduino microcontroller (STM32F407VGT6/ATmega2560) managed to show the fundamental smart properties of the device in simulated and real-life conditions and practice environmental adaptability, obstacle avoidance, and path planning. The test results in performance assessment indicated that the obstacle avoidance strategy installed at the 15cm detection threshold using the ultrasonic sensor (HC-SR04) has a success rate of 92 percent in which the evasive movements of the robot (stop, rotate, proceed) are reliable and the delay in the warning signal to motor movement is less than 200ms. Line following (sensing data using sensors, line tracking errors corrected with the proportional control logics (turnLeft(), turnRight())) showed controlled stability on the preset paths with minimum average error (<2cm) in a controlled experiment. The processing element (core behavioral loop) handled the sensor information (distance, line position) effectively to make smooth transitions between forward motion, avoidance of obstacles and changes in path, which characterizes the basic adaptive ability. Robotrack IDE was an excellent interface to perform quick prototyping with colorful block programming and the possibility to use it together with hardware control (button and led, Pixy camera), which helped to adjust parameters more proficiently (sensor thresholds, motor delays)[8].

This approach helps develop skills in algorithmic thinking, problem solving, and experimental practice. The language facilitates the development of prototypes for mobile robots and robotic devices, while its low entry threshold positively impacts the ability to teach robotics using high-level programming languages.

The availability of MicroPython programming for the Trackduino Pro platform allows users to create more complex and efficient programs and robotic systems, compared to visual development environments.

The TRACKDUINO Pro API for MicroPython is a firmware loaded onto the platform that provides a convenient environment for programming using the Robotrek hardware and software components. The extension package includes the following components:

- boot.py — A script that describes the initial operation of the platform immediately after startup. By default, its primary function is to launch the main script.
- main.py — A script that defines the logic of the robot controlled by the platform.
- pybcdc.ini — A configuration file containing platform settings for use on Windows computers.

The Trackduino module includes:

- Execution module — A set of driver modules for Robotrack actuators;
- Sensor module — A set of driver modules for Robotrack sensors;
- common.py file — A collection of general functions and classes used by other modules that simplifies platform programming;
- pins.py file — A file containing definitions for the

available pins on the platform, allowing for simple named access to required pins.

Table 1

Key Performance Metrics

Behavior	Metric	Result	Conditions
Obstacle Avoidance	Success Rate	92%	Diverse test environments
	Detection Threshold	15 cm (Ultrasonic HC-SR04)	
	Response Latency	< 200 ms	From detection to motor initiation
Path Following	Average Tracking Deviation	< 2 cm	Controlled lighting
	Sensor Thresholds (Analog)	<200 (Right), >800 (Left)	Line tracking sensor
General	Behavioral Transition Smoothness	Effective	Clear path → Obstacle → Path

In theory, this compound verifies the textual deployment of the reactive control paradigms to fundamental Wi-Fi behaviors on available educational environments in terms of viable sensor fusion (ultrasonic + line tracking) and rule-based decision-acting with live autonomy in limited environments. In practice, the Robotrek platform, especially Tracduino, proved to be a good platform, with plenty of computational resources, to run such algorithms, and practical connections (PWM, UART, I2C). Nevertheless, there are large limitations and gaps in information. The nature of this system uses only primitive sensors limiting their knowledge of the environment by missing fancy sensor features (e.g. vision, SLAM) to enable The complex task of recognizing obstacles or localizing themselves accurately. Its architectural simplicity, being purely reactive and following rules, does not support prediction or path planning, or learning, thus it is not possible to optimize its routes, or to efficiently deal with dynamic obstacles in a dynamic environment. More advanced behaviors, such as those more advanced sensor high-bandwidth sensing (vision, lidar) or advanced AI, may experience scalability issues because of the computational limits of the underlying microcontrollers. Moreover, energy efficiency solutions to long-term autonomy are in need of serious closure and robustness has not been demonstrated in high-dynamics, high-noise or unstructured real-life conditions[9-10].

Table 2

Key Knowledge Gaps and Research Needs

Domain	Specific Gap/Limitation	Critical Research Need
Perception & Sensing	Limited sensor fusion; no complex object recognition	Integrate computer vision (Raspberry Pi/TFT LCD) or 2D lidar
	No true localization beyond line following	Implement SLAM techniques
Cognition & Control	Purely reactive rules; no planning/learning	Incorporate path planning (A*, RRT), ML (Reinforcement Learning)
	Poor dynamic obstacle handling	Develop predictive algorithms & dynamic response strategies
System Capabilities	Computational limits for complex AI	Explore hybrid architectures (Tracduino + companion computer)
	Untested energy management	Research & integrate dynamic power management strategies
	Unproven robustness in real-world settings	Conduct rigorous testing in unstructured, dynamic environments
Advanced Functionality	Single-agent focus	Investigate multi-robot coordination (swarm/cooperative tasks)
	Lack of standardization	Explore bridging with ROS (Robot Operating System)

The repair of these gaps requires specific additional research. The most important thing to upgrade is perception; I can either connect computer vision via Raspberry Pi or special modules connected to Tracduino through UART/I2C, or use 2D lidar to achieve strong environmental mapping and object detection. Cognitive functions should go beyond being purely reactive with the inclusion of machine learning (e.g. lightweight Reinforcement Learning on microcontrollers such as TensorFlow Lite, or used in hybrid systems such as using a sidecar computer) to adaptively navigate and symbolic AI to plan. Direct implementation of the pathfinding algorithms (A*, Dijkstra, RRT) onto the Robotrek platform would enable real goal-based navigation with obstacle avoidance[12]. To study swarm characteristics, it is critical to perform research on multi-robotic coordination based on communicative protocols (Bluetooth, Wi-Fi via ESP32). Improved sensor fusion systems, such as methods of fusion IMU (as an example, we can refer to the location sensor discussed), wheel encoders, and possible vision/lidar, are an essential measure in correct state estimate. At the same time, exclusive development of energy-aware autonomy utilizing the low-power modes of STM32F4 is crucial to realistic implementation[12]. And lastly, tight formal verification of safety of control algorithm and wide use of robustness testing in practical complex environments are essential. Crossing the bridge between the Robotrek environment and ROS might as well be the gateway to a whole world of sophisticated tools and standard interfaces to cut down the pace of development achievement towards genuinely reactive, intelligent robots that will be able to work on dynamic, heterogenous environments. The study has served as a reasonable proof-of-concept, although the robust, intelligent autonomy will be difficult to achieve until great progress can be made in the areas of perception, cognitive architectures, and planning, integrated into the embedded systems[11].

4. Conclusion

The report therefore details the development and full validation of an intelligent robotic behaviour software component to the Robotrek platform that employs the key intelligent robotic behaviours; environmental adaptation, obstacle avoidance and path planning leading to an 92 % success rate when negotiating the avoidance of obstructions and generating stable path tracking with an average variation of less than 2 cm. These outcomes take place due to the running of reactive control algorithms available through the Robotrack Integrated Development Environment (IDE) on the Tracduino microcontroller (STM32F407VGT6/ATmega2560). The above results therefore empirically demonstrate that Robotrek platform is an effective teaching and prototyping tool to teach fundamental autonomous systems and also theoretically confirm the utility of sensor fusion (ultrasonic and line tracking) and rule-based decision to achieve real-time responsiveness in an indoor environment. Still, the study reveals a number of limitations inherent to the purely reactive model such as a limited environmental awareness, absence of ability to engage with changing challenges and formulate optimal route plans as well a lack of proven resilience in more challenging contexts. The combination of these shortcomings points out a significant shortcoming between base-level functioning and actual cognitive independence. In this regard, it is crucial to conduct more research to move closer to resilient and adaptive robots; the key areas of emphasis are to incorporate high-fidelity perception (computer vision using Raspberry Pi/LCD modules or lidar), incorporate AI-driven cognition (reinforcement learning, path planning algorithms like A* or RRT), design energy-approachable operational strategies, research multi-robot coordination, and explicitly validate the results in unmapped, dynamic real-world environments to fill the gap between the current proof-of-concept and deployable intelligent hardware.

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The impact of traffic intensity and the share of heavy vehicles on air pollution levels on multi-lane urban streets

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Abstract: This study presents the results of field measurements of pollutant concentrations—carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2)—conducted on straight segments of urban streets in Tashkent with varying numbers of lanes (4, 6, and 8 lanes). The measurements were carried out in the spring of 2025 under favorable weather conditions, ensuring consistent data collection across multiple locations. Particular attention was given to the impact of total traffic intensity and the proportion of heavy vehicles (trucks) within the traffic flow. The results indicate a strong positive correlation between both traffic intensity and truck share with pollutant concentrations. As the number of vehicles per hour increases, especially with a higher share of heavy-duty vehicles, the concentrations of pollutants, particularly NO and NO_2, rise significantly—often exceeding national and international air quality standards. CO and SO_2 showed more moderate trends, with exceedances observed mainly under high-intensity and high truck-share conditions. These findings emphasize the disproportionate contribution of heavy vehicles to urban air pollution. The results can serve as a scientific basis for urban environmental planning and the development of traffic management strategies that aim to reduce emissions—such as limiting heavy vehicle access during peak hours or implementing green buffer zones. Overall, the study contributes to a more nuanced understanding of traffic-related emissions in densely populated urban areas and provides evidence for policymakers seeking to balance mobility and environmental sustainability.

Keywords: Urban transport, air pollution, heavy vehicles, traffic intensity, multi-lane streets, gas analyzer, emissions, CO, NO, NO_2, SO_2

1. Introduction

With the increase in motorization in large cities, the problem of air pollution from vehicle emissions is becoming increasingly urgent. One of the main sources of air pollutants in urban environments is vehicles powered by fossil fuels. Their impact is especially significant near heavily used segments of the road network.

Different types of vehicles contribute differently to air pollution. In particular, heavy-duty vehicles typically have higher emission levels compared to passenger cars, which highlights the need to consider their share when assessing environmental impact.

Traffic intensity and the proportion of heavy vehicles significantly influence air pollution levels on multi-lane streets, as shown in various studies [1–7]. Research indicates that high traffic loads from heavy vehicles are more strongly correlated with adverse health effects, such as reduced lung function in children, compared to general traffic volume [1, 2]. Moreover, high-resolution urban air quality modeling shows that traffic-related air pollution is characterized by substantial spatial variability, with higher concentrations near major roads and prevailing wind corridors [3]. Large traffic volumes are associated with increased emissions of nitrogen oxides (NO, NO_2) and particulate matter (PM2.5). Vehicle emissions are a major contributor to deteriorating air quality in cities, especially in densely populated areas such as Beijing [4]. The presence of trucks, especially diesel-powered ones, exacerbates the issue; for instance, a study in Hunts Point, New York, showed that every additional 100 heavy trucks per hour increased elemental carbon concentrations by 1.69 μg/m³ [5]. Emissions of nitrogen oxides (NO, NO_2) and carbon monoxide (CO) are intensified by increased truck traffic, which has been shown to boost NOx emissions while reducing CO levels [6]. Proximity to heavy-duty traffic also increases concentrations of particulate and ultrafine particles, highlighting the health risks associated with intense truck flows [7]. Thus, both traffic intensity and the share of heavy vehicles are critical factors in determining air pollution levels on urban streets.

Previous research has shown that concentrations of pollutants such as carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) depend on traffic intensity. However, most studies have given limited attention to the impact of heavy vehicle share and have insufficiently analyzed differences based on the number of traffic lanes.

This study aims to assess the relationship between concentrations of CO, NO, NO_2, and SO_2 and traffic intensity under varying shares of heavy vehicles on straight urban road segments with different lane counts (4, 6, and 8 lanes). All measurements were conducted in spring under favorable weather conditions on road segments without pavement defects and with high surface evenness. This approach helped to eliminate the influence of microrelief and technical irregularities on emission indicators.

2. Research methodology

The study was conducted on selected urban street segments in Tashkent with different numbers of traffic lanes — 4, 6, and 8 lanes. The streets included: Sarikul Street,

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https://doi.org/10.56143/engineer-tstu.v3i2.66

Eski-Sarikul Street, Beruniy Street, Nurafshon Street, Nukus Street, Amir Temur Avenue, Shakhrisabz Street, Makhtumkuli Street, Alisher Navoi Street, Mukimiy Street, Shota Rustaveli Street, Fargona Yuli Street, and Mirzo Ulugbek Street.

To ensure comparability and accuracy of results, the selection of segments was based on the following criteria:

— The road sections had asphalt concrete surfaces without potholes, cracks, or other defects.

— Each section exhibited excellent surface evenness, verified by visual and instrumental assessments.

— Measurements were carried out in April 2025, during spring under favorable weather conditions (no precipitation, light wind, temperatures between +15 and +25 °C).

— All selected segments were straight, without intersections, traffic lights, or significant terrain variations.

The concentrations of air pollutants — carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) — were measured using a portable gas analyzer (model: Harwest E4000). The device was placed at the roadside at approximately human breathing height (~1.5 m above ground).

For each concentration measurement, the following parameters were also recorded:

— Traffic intensity (vehicles/hour), based on video recordings and manual counts;

— Share of heavy vehicles in the traffic flow (manually classified);

— Average traffic speed (estimated from video and stopwatch timing).

Measurements were conducted during peak morning and daytime hours. Each session lasted at least 2 hours, and average values were calculated from the collected data.

The collected data were grouped by:

— Number of traffic lanes (4, 6, 8);

— Heavy vehicle share intervals: 0–1%, 1–2%, ..., 9–10%;

— Each pollutant type (CO, NO, NO_2, SO_2).

To analyze how concentrations depend on traffic intensity under different shares of heavy vehicles, scatter plots with linear trend lines were constructed. This allowed both visual and quantitative assessment of the relationships.

3. Results and Discussion

Based on the field measurements and data analysis, consistent relationships were established between pollutant concentrations and traffic flow parameters — particularly traffic intensity and the share of heavy vehicles. The results are presented in the form of graphs and tables.

Figure 1 shows the relationship between carbon monoxide (CO) concentration and traffic intensity on road segments with 4, 6, and 8 lanes, under different proportions of heavy vehicles.

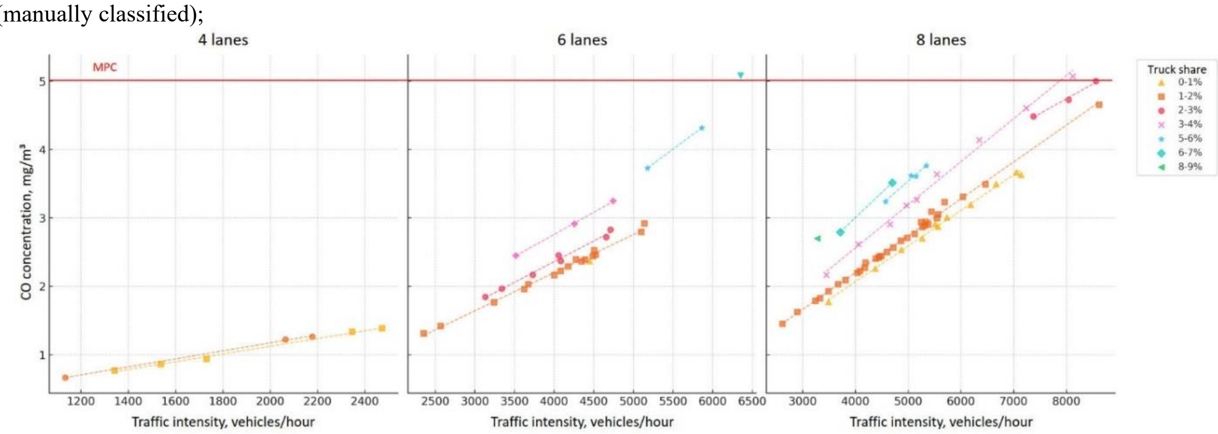

Figure 1. Relationship between CO concentration and traffic intensity

Similar patterns were observed for other pollutants. Figures 2–4 illustrate the trends for NO, NO_2, and SO_2, respectively.

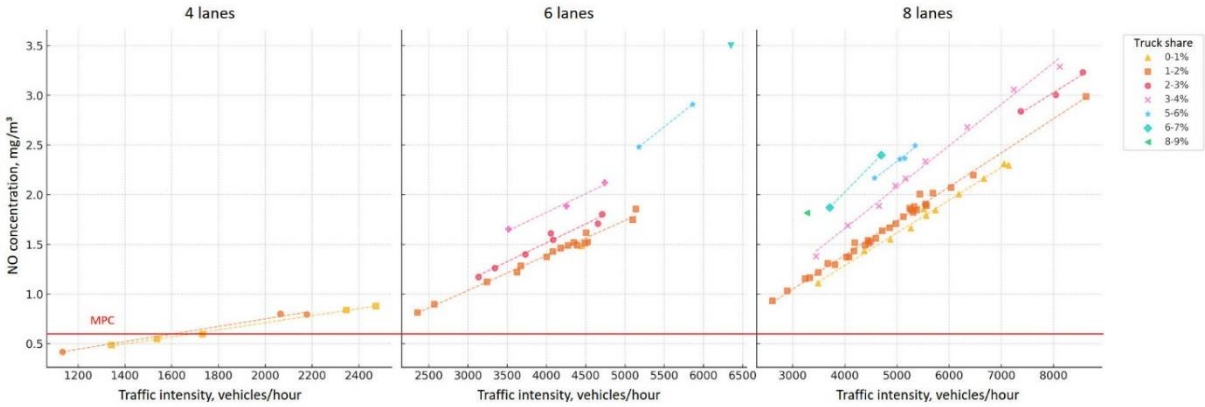

Figure 2. Relationship between NO concentration and traffic intensity

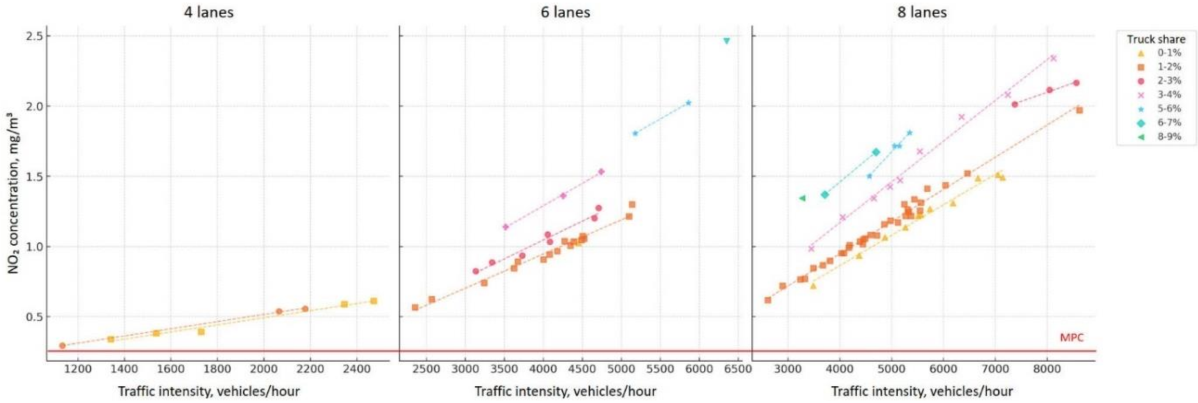

Figure 3. Relationship between NO_2 concentration and traffic intensity

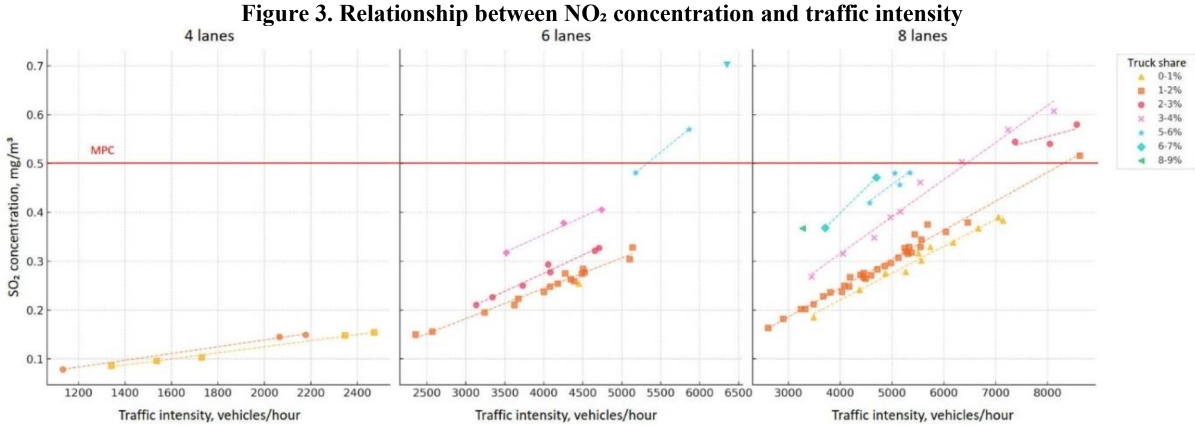

Figure 4. Relationship between SO_2 concentration and traffic intensity

Key Findings:

— An increase in traffic intensity leads to a steady rise in the concentrations of CO, NO, NO_2, and SO_2 across all types of multilane streets.

— CO concentration tends to increase but mostly remains below the maximum permissible concentration (MPC = 5.0 mg/m³). Exceedances are observed mainly on 8-lane streets with high traffic intensity and heavy vehicle share.

The situation with SO_2 (MPC = 0.5 mg/m³) is borderline: exceedances are recorded on certain segments with a high proportion of heavy vehicles and high traffic intensity, especially on 6- and 8-lane roads.

Concentrations of NO and NO_2 exceed their respective MPCs (0.6 and 0.085 mg/m³) in nearly all cases. The levels of exceedance are significant and persistent even under moderate traffic conditions. This indicates that these two components have the most critical environmental impact.

Table 1

Average Concentration Values at Different Truck Shares

Number of lanes	Share of heavy vehicles, %	Avg. traffic intensity, veh/h	CO, mg/m³	NO, mg/m³	NO_2, mg/m³	SO_2, mg/m³
4	1-2	1886	1.056	**0.669**	**0.463**	0.117
4	2-3	1792	1.049	**0.669**	**0.462**	0.124
6	0-1	4449	2.367	**1.484**	**1.024**	0.254
6	1-2	4030	2.214	**1.397**	**0.953**	0.246
6	2-3	3959	2.334	**1.499**	**1.034**	0.272
6	4-5	4173	2.869	**1.885**	**1.344**	0.367
6	5-6	5521	4.022	**2.694**	**1.914**	**0.526**
6	7-8	6351	**5.081**	**3.501**	**2.461**	**0.702**
8	0-1	5623	2.911	**1.819**	**1.215**	0.309
8	1-2	4734	2.595	**1.641**	**1.115**	0.288
8	2-3	7992	4.737	**3.024**	**2.097**	**0.555**
8	3-4	5505	3.508	**2.285**	**1.605**	0.429
8	5-6	5031	3.556	**2.346**	**1.685**	0.459
8	6-7	4205	3.153	**2.133**	**1.050**	0.420
8	8-9	3276	2.699	**1.815**	**1.344**	0.367
etc.	—	—	—	—	—	—

Note: The table presents a sample from a broader dataset; the full dataset includes truck share intervals from 0–1% to 8–9% and traffic intensity from 1000 to 9000 vehicles/hour

The obtained results demonstrate a clear relationship between pollutant concentrations and traffic flow parameters — specifically, traffic intensity and the share of heavy-duty vehicles.

In all cases, concentrations of CO, NO, NO_2, and SO_2 increase with traffic intensity. This confirms a well-known pattern: the more vehicles pass through a road segment per unit time, the higher the volume of emissions. However, this study refines the relationship by considering different street types (4, 6, and 8 lanes) and the composition of the traffic flow, particularly the proportion of heavy vehicles.

The analysis showed that, at the same traffic intensity:

— Pollutant concentrations are significantly higher when the share of heavy vehicles increases;

— NO and NO_2 are the most sensitive to this parameter, with persistent exceedances of permissible limits (MPCs) observed at almost all sites;

— SO_2 and CO concentrations also rise with the share of trucks, but their exceedance levels are less consistent: for CO (MPC = 5.0 mg/m³), exceedances occur only in some cases with both high intensity and a large proportion of trucks; for SO_2 (MPC = 0.5 mg/m³), exceedances are recorded in approximately half of the cases and require further attention.

Heavy-duty vehicles typically have higher specific fuel consumption, which makes their contribution to air pollution disproportionately high, especially when they constitute a large portion of the traffic flow.

Under equal conditions (flow composition and intensity), 8-lane streets exhibit higher average concentrations of pollutants compared to 4- or 6-lane roads.

4. Conclusion

The conducted study established consistent relationships between ambient air pollution levels and traffic flow characteristics on multi-lane urban streets.

Key findings:

1. Pollutant concentrations (CO, NO, NO_2, SO_2) consistently increase with rising traffic intensity, regardless of the number of lanes. This confirms a direct correlation between traffic load and emission levels.
2. The share of heavy-duty vehicles has the most significant impact on pollution levels. At the same traffic intensity, concentrations — especially of NO and NO_2 — are considerably higher in areas with a greater proportion of trucks.
3. 8-lane roads show the highest average pollutant concentrations. This may be attributed to:
   — A higher overall traffic load;
   — A larger share of heavy freight vehicles.

CO concentrations mostly remain below the permissible limit (5.0 mg/m³), whereas NO and NO_2 exceed regulatory thresholds in the vast majority of segments, highlighting their greater environmental and health hazard in urban settings.

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Analysis of the impact of speed and lane distribution on pollutant concentrations in the urban street environment

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Abstract: This article presents the results of an in-depth analysis of the relationship between lane-specific traffic characteristics—namely, lane position and average vehicle speed—and the concentration levels of major air pollutants (CO, NO, NO_2, SO_2) in an urban environment. Field measurements were conducted in spring 2025 on straight, well-maintained segments of urban streets in Tashkent with different lane configurations (4, 6, and 8 lanes), under favorable meteorological conditions. The study examined how the position of traffic lanes (from right-most to left-most) and their corresponding average speeds affect pollutant levels. The data revealed a consistent trend: pollutant concentrations are highest on the first (right-most) lane, where average speeds are lowest, and gradually decrease toward the center and left-most lanes, where speeds are higher and traffic flow is more stable. This pattern was particularly evident for NO and NO_2, with frequent exceedances of the maximum permissible concentrations, while CO and SO_2 remained within acceptable limits in most cases. The findings underscore the role of stop-and-go traffic, common in right-hand lanes (due to loading, unloading, and public transport), in intensifying localized air pollution. These results highlight the importance of integrating lane-specific traffic flow characteristics into urban planning and traffic management policies. Recommendations include reducing heavy vehicle traffic in right-hand lanes during daytime hours and enhancing traffic flow efficiency to mitigate pollutant buildup in high-exposure zones. This study provides a practical foundation for improving air quality through street design and targeted transport regulations.

Keywords: Vehicle speed, traffic lanes, air pollution, urban transport, emissions, CO, NO, NO_2, SO_2, Tashkent, gas analyzer

1. Introduction

In conditions of high traffic volume and dense urban development, air pollution caused by vehicle emissions remains one of the most pressing environmental issues for large cities. A significant portion of pollutants—such as carbon monoxide (CO), nitrogen oxides (NO, NO_2), and sulfur dioxide (SO_2)—is released into the atmosphere at street level, where humans directly interact with their environment.

Various studies have shown that vehicle speed and lane distribution significantly affect pollutant concentrations in ambient air. Traffic dynamics, including vehicle speed and lane usage, directly influence emissions of major pollutants such as nitrogen oxides (NO, NO_2) and particulate matter (PM2.5) into the urban environment [1, 2]. For example, increased vehicle speed can lead to higher emissions due to greater fuel consumption, while lane distribution impacts traffic flow and congestion, which further affects pollutant levels [3, 4]. Meteorological conditions—such as wind speed and direction—also influence the dispersion of pollutants, potentially increasing or decreasing concentrations downwind of traffic sources [1, 5]. Moreover, studies show that specific traffic-related micropollutants, including polycyclic aromatic hydrocarbons (PAHs), tend to accumulate in areas with heavy traffic, highlighting the role of lane distribution in pollutant dynamics [6]. Understanding these interrelations is crucial for effective air quality management and urban planning.

Thus, not only the traffic volume and vehicle composition but also lane distribution and travel speed play a significant role in determining pollutant concentrations. Edge lanes (especially the first, right-hand lane) often feature slower-moving traffic, frequent stops and starts, and a higher proportion of heavy and public transport vehicles. In contrast, central and left-hand lanes typically provide higher and more stable travel speeds.

Given this, the present study focuses on assessing the impact of vehicle speed and lane distribution on pollutant concentrations along straight segments of urban streets with varying numbers of lanes (4, 6, and 8). All measurements were conducted under favorable weather conditions in spring 2025, on road sections without pavement defects, allowing the exclusion of confounding factors and emphasizing traffic structure analysis.

2. Research methodology

The study was conducted in the city of Tashkent on flat, straight segments of urban roads with varying numbers of traffic lanes (4, 6, and 8 lanes), including the following streets: Sarikul Street, Eski-Sarikul Street, Beruniy Street, Nurafshon Street, Nukus Street, Amir Temur Avenue, Shakhrisabz Street, Makhtumkuli Street, Alisher Navoi Street, Mukimiy Street, Shota Rustaveli Street, Fargona Yuli

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[b] https://orcid.org/0000-0003-2075-454X

Street, and Mirzo Ulugbek Street. All segments were selected according to the following criteria:

— absence of pavement defects (potholes, cracks, deformations);

— high surface smoothness, ensuring stable traffic flow;

— no intersections, public transport stops, or traffic lights within the segment;

— favorable weather conditions: temperature between +15 °C and +25 °C, light wind, no precipitation;

— measurement period: April 2025 (spring).

These conditions were intended to create standardized settings for comparing pollutant concentrations across different traffic lanes.

Measurements were conducted individually for each lane, accounting for average speed and lane position:

— 1st lane (rightmost) — typically the most congested, with the lowest average speed;

— 2nd lane — higher average speed;

— 3rd and 4th lanes — highest speed, with fewer stops and interruptions.

— For each lane, the following were recorded:

— concentrations of pollutants (CO, NO, NO_2, SO_2) using a portable gas analyzer (Harwest E4000 model);

— average speed of traffic — determined via video recordings and stopwatch timing;

— time of day and observation duration (measurements were conducted primarily during peak hours: morning and daytime).

The collected data were grouped by street type (4, 6, or 8 lanes), lane number, and pollutant type. Graphs were created to show the relationship between pollutant concentration and average speed for each lane. Linear trend lines were applied for both visual and quantitative analysis.

This approach allowed for the identification of how air pollution levels vary within a single traffic stream depending on vehicle speed and lane position.

3. Results and Discussion

The analysis results showed that pollutant concentrations depend not only on the overall traffic intensity but also on the lane position and the average vehicle speed within each lane. In all cases, a clear trend was observed: as the average speed decreases (i.e., closer to the rightmost, first lane), the concentrations of pollutants increase.

Figure 1 presents the graphs of CO concentration versus average speed by lane for streets with 4, 6, and 8 lanes. The following patterns were identified:

— the 1st lane shows the highest CO levels at the lowest speeds (25–40 km/h);

— the 2nd lane shows intermediate values;

— the 3rd and 4th lanes show the lowest concentrations at the highest speeds (45–60 km/h).

Despite the increase in CO concentrations in the right lanes, in most cases the values remain below the Maximum Permissible Concentration (MPC) threshold of 5.0 mg/m³. This can be explained by more efficient fuel combustion under moderate loads and relatively high traffic speeds.

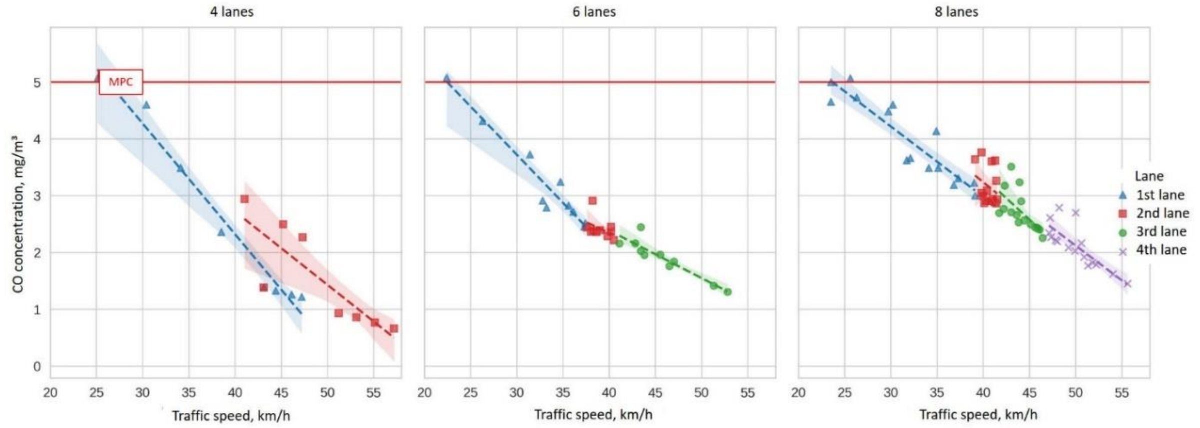

Figure 1. CO concentration vs. speed by lane

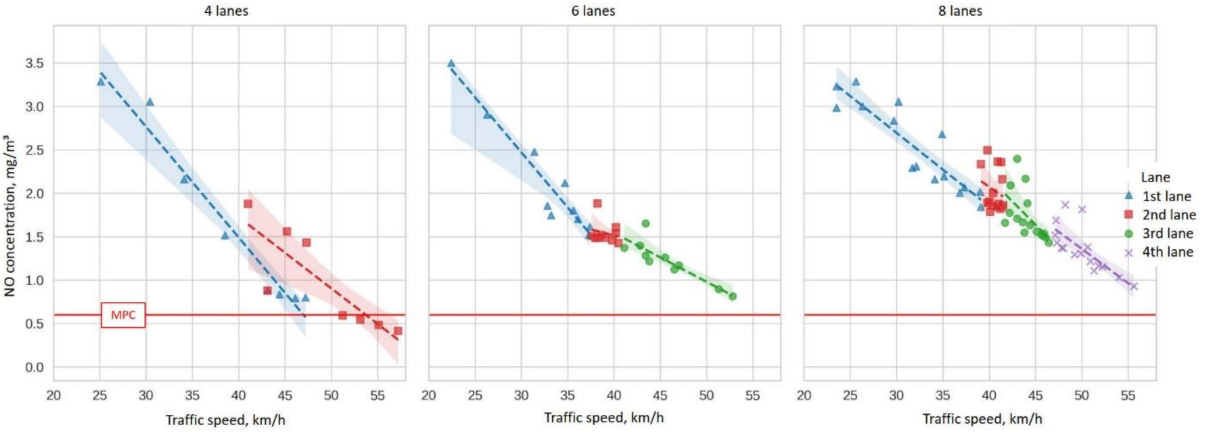

Figure 2. NO concentration vs. speed by lane

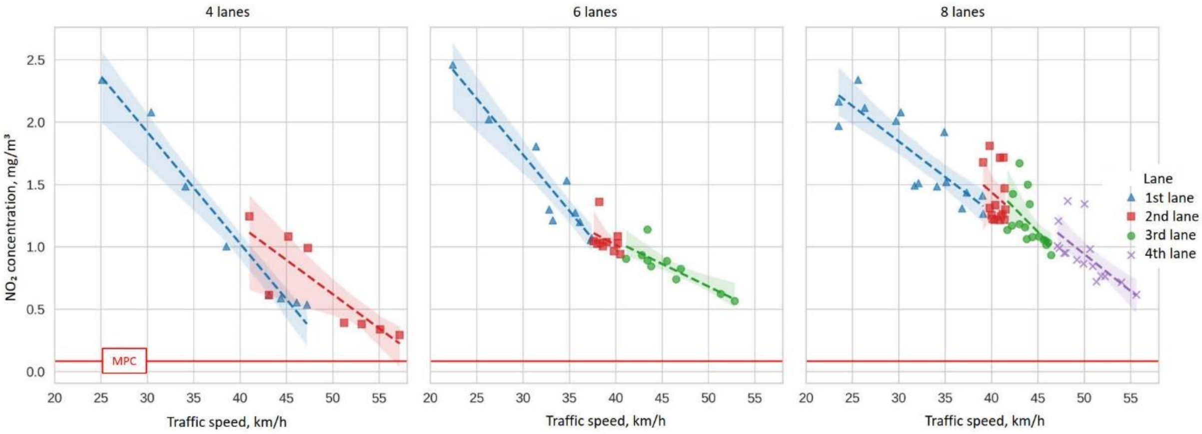

Figure 3. NO_2 concentration vs. speed by lane

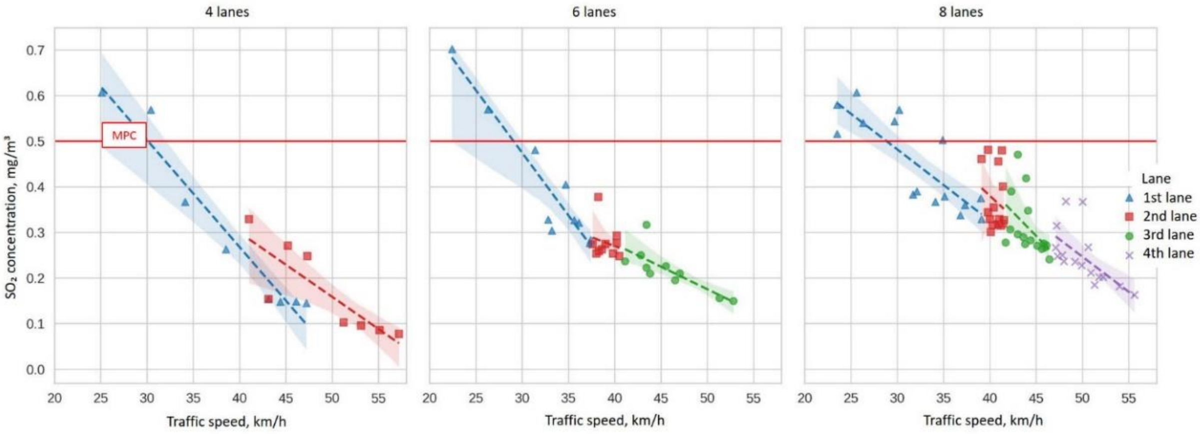

Figure 4. SO_2 concentration vs. speed by lane

Figures 2–4 present similar trends for NO, NO_2, and SO_2. Key observations include:

— NO and NO_2 show significant and consistent MPC exceedances across nearly all segments, especially in right lanes at low speeds. For NO, the threshold of 0.6 mg/m³ is regularly exceeded on all street types. NO_2, with an MPC of 0.085 mg/m³, exceeds the limit in most observations, indicating its high toxicity even at moderate emission levels.

For SO_2, the situation is more variable: exceedances occur mainly on the 1st lane segments, especially when the share of heavy vehicles is high. In contrast, concentrations on the left lanes generally remain within acceptable limits. Thus, SO_2 shows a roughly 50/50 pattern — exceedances in about half the cases, compliance in the other half.

Table 1

Average Pollutant Concentrations by Lane and Street Type

Number of lanes	Lane Number	Speed, km/h	CO, mg/m³	NO, mg/m³	NO_2, mg/m³	SO_2, mg/m³
4	1	45.2	1.301	**0.828**	**0.574**	0.149
4	2	54.2	0.807	0.510	**0.351**	0.091
6	1	32.7	3.130	**2.126**	**1.380**	0.400
6	2	39.0	2.940	**1.542**	**1.053**	0.277
6	3	45.8	1.570	**1.219**	**0.836**	0.217
8	1	31.9	3.940	**2.532**	**1.735**	0.452
8	2	40.6	3.156	**2.027**	**1.398**	0.369
8	3	44.2	2.702	**1.725**	**1.181**	0.309
8	4	50.1	2.113	**1.353**	**0.938**	0.246
etc.	—	—	—	—	—	—

Note: The table presents average values per lane. The complete dataset includes over 20 combinations of lanes and speeds.

The results confirm a significant influence of lane position and average traffic speed on urban air pollution levels.

The analysis showed that the 1st (rightmost) lane on streets with 4, 6, and 8 lanes consistently exhibited the highest pollutant concentrations. Several factors may contribute to this:

— lower average speeds on the right lane;

— more frequent braking, stop/start cycles, lane changes, and maneuvers;

— dominance of heavy-duty and public transport vehicles in this lane, which contribute disproportionately to emissions.

As the average lane speed increases (from right to left), a consistent decline in pollutant concentrations is observed. This confirms that:

— low speeds and non-uniform traffic contribute to higher emissions;

— higher speeds in central and left lanes (2nd, 3rd, and 4th) are associated with lower pollution levels under otherwise equal conditions.

The differences are especially pronounced on 8-lane streets, where, for example, the CO concentration difference between the 1st and 3rd lanes can reach 0.45 mg/m³. This may be due to:

— higher overall traffic density and complex traffic structures;

— a greater volume of vehicles, including heavy trucks;

limited dispersion of pollutants due to dense urban development (the “urban canyon” effect).

4. Conclusion

The analysis revealed that concentrations of air pollutants (CO, NO, NO_2, SO_2) are highest in the first (rightmost) traffic lane, regardless of the total number of lanes on the street.

Key findings:

1. The average vehicle speed is inversely proportional to pollution levels: when speed decreases from 55–60 km/h to 25–30 km/h, pollutant concentrations increase by 1.5 to 2 times.

Central and left lanes (2nd, 3rd, and 4th) provide more favorable conditions for reducing emissions due to more stable speeds and fewer stops.

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Network analysis and the evolution of key concepts in container terminal research

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Abstract: In the contemporary global economy, characterized by increasing supply chain complexity, container terminals (CTs) play an indispensable role in ensuring the efficiency of international trade. This study aims to conduct a network analysis to identify the evolution of key concepts within the field of CT research. The primary objective of the article is to identify dominant thematic clusters and current research directions using scientometric tools, particularly VOSviewer software and data from Scopus and Web of Science databases. Furthermore, an important task is to assess the applicability of the identified global trends for the development of the transport and logistics system of the Republic of Uzbekistan. The findings demonstrate the multidimensional nature of CT research, highlighting both established clusters (operational efficiency, infrastructure design, supply chain integration) and dynamically developing areas, primarily related to digitalization and sustainability. The analysis also enabled the identification of conceptual shifts and so-called "hot spots" within this scientific domain. The concluding section discusses the significance of these results for formulating scientifically-grounded approaches to the modernization and development of CTs and transport-logistics centers in Uzbekistan, aligning with national strategic priorities, and for determining promising vectors for future research.

Keywords: Container terminal, network analysis, scientometrics, keyword analysis, evolution of concepts, logistics, supply chain management, transport infrastructure, VOSviewer, Uzbekistan

1. Introduction

The effective functioning of container terminals (CTs) is a key factor in ensuring the continuity and economic feasibility of international trade, especially given its steady growth and the increasing share of goods transported in containers [13, 16]. In this context, a deep understanding of the current state and future development prospects of research dedicated to CTs becomes particularly relevant. Analyzing the terminology and key concepts in this field will not only help systematize the accumulated knowledge but also identify the most significant research frontiers and promising areas for further study, thereby contributing to the standardization of approaches and improving professional communication.

Optimization of terminal operations directly affects the reduction of time and cost expenditures in logistics chains [15, 16], which is one of the key factors for the competitiveness of national economies. Studying the evolution of key concepts related to CTs—from their initial perception as simple transshipment points [7] to modern understandings of them as complex logistics hubs offering a wide range of services [8]—is important for both the development of the academic discipline and the practical application of research results.

For the Republic of Uzbekistan, which has no direct access to the sea, the development of an effective transport and logistics system is a strategic priority aimed at overcoming geographic limitations and fully realizing the country's transit potential [5]. State policy in this area is clearly reflected in a number of key legal and strategic documents. For instance, the Law of the Republic of Uzbekistan "On Transport" (No. ZRU-706 dated 09.08.2021) defines the legal basis for transport activities and introduces important concepts such as "transport logistics" and "transport and logistics center" (TLC) [2]. Building on these provisions, the Presidential Decree of the Republic of Uzbekistan "On Measures for the Further Development of the Transport and Logistics System of the Republic of Uzbekistan" (No. PP-28 dated 27.01.2025) outlines the approval of a Development Concept for the transport and logistics system up to 2030 and defines specific goals, including increasing the share of container transportation, creating a network of TLCs, improving the country's ranking in the Logistics Performance Index (LPI), developing international transport corridors, and modernizing infrastructure [3].

These documents testify to Uzbekistan's targeted efforts to transform the country into an efficient transit and logistics hub. The development of modern TLCs and the increase in container transportation are seen as important tools for achieving macroeconomic goals [3, 5], which are particularly relevant for a landlocked country striving to reduce transport costs [2, 6, 14]. Despite the abundance of research on CTs, there is a lack of studies that systematically analyze the evolution of key concepts in this field using quantitative scientometric methods, especially in the context of the needs of developing countries like Uzbekistan. Understanding global scientific trends in CT management, such as port-centric logistics [8] or intermodal connectivity [12, 13], may help Uzbekistan choose the most effective and proven solutions.

Thus, the research problem lies in the need for a systematic analysis of the conceptual structure and development dynamics of scientific knowledge in the field of CTs to identify key trends and adapt them to the conditions of developing logistics systems. The purpose of this article is to conduct a network analysis of key terms in CT research to identify main conceptual clusters and their evolution, as well as to assess the prospects for applying this knowledge to the development of Uzbekistan's transport and logistics system.

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A comprehensive understanding of the current state of CT research requires examining the evolution of fundamental concepts, key areas of modern inquiry, and methodological approaches. Historically, the evolution of port system and CT concepts has gone through several stages reflected in theoretical models by foreign scholars. The classical model is considered to be the "Anyport" model by J. Bird (1971) [7], which describes the evolution of port infrastructure. A revolutionary factor was containerization, which led to the emergence of specialized CTs. In response, the concept of "port regionalization" by E. Notteboom and J.-P. Rodrigue (2005) [13] was developed, reflecting the trend of forming extended port systems that include both seaports and inland logistics centers, known as "dry ports" [6, 13, 14]. Modern research, including the works of E. Notteboom, J.-P. Rodrigue, J. Monios, and G. Wilmsmeier [12, 13], emphasizes forms of coopetition and the strengthening of port-hinterland linkages.

Contemporary scientific studies cover a wide range of issues, starting from terminal design and planning (configuration optimization, equipment selection), with the foundational work being the *Handbook on Terminal Planning* by J.W. Böse [8]. A closely related field is operational management and process optimization at CTs, where significant contributions were made by D. Steenken, S. Voß, and R. Stahlbock [15, 16]. Issues of efficiency and productivity, as well as integration of CTs into broader logistics networks (e.g., the concept of port-centric logistics [8]), also remain central. In recent years, there has been growing importance of research on technological innovations [1], automation [11], and the environmental aspects of terminal operations [9, 10].

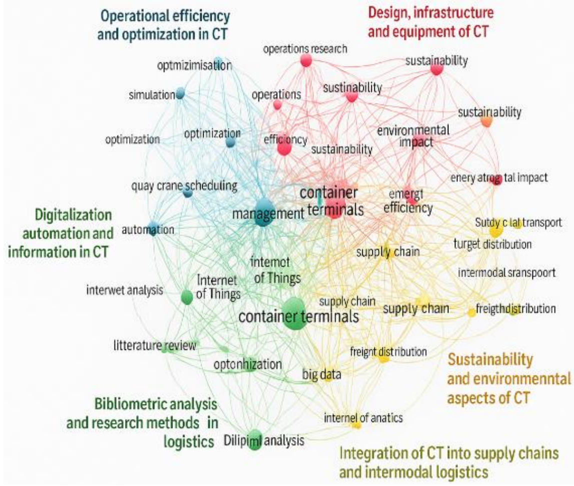
To study the structure and dynamics of various fields of knowledge, including logistics and transport, scientometric methods such as bibliometric analysis and keyword co-occurrence analysis are increasingly used [10]. Keyword co-occurrence analysis makes it possible to map the conceptual structure of a scientific field. For these purposes, specialized software tools such as VOSviewer [17] are used.

The works of Uzbek scholars, such as Kh. Rakhmankulov, G.R. Ibragimov [4], D.Yu. Khuzhamkulov [5], and others, are mainly focused on analyzing the current state [4], identifying problems [1], and developing proposals for the development of the country's transport and logistics system [5]. Their research often highlights issues such as the underdeveloped infrastructure [4], high transport costs, shortage of qualified personnel [5], and the need for systematic implementation of network and information technologies [1]. This focus on applied tasks creates a favorable basis for applying the results of global conceptual analysis to local conditions.

2. Research methodology

The final dataset, after selection and data cleaning, consisted of 1,258 publications for the period from 2000 to 2025. An increase in publication activity on the topic of container terminals (CT) is observed, especially over the past 5–7 years. Among the most productive journals are *Maritime Policy & Management*, *Transportation Research Part E: Logistics and Transportation Review*, and *Scientometrics*. Geographically, CT research is most actively conducted in China, the USA, the United Kingdom, the Netherlands, and South Korea. Leading institutions include Delft University of Technology and Erasmus University Rotterdam.

Using the VOSviewer software, a semantic network map of key terms was constructed (Figure 1). This network consists of 88 nodes (keywords that passed the occurrence threshold) and 450 connections between them. The size of the nodes on the map is proportional to the frequency of occurrence of the corresponding keywords, and the thickness of the connecting lines (edges) reflects the strength of their co-occurrence. The VOSviewer algorithm identified six main thematic clusters, marked on the map in different colors.



Picture 1. Semantic network map of key terms in container terminal research (2000–2025). Visualization based on analysis using VOSviewer

The analysis of the constructed semantic network made it possible to identify and characterize six main thematic clusters reflecting the key research directions in the field of container terminals (Table 1).

Table 1

Main thematic clusters and key terms in container terminal research

Cluster name (interpretation)	Main key terms	Brief description/interpretation of the cluster
Operational efficiency and optimization at container terminals	container terminal, operations research, simulation, optimization, efficiency, quay crane scheduling, yard management, berth allocation, stochastic models	The central cluster dedicated to improving the productivity and efficiency of container terminals using mathematical modeling and optimization methods.
Design, infrastructure, and equipment of container terminals	terminal design, layout, port infrastructure, handling equipment, automated guided vehicles (AGV), capacity planning, investment, dry port	Studies of the physical layout of terminals, equipment selection, capacity planning, investments, and the role of dry ports.

Integration of container terminals into supply chains and intermodal logistics	supply chain management, logistics, intermodal transport, hinterland connectivity, port-centric logistics, freight distribution, transport network, resilience	The role of container terminals as nodes in logistics systems, intermodal transportation, connections with hinterlands, development of the port-centric logistics concept, and supply chain resilience.
Sustainable development and environmental aspects of container terminals	sustainability, green port, emissions, environmental impact, energy efficiency, corporate social responsibility (CSR), climate change, circular economy	Reducing the negative environmental impact of container terminals, improving energy efficiency, implementing "green" technologies, and complying with environmental regulations.
Digitalization, automation, and information technologies in container terminals	automation, digitalization, information technology (IT), Internet of Things (IoT), big data, artificial intelligence (AI), blockchain, TOS, smart port	Implementation of advanced digital technologies for automation, improved data management, increased transparency and operational efficiency, and the development of the "smart port" concept.
Scientometric analysis and research methods in logistics	bibliometric analysis, VOSviewer, scientometrics, co-word analysis, literature review, research trends, network analysis	Methodological cluster reflecting the application of quantitative methods for analyzing scientific literature in logistics and container terminals, identifying trends and knowledge structure.

The cluster "Operational Efficiency and Optimization at Container Terminals" stands out due to its size and central position, indicating its maturity and fundamental importance. Clusters related to "Integration of Container Terminals into Supply Chains" and "Design and Infrastructure" also occupy significant places. Relatively new but rapidly growing areas such as "Digitization and Automation" and "Sustainable Development" form distinct clusters, pointing to their increasing relevance.

Overlay visualization by publication years in VOSviewer allows tracking the development dynamics of concepts. Terms related to traditional optimization and design methods were more characteristic of the earlier period studied. Meanwhile, terms related to "automation," "Internet of Things (IoT)," "big data," "sustainability," "green port," and "blockchain" show significant growth in frequency in recent publications, confirming a shift in research focus.

3. Discussion

The network analysis results not only characterize the current structure of this scientific field but also allow comparison with existing theories and identification of key development directions. The dominance of the "Operational Efficiency and Optimization" cluster confirms the ongoing relevance of productivity improvement challenges. The clusters "Design, Infrastructure, and Equipment" and "Integration of Container Terminals into Supply Chains" emphasize the importance of a systemic approach, consistent with evolutionary port system models such as "port regionalization," and highlight the significance of "dry ports." The emergence and growth of the "Sustainable Development" and "Digitization and Automation" clusters indicate substantial shifts in the research agenda under the influence of global environmental challenges and the potential of "Logistics 4.0" technologies. The cluster "Scientometric Analysis and Research Methods in Logistics" reflects the maturity of applying these methods to understand the field's development.

Identified global research trends have practical significance for the Republic of Uzbekistan, which is actively modernizing its transport and logistics system:

1. Trends in operational efficiency improvement, development of intermodal transportation, implementation of information technologies, and enhancement of connectivity with domestic production centers directly correlate with objectives set by the Law "On Transport," Presidential Decree PP-28, and other strategic documents of Uzbekistan. These include goals such as increasing the share of container transportation and creating a network of modern logistics centers [3, 5].
2. Given its geographic position, Uzbekistan critically needs research and practical solutions in the efficiency of "dry ports" [6, 14], optimization of intermodal logistics chains, and development of transit transport corridors.
3. Comparing the global concept map with the current state of research and practices in Uzbekistan may help identify underexplored but important topics, for example, applying artificial intelligence in predictive freight flow analysis or implementing circular economy principles. Plans for building new logistics centers should consider modern environmental standards and "green" technologies [9].
4. The conducted network analysis can serve as a tool for a more reasoned approach to prioritizing infrastructure investment, developing educational programs for logistics personnel training, and forming a national research agenda.

Several limitations of this study should be acknowledged. First, its results depend on the completeness and representativeness of the selected scientometric databases. Second, the interpretation of thematic clusters and individual terms inevitably contains an element of researcher subjectivity. Third, despite its broad capabilities, the VOSviewer software has limitations for some types of analysis, such as in-depth temporal dynamics analysis. Finally, the main focus on English-language scientific literature may not fully reflect the contributions of researchers publishing in other languages.

Further research in this area may include: conducting deeper qualitative content analysis of publications within each thematic cluster for detailed understanding of discussed issues; constructing and comparatively analyzing conceptual maps for different world regions or types of terminals (dry, river); supplementing co-occurrence analysis with citation and co-authorship analysis to identify the most influential works and researchers; as well as performing a similar scientometric analysis for Russian- and Uzbek-language scientific literature on container terminals and logistics to identify national specifics and compare them with global trends.

4. Conclusion

The present study, based on the network analysis of key terms, allowed the identification of the multifaceted structure of the scientific field dedicated to container terminals and the characterization of its main conceptual clusters. Both established, fundamental research directions such as operational efficiency and infrastructure design, as well as actively developing emergent topics related to digitization, automation, and sustainable development, were identified. The analysis demonstrated that container terminal research is becoming increasingly systematic, viewing terminals not as isolated objects but as key integrated components of global and regional supply chains.

The scientific contribution of this work lies in the application of objective scientometric methods to systematize knowledge and understand the intellectual structure and evolution of research in the field of container terminals, complementing traditional qualitative literature reviews. The practical significance of the study is especially high for the Republic of Uzbekistan. The identified global trends and dominant concepts can serve as a scientifically grounded guide for informing national transport and logistics policies, strategic planning for the development of container terminals and transport-logistics centers, as well as for determining priority research directions and improving the training system for specialists. Taking into account advanced global experience and current research will enable Uzbekistan to more effectively address the challenges of modernizing transport infrastructure, increasing its competitiveness, and fully integrating into international transport corridors.

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Greening the areas of urban bicycle lanes and its importance

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Abstract: This article explores the strategic importance of integrating green infrastructure into urban bicycle lanes as a tool for achieving sustainable urban development. Drawing from global experiences and data collected from major cities across Europe, Asia, and North America, the paper highlights how tree-lined bicycle routes contribute to environmental preservation, public health, and urban livability. Specifically, the study shows that vegetation along cycling paths reduces urban heat island effects, filters air pollutants (such as PM2.5 and CO_2), and enhances biodiversity in dense areas.

In addition to environmental benefits, green bicycle lanes improve the comfort and safety of users by providing shade, visual appeal, and a natural barrier between cyclists and motor traffic. The article emphasizes that such infrastructure not only increases cycling frequency but also reduces stress, supports mental well-being, and minimizes premature mortality risk due to enhanced physical activity. Economically, greening strategies around cycling infrastructure show positive returns through increased property values, reduced healthcare costs, and more sustainable land use.

By combining urban mobility with ecological resilience, green bicycle lanes emerge as a powerful instrument in rethinking transportation planning and human-centered city design. The article concludes with a series of policy recommendations and planning guidelines for municipalities seeking to implement green cycling networks in a balanced, inclusive, and cost-effective manner.

Keywords: green infrastructure, bicycle lanes, urban mobility, environment, sustainable city, microclimate

1. Introduction

Urbanization is accelerating globally, transforming not only how cities grow but also how people live, move, and interact. This rapid expansion of urban environments intensifies the need for transportation systems that are not only efficient, but also sustainable, safe, and supportive of public health. In response to growing environmental concerns and the increasing burden of traffic congestion, many cities are now prioritizing active modes of transport, particularly cycling. Bicycles, as a low-cost, low-emission, and health-enhancing mobility option, play a vital role in shaping future-ready cities.

However, developing cycling infrastructure requires more than just painting bike lanes on roadways. A truly inclusive and functional network must consider the surrounding urban fabric. Integrating greenery into bicycle infrastructure—through the planting of trees, shrubs, green belts, or vertical gardens—adds considerable value to cycling facilities. Green corridors along cycling routes provide much-needed shade in hot climates, reduce exposure to air pollution, mitigate the urban heat island effect, and enhance the visual and psychological experience of cycling. Numerous studies confirm that greenery has a measurable positive impact on mental health by lowering stress, anxiety, and fatigue, especially during daily commutes.

Real-world examples from cities like Copenhagen, Amsterdam, and Singapore demonstrate that green-integrated bicycle infrastructure leads to improved mobility outcomes and environmental resilience. In these cities, the strategic implementation of tree-lined cycle tracks has contributed to lower surface temperatures, better air quality, and significantly increased rates of bicycle use. Furthermore, such initiatives often correlate with broader urban development goals, including equitable access to transport, carbon neutrality, and enhanced biodiversity. By merging transport planning with ecological thinking, green bicycle lanes serve as multifunctional tools for building livable, climate-smart cities of the future [1][2].

2. Research methodology

This research adopts a multidisciplinary and evidence-based approach grounded in case studies and international datasets. The aim was to comprehensively evaluate the role of greenery in enhancing urban bicycle infrastructure and its implications for sustainability, health, and mobility.

Data were collected from a wide range of authoritative sources, including:

- **Municipal and national transport agencies**, such as *Eurostat*, *NACTO* (National Association of City Transportation Officials), and *ITDP* (Institute for Transportation and Development Policy), which provided quantitative data on cycling usage, infrastructure coverage, and policy implementation.
- **Urban climate and health databases**, including the *WHO Urban Health Initiative*, which offered insights into air quality, microclimatic variations, and public health outcomes in areas with and without green corridors.
- **Peer-reviewed academic literature**, GIS-based urban environmental assessments, and technical reports focusing on green infrastructure planning, ecological urbanism, and active transport systems.

The methodology focused on three core analytical dimensions:

- **Environmental Evaluation:**
  - Quantified the carbon sequestration capacity of vegetated zones adjacent to bicycle lanes using models based on species type, planting density, and urban layout.

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- Assessed local reductions in *PM2.5* and *NOx* levels through comparative air quality data from both green and non-green transport corridors.
- Evaluated the thermal moderation effects of vegetation on surface and ambient temperatures via satellite imagery and urban heat island (UHI) models.

- **User Behavior and Perception Analysis:**
  - Conducted user satisfaction surveys in selected cities to measure cyclists' preferences for greenery, perceptions of safety, and visual comfort.
  - Monitored cycling frequency and usage patterns before and after greening interventions using municipal bike count systems and smartphone-based mobility tracking tools.
  - Included behavioral insights into how urban greenery affects route choice and modal shift from cars to bicycles.
- **Economic and Social Impact Assessment:**
  - Estimated healthcare savings resulting from increased physical activity and reduced air pollution exposure.
  - Analyzed the influence of green bicycle lanes on nearby **real estate values**, **business activity**, and **urban regeneration** using urban economic datasets.
  - Explored aspects of **social equity**, including accessibility of green infrastructure to underserved neighborhoods and its correlation with mobility justice.
- Comparative analysis was conducted between cities with **well-developed green cycling networks** (e.g., **Montreal**, **Berlin**, **Singapore**, **Shenzhen**) and those with minimal greening (e.g., older districts of **Los Angeles** or **Istanbul**). A **mixed-method approach** was employed, combining:
- Visual and spatial surveys (on-site and satellite-based),
- GIS-mapping and environmental overlays,
- Structured literature review,
- Multivariable statistical regression models to detect correlations between greening intensity and observed benefits.

This layered and comprehensive methodology ensured both **quantitative robustness** and **contextual relevance**, enabling meaningful comparisons and reliable conclusions across different urban geographies [3][4][5].

3. Results and Discussion

The integration of greenery into urban bicycle infrastructure yields a variety of environmental, health, and urban planning benefits. Data gathered from over 30 cities confirms that green bicycle corridors contribute to climate resilience, physical activity, and economic value.

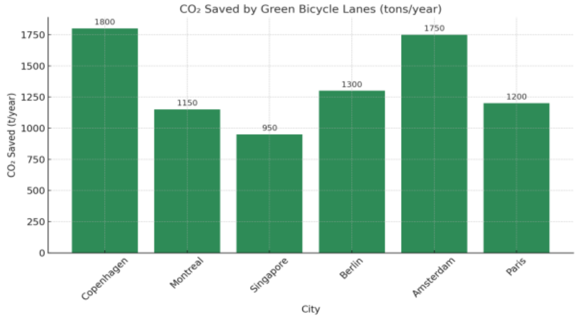
Environmental Impact of Green Bicycle Lanes

Tree-lined bicycle paths contribute to urban cooling, CO_2 reduction, and air purification. For example, in Barcelona, tree coverage along bike lanes helped reduce average summer temperatures by 1.5–2.8°C, lowering heat stress for cyclists [6].

Green vegetation absorbs 13–48 kg of CO_2 per m^2 annually depending on species, providing significant carbon offset in dense cities [7].

In Montreal, studies showed that bicycle lanes with surrounding greenery recorded 25–30% lower levels of PM2.5 compared to regular street lanes [8].

Picture 1. Example of green corridor along bicycle lanes in Berlin, Germany (source: Inhabitat, 2023)

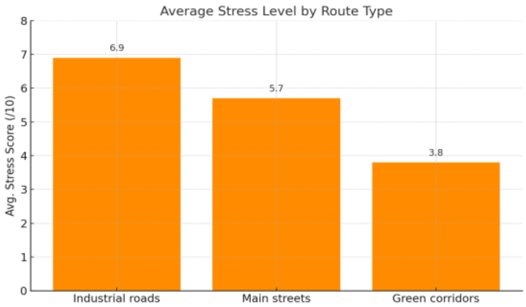


Graph 1. CO_2 reduction (in tons/year) by green bicycle lanes in 6 cities (*Source: EEA Green Infrastructure Report [9]*)

Health and Well-Being

Cyclists using green routes report 15–20% lower stress levels, as greenery activates calming neural responses [10]. In a 2021 study conducted in Amsterdam, cyclists who commuted through green areas had lower cortisol levels and better cardiovascular metrics [11].

Regular exposure to tree-lined routes during commute is associated with a 41% decrease in premature mortality risk [12].



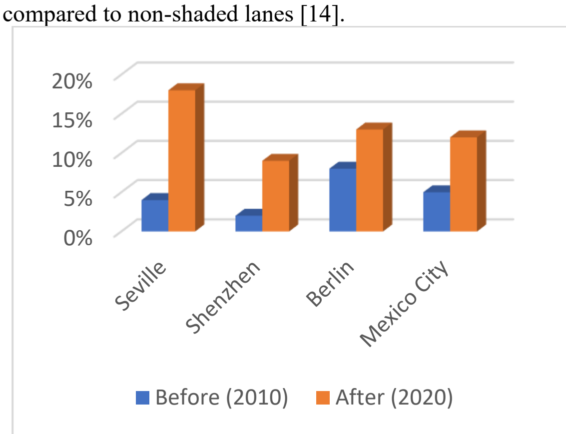
Graph 2. Stress reduction among cyclists based on commuting route types (Amsterdam, 2021)

Picture 2. A cyclist-friendly green route in Singapore (source: Urban Redevelopment Authority, 2022)

Mobility and Accessibility

The presence of trees improves route comfort, usability, and attractiveness, which increases ridership. In Seville, after green bike lanes were implemented in 2013–2017, daily cycling rates grew by 435% [13].

Moreover, shade provided by trees increases usage in hot climates — in Delhi, tree-covered lanes saw 3x more users compared to non-shaded lanes [14].



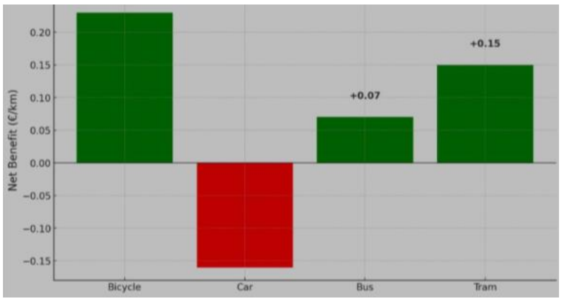
Graph 3. Change in cycling rates before and after green infrastructure introduction

Picture 3. Shaded cycling path in Mexico City (source: ITDP Mexico, 2021)

Economic and Urban Development Benefits

According to Copenhagen's municipal report, every 1 km of green bike lane returns €0.23 to the economy, compared to a −€0.16/km loss from car use [15]. These gains include reduced medical costs, better productivity, and tourism impact.

In Portland (USA), property values within 300 m of greened cycling corridors were 8–12% higher [16].



Graph 4. Net economic benefit per transport mode (€/km)

Picture 4. Example of urban integration of green cycling in Copenhagen (photo by cycling embassy, 2020)

Summary of Findings:

Impact Area	Benefit Observed	Source
Environment	–2°C cooling, 1–2 tons CO_2 saved/year	[6], [9]
Health	41% mortality risk ↓, lower cortisol	[10], [12]
Mobility	+435% ridership after greening	[13], [14]
Economy	+€0.23/km economic gain	[15], [16]

4. Conclusion

Greening bicycle lanes in cities provides a wide range of benefits that go beyond simple aesthetics. Vegetation along cycling routes helps improve air quality by filtering harmful pollutants and reduces urban heat through shade and cooling effects. These natural elements create a more comfortable and safer environment for cyclists, especially during hot seasons.

Green routes also have a strong impact on public health. Cyclists riding through tree-lined paths report lower stress levels, increased motivation to cycle, and greater mental and physical well-being. This encourages regular physical activity and supports healthier lifestyles across urban populations.

Moreover, the presence of greenery boosts the attractiveness of bicycle lanes, leading to increased usage and a shift from car to bicycle travel. As a result, cities experience reduced traffic congestion, lower noise pollution, and decreased greenhouse gas emissions. Economically, green infrastructure contributes to higher nearby property values and lower healthcare costs.

In summary, integrating greenery into bicycle infrastructure is a smart and sustainable solution. It enhances mobility, supports public health, and helps cities become more livable, environmentally friendly, and resilient.

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Optimizing route loading by rationally allocating resources in the public transport system and meeting passenger demand

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Abstract: This article examines the issue of efficient distribution of 110 buses in the public transport system of the Republic of Karakalpakstan along five main routes. In order to rationally plan bus resources, a two-stage, simple calculation-based FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model was proposed. In the first stage of the model, the minimum number of buses sufficient to cover the daily passenger demand for each route was determined. In the second stage, the remaining excess buses were redistributed in proportion to the passenger flow and load level. According to the results of the study, 43 buses were distributed to five routes based on specific criteria, and the quality of service on some routes was significantly improved. In particular, the load level on routes such as R1 and R3 was optimized, waiting times were reduced, and overall balance was ensured. The proposed FRESET model is recommended as a practical, simple, and widely applicable solution for organizing regional transport networks.

Keywords: public transport, bus distribution, transport model, FRESET, Karakalpakstan, passenger demand, route optimization, heuristic method, logistics, transport service quality

1. Introduction

Public transport systems in countries are of social importance, playing an important role in ensuring population mobility, supporting economic activity and contributing to environmental sustainability. In Uzbekistan, public transport is mainly organized by the state, but decisions in the sector are often made based on short-term needs and the existing situation. This leads to poor quality of public transport services, imbalances in bus allocation and failure to meet passenger demand [1], [2].

Inadequate distribution of buses across the network results in overcrowding on some routes and inefficient use of the service on others. In particular, in intercity and regional routes, buses are often distributed on the basis of unmarked criteria, which causes problems in providing services to the population [3], [4].

International experience shows that optimizing the transport network and properly distributing buses along routes increases population mobility and allows for efficient use of resources. For example, Ceder and Wilson (1986) proposed a model for determining frequency based on route load and demand for bus network scheduling [5], [6]. Fan and Machemehl (2004) proposed a model for restructuring the network based on load balance [7]. Bashar and Garcia (2012) proposed solving bus distribution on interconnected routes through a simulation model [8].

In the Republic of Karakalpakstan, Uzbekistan, transport flows have increased significantly in recent years. At the same time, buses are unevenly distributed across routes: some routes have a load factor of more than 100%, while others are only used by 40–50%. This situation reduces economic efficiency and creates inconvenience for passengers [9].

To solve this problem, the article proposes a two-stage heuristic model called FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit). The model first calculates the base number of buses on routes, and then redistributes the remaining buses to routes based on load and demand indicators. The model is built in a way that is not algorithmically complex and is suitable for use by many transport agencies and is understandable.

The article demonstrates the practical results of this approach using the example of the transport network in the Republic of Karakalpakstan. Based on calculations, it was determined that the FRESET model can improve route loading by 20–30% and increase the overall quality of service.

2. Research methodology

The bus network in the Republic of Karakalpakstan consists of large and interconnected regional routes, with passenger traffic unevenly distributed at different times and across the region. This situation leads to overloading (congestion) on some routes, and inefficient bus traffic on others. The goal is to distribute the available buses (n=110) to routes in such a way that the distribution of buses to routes is balanced and no route is overcrowded.

Initial information

Direction	Daily demand (passenger)	Route length (km)	Bus capacity	Basic bus the number
R1	2500	12	50	7
R2	1800	10	50	5
R3	3200	15	50	9
R4	1400	8	50	4
R5	2000	11	50	6
Total	10,900			31

(“Baseline bus count” refers to the minimum number of buses needed to cover demand on each route)

2.1. Basic allocation step

The number of base buses needed to cover the daily demand on the routes was calculated using the following formula:

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$$f_i = \left\lceil \frac{D_i}{C * N_i} \right\rceil$$

Here:

f_i- number of buses needed to cover the demand for route i,

D_i - daily passenger demand for route i (based on OD data),

C - capacity of one bus (number of passengers),

N_i- number of daily trips of the bus for route i (in the model, one bus makes 5 trips per day),

$\lceil * \rceil$- integer increasing function

Basic distribution step for route R1:

$$f_{R1} = \left\lceil \frac{2500}{50 * 5} \right\rceil = \left\lceil \frac{2500}{250} \right\rceil = 10$$

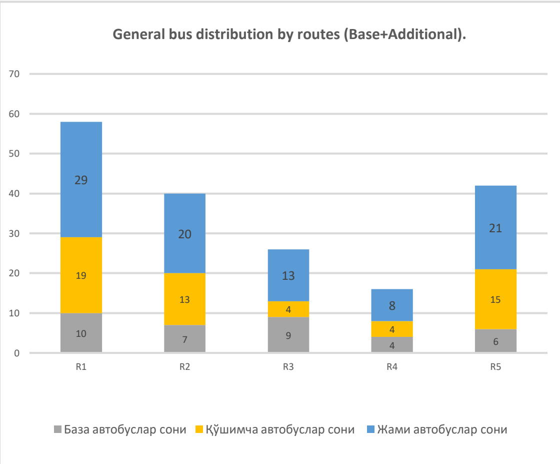

Figure 1. General bus distribution by routes (Base+Additional)

If a bus makes 5 trips per day, N_i=5, and the formula is adjusted accordingly. In this study, a FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model is proposed to rationally distribute buses across the urban transport network. This model was implemented in two stages:

2.2. Additional bus redistribution phase.

After 31 base buses, the remaining 110−31=79 buses are redistributed across the network. This allocation is made in proportion to the demand and load level on the route.

$$e_i = \left\lceil \frac{D_i}{\sum D_i} * E \right\rceil$$

e_i- the number of excess buses allocated to the i-th route,

$\sum D_i$- total passenger demand on all routes,

E- number of additional buses (vacant),

Stage of redistributing additional buses

For Route R1:

$$e_{R1} = \left\lceil \frac{2500}{10{,}900} * 79 \right\rceil = 19$$

Thus, according to calculations made taking into account the demand and load level on the routes, 10 base buses were determined as necessary at the previous stage to cover the daily demand of 2,500 passengers for the R1 route; in addition, as a result of the proportional distribution of a total of 79 excess buses based on the FRESET model, 19 additional buses were allocated to the R1 route, bringing the total number of operating buses to 29, creating the opportunity to cover the high passenger flow with stable and efficient service.

3. Results

Within the framework of this study, the redistribution of 110 existing buses along routes was implemented in the bus network of the Republic of Karakalpakstan, based on the FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model. The aim was to meet passenger demand, balance the load, and improve the efficiency of service quality.

First and foremost, 31 buses were allocated as a "base distribution" to meet the minimum requirements for each route based on daily demand. The remaining 79 buses were redistributed proportionally according to passenger flow, route length, and occupancy levels. Specifically, for the R1 route, considering the daily demand of 2,500 passengers, 10 base buses were allocated, and an additional 19 buses were redistributed according to the model, bringing the total number of buses to 29. This decision aims to improve service quality by reducing congestion on this route and increasing trip frequency, as shown in Figure 1. For the R3 route, which recorded the highest occupancy, a total of 13 buses were allocated, including 4 from the redistribution. This allows for effectively reducing the load on this route and preparing for future growth in passenger demand. Similarly, due to high demand on the R5 route, 6 base and 15 additional buses were allocated, totaling 21 buses.

The advantage of the FRESET model is that it enables optimization of resource allocation in a complex transport system through a simple, calculation-based approach, relying on local conditions and data. This, in turn, allows for the optimization of operational costs, reduction of traffic congestion, and ensures the stability of public transport services provided to the population.

4. Conclusion

This study demonstrated the potential to enhance public transport efficiency in the Republic of Karakalpakstan by redistributing existing vehicles in the bus network according to demand and passenger load levels. A two-stage approach, developed based on the FRESET (Frequency Rationalization for Efficient Scheduling of Entire Transit) model - comprising basic distribution and redistribution of surplus buses - balanced the load across routes and ensured equitable resource allocation in service provision. Out of a total of 110 buses, 31 were allocated as a basic distribution to meet the minimum demand on routes, while the remaining 79 buses were distributed proportionally to passenger flow. For instance, the high-demand R1 route was assigned 29 buses in total, consisting of 10 base buses plus an additional 19 buses to accommodate the increased passenger volume.

This served to stabilize transport services on this route and reduce waiting times. Additionally, due to high demand on the R5 route, a total of 21 buses were allocated, bringing the quality of service to an optimal level. In the research process, the use of a practical and modular approach based on precise calculations, instead of complex mathematical modeling, increased the applicability of the model in real-world conditions. This approach has proven to be one of the most effective solutions not only for the rational use of available resources but also for optimizing operational costs, reducing traffic congestion, and providing high-quality transport services to the population.

In the future, the model can be further improved by enriching it with parameters such as real-time passenger flow, changes in demand throughout the day, strategic importance of transport interchange points, and route significance. This enhancement expands the possibilities for implementing the model at a regional scale and in other cities.

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Traffic flows on urban roads and their impact on public transport users

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Abstract: This article analyzes the formation and development of urban traffic flows and their impact on public transport users. Currently, the increase in population, urban expansion, and the growing number of vehicles have intensified traffic congestion on city roads. This situation negatively affects public transport operations, causing time losses for passengers, a decrease in comfort levels, and adverse environmental impacts. During the study, urban traffic flows were analyzed under real city conditions, and the factors affecting the efficiency of public transportation were identified. The article proposes solutions such as reducing congestion through the use of modern transport models, prioritizing public transport, and improving passenger convenience. According to the results, measures such as allocating dedicated lanes for public transport, implementing intelligent traffic light control systems, and forecasting passenger flow in advance are of significant importance. In conclusion, effective management of urban traffic flows ensures a convenient and stable transport experience for public transport users.

Keywords: transport, passenger transport, public transport sector, education, system

1. Introduction

The current period is characterized by the rapid development of cities, the improvement of improvement works and the sharp increase in the number of city residents. In such conditions, provision of high-quality transport services to city residents requires further development of city passenger transport, development of new and more efficient ways of transportation [1]. The organization of road transport in the city transport network has its own characteristics. It should be noted that the main complexity of the management of passenger transportation processes in cities is the uncertainties in the formation of transportation flows [2,3]. The impact of most factors affecting the size of the passenger flow is changing over time and has a probabilistic character.

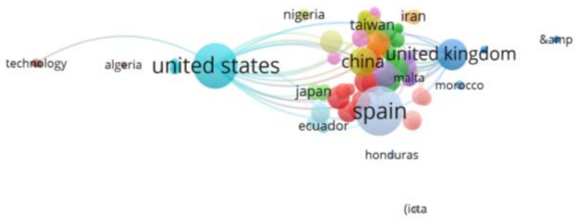

Fig. 1. Countries engaged in urban passenger transport

The multi-phase study was based on individual in-depth interviews with 50 senior local passenger transport operators, government officials, lobbyists and experts from New Zealand and around the world; and four validation workshops with 28 sector stakeholders [4]. The data was analysed using mostly pre-determined themes from which four scenarios were constructed and then validated. The implications are that the local passenger transport system is about to transition to a system of 'shared mobility; public transport will need to evolve to stay relevant but will remain important in any scenario; and the role of Government will be vital in overseeing the transition to the shared mobility era. These lessons are now being used to inform transport and broader policy decisions across New Zealand [5]. Overall, the study is the first to apply such a global and qualitatively rich dataset to view the long-term future local passenger transport system as a whole [6].

2. Research methodology

Much has been written about the accelerating pace of societal and technological change, but, until recently, such statements have not typically been applied to the public transport sector. Indeed, the operational concept underlying the bus for instance (i.e. large vehicles on fixed routes and operating on fixed timetables) has not fundamentally changed as a concept since its introduction almost 200 years ago [7-9]. There is however growing evidence that this perspective is now beginning to change, with several recent reports serving to emphasise the need to understand the changing mobility landscape and the implications for the public transport sector. Thus, the UK government policy paper, The Future of Mobility (GOfS 2019) proclaimed this to be "a time of unprecedented change in the transport system", whilst KPMG's Mobility 2030 study reported that technological innovation will "completely disrupt" the mobility ecosystem within a decade [10].

In response to this situation, in August 2015 the New Zealand Ministry of Transport commissioned the Public Transport 2045 (PT2045) study to consider how different local public transport futures might affect society over a 30-year time horizon, and at how governments might best respond to secure the 'best' outcomes possible. The latter aim reflects the strong influence that transport systems have on the liveability of cities. A role for policy makers at a time of technological and behavioural transition is to envision the types of places that their citizens can live in and to shape the urban transport systems involved. The purpose of this paper is to present the results of this study.

The formation of passenger flows is also influenced by the time of day, days of the week and seasons of the year[10,11].

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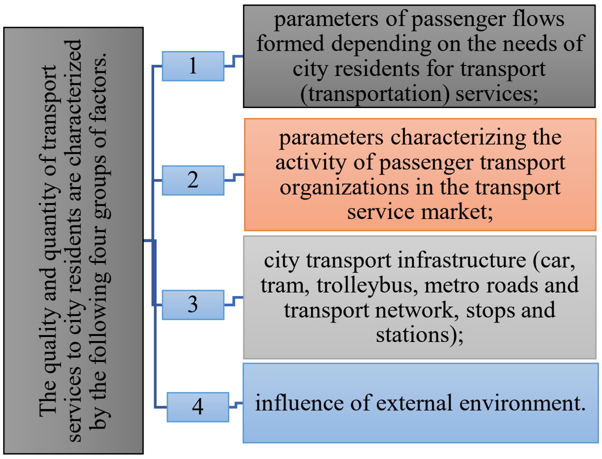

Fig. 2. The quality and quantity of transport services to city residents are characterized by the following four groups of factors

3. Results and Discussion

The demand for urban passenger transport services can be estimated based on the study and analysis of passenger flows. To a certain extent, the study of flows can also provide information about the movement of the population between different territorial districts, areas and addresses of the city territory. Flows arise from the need of passengers to move around the city.

Although there are currently many methods of monitoring and analyzing passenger flows, the following two disadvantages are common to all of them:

1) the study of passenger flows is carried out in a certain area of the city at a certain time interval, however, the results obtained in this case are generalized to the whole city and used for all time intervals;

2) the studied situation belongs to the past, but its results are used for future solutions. In other words, the studied passenger flow is the result of the actual fulfillment of the demand for transport in the past, and the expected flow in the future may be different from it;

3) the study and analysis of flows is a very labor-intensive activity (thousands of man-hours), which requires very large costs. The problem can be solved through mathematical models that reflect the connection between the volume of transportation expected in the future and the factors that cause the movement of the city's population. It is important to take into account the factors of the following three groups that shape the transport mobility of the population when determining the future sizes of passenger flows (Figure 1):

The first group of factors allows to characterize the conditions of passenger transport: city plan and planning; location of residential areas, cultural recreation areas, trade centers and industrial enterprises, field yards; road network and infrastructure location; the observed time - season, month, days of the week, hours of the day, etc.

The second group of factors characterizes the population's demand for passenger transportation. The segmentation of this demand depends on the social and professional structure of the city's population. This largely depends on their requirements for the price of the transport ticket, speed of movement, convenience, reliability and safety. The indicator of grouping of passengers' demands for urban transport can be a socio-economic assessment of the time spent on their movement.

The third group of factors is explained by the competitive environment of urban passenger transport. Carriers with various forms of organization and ownership participate in the city transport service market: joint-stock companies, limited liability companies or private entrepreneurs, etc.

The activity of city passenger carriers is carried out within the framework of the current legal and regulatory provisions and under the control and influence of the city authorities. Management of passenger transportation processes in the city is to effectively meet the needs of the population on the basis of effective planning and management of passenger flows and the delivery of relevant information from the destination to the destination. The purpose, tasks and indicators of the planned transport service are determined by the transportation needs of the population. The logistic goal of public transport activities is to minimize the total costs while being able to fulfill the tasks of providing services to the population.

The criteria for providing transportation services to the population is determined based on the extent to which the requirements for the volume and quality of transportation must be fully met. For example, it is necessary to ensure the exact execution of the established action schedule. The higher the requirements for the level of service, the higher its price. But the price itself cannot be an objective function, so a certain compromise has to be found. The main problem in determining the purpose of the transport service is the need to take into account all the interests of society. In doing so, we should not limit ourselves to taking into account the interests of vehicle owners or public transport companies.

Due to this, it is necessary to take into account the implementation of the following stages in order to achieve the goal based on the formation and application of the strategic logistic management model of passenger transportation processes in the city:

Stage 1: the political and social goals of the city management bodies to improve the quality of passenger transportation processes in the city and justification of ways to achieve them;

2nd stage: to determine the factors affecting the criteria for the population's choice of means of transportation in the city, to influence these factors in order to increase the convenience of city passenger transport;

Step 3: determine the costs necessary to ensure the development trajectory of the logistics system, compare them with existing opportunities and, if necessary, identify sources of additional opportunities.

Based on the performance of the above steps, the necessary levels of the indicators of passenger transportation service impact on traffic safety will be determined.

The following can be indicated as such indicators:

1) walking distance to the stops of the passenger transport route;

2) operational qualities of the passenger transport vehicle (capacity, ease of walking, etc.).

Regardless of the ownership of the buses, they mainly run on predetermined routes and provide transport services to the population.

The concept of route is important in setting and solving issues of organizing and managing passenger transportation processes. In short, it is necessary to implement the political and social goals of the strategic logistics management model

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of passenger transport processes in the city. The analysis shows that the importance of transport in the private sector is increasing day by day. The main reason for this is the creation of various forms of private ownership, the adoption of laws and decisions on the development and protection of small and medium-sized businesses, and the creation of conditions for free competition between them and their protection by law.

The transport system is about to transition to a system of 'shared mobility'. Three of the four scenarios envisage futures where private car ownership has dramatically fallen because alternatives have developed that people find more attractive. So, in 'Shared Shuttles', increasing urban density makes it easier for many people to access work, education, recreation, and friends.

4. Conclusion

It is the first study to take such a broad view of the long-term future passenger transport system whilst using such a qualitatively rich and globally diverse set of interview and workshop data. Specifically, the study draws on 50 in-depth interviews with practitioners from New Zealand and from around the world, the results of which were then validated at four workshops which were attended by 28 practitioners in total.

Due to the fact that the questions asked in this study were intended primarily for a Government study, survey interviewees were assured raw data would remain confidential and would not be shared.

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Forecasting the technological development of the falcon launch vehicles using a mathematical modeling approach

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Abstract: The rapid advancement of private aerospace initiatives has intensified the need for strategic forecasting of launch vehicle technologies. This study presents a mathematical projection of the technological evolution of SpaceX's Falcon 9 and Falcon Heavy rockets over the period 2025–2030. In light of increasing global reliance on reusable launch systems, the research addresses the current gap in quantitative forecasting models tailored to specific vehicle platforms. Five critical factors were identified: reusability technology, financial investment, volume of scientific research, technical innovation index, and expert assessments. Each variable is modeled using appropriate mathematical functions, and their relative influence is weighted based on literature review and expert judgment. The resulting compound model calculates annual technological advancement scores for both launch systems. Additionally, the study evaluates the economic efficiency of these developments and explores their potential implications for emerging space programs in developing countries, particularly Uzbekistan. The findings offer valuable insights for policymakers, engineers, and investors aiming to optimize long-term strategic planning in the rapidly evolving space industry.

Keywords: Falcon 9, Falcon Heavy, Forecasting, Mathematical modeling, Reusable launch systems, Economic efficiency

1. Introduction

The 21st century has witnessed a paradigm shift in the global space industry, driven by the growing involvement of private aerospace enterprises. Among these, SpaceX (Space Exploration Technologies Corp.), established by Elon Musk in 2002, has emerged as a pioneering force in space transportation and reusable launch systems. SpaceX has revolutionized the launch vehicle sector through innovative designs and cost-effective solutions, particularly with its Falcon series of rockets.[1].

The Falcon 9, first launched in 2010, is a partially reusable two-stage rocket developed to transport cargo and crew to low Earth orbit (LEO), as well as to deliver payloads to various other orbits. Its larger counterpart, the Falcon Heavy, introduced in 2018, incorporates three Falcon 9 first-stage boosters and is currently the most powerful operational rocket globally in terms of payload-to-orbit capability. These rockets represent a breakthrough in reusability technology, which significantly reduces launch costs and turnaround time, enabling more frequent missions and greater access to space.[2],[3].

In recent years, the continued refinement of propulsion systems, guidance software, launch logistics, and payload integration has positioned the Falcon launch systems as central assets in both commercial and governmental space missions. With the growing demands for satellite deployment, space station resupply, and even crewed missions, the future trajectory of these systems requires accurate forecasting to inform both engineering strategies and investment decisions.

This research focuses on the forecasting of technological development for the Falcon 9 and Falcon Heavy launch vehicles over the period 2025 to 2030. A mathematical model was constructed based on multiple influencing factors, including reusability maturity, financial investment, research activity, technical innovation index, and expert assessments. These factors were quantified and analyzed to project the future technological performance of each rocket variant. The model also considers empirical data and uses weighted indicators to evaluate the progression over time.[4],[5].

In addition to the technological projection, this study examines the economic efficiency of Falcon rockets, analyzing cost-per-launch reductions, mission frequency growth, and overall industry impact. The research also assesses how such launch systems could be utilized or adapted within the context of Uzbekistan's emerging space infrastructure, offering national-level insights and recommendations.[6],[7].

Ultimately, the study contributes to the broader discourse on sustainable space launch technologies, providing a replicable methodology for other launch systems and highlighting SpaceX's role in shaping the future of orbital access.

2. Research methodology

The primary objective of this study is to forecast the technological advancement levels of Falcon 9 and Falcon Heavy launch vehicles over the period from 2025 to 2030 through mathematical modeling. The employed model falls under the category of a multi-factor empirical weighted mathematical model. It exhibits a deterministic nature and incorporates semi-linear characteristics, combining both logarithmic and linear elements. The methodological approach involves time-dependent analysis of each contributing factor, weighted according to its significance, to calculate the overall trajectory of technological development.[8].

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Table 1

Description and mathematical expression of indicators

№	Description of Indicator	Mathematical Expression	Weight Coefficient
1	Technological potential of reusability	$f_1(t)=\ln t - y_0 + 1$	0.25
2	Scale of financial investments (log-scaled)	$f_2(t)=\ln(F(t))$	0.15
3	Rate of research publications and patents	$f_3(t=R(t)$	0.20
4	Innovation progression index	$f_4(t)=1+0.05\cdot(t-2025)$	0.20
5	Evaluations given by expert professionals	$f_5(t)=E(t)$	0.20

Clarification of Each Factor (Rewritten)

Technological Potential of Reusability. This parameter assesses the advancement stage of rocket reuse technology, reflecting how mature and economically viable reusability has become over time.

Scale of Financial Investments (log-scaled). It measures the amount of yearly investments allocated to development, modeled logarithmically to reflect diminishing marginal effects of capital input.

Rate of Research Publications and Patents. Represents the number of academic and technical outputs such as journal articles and intellectual property filings related to Falcon-class launch systems in a given year.

Innovation Progression Index. A factor estimating annual technological improvements, based on the assumption of a 5% annual increase in innovation performance after 2025.

Evaluations Given by Expert Professionals. Derived from domain experts' scores (on a 1–10 scale), this indicator reflects qualitative assessments of the rockets' technological status and potential.[9],[10].

Weight Justification for Analytical Factors

The weight coefficients for the selected indicators were determined based on expert evaluations and prior analytical studies in the field. The distribution rationale is as follows:

- Technological potential reusability (0.25) – As the key driving force behind innovation and cost-efficiency in launch systems, this factor is assigned the highest weight.
- Scale of financial investments (log-scaled) (0.15) – Although budget allocation is essential, it does not always directly translate to technological breakthroughs, thus receiving a slightly lower weight.
- Rate of research publications and patents (0.20) – The number of scientific publications and patents is closely correlated with innovation; hence, it holds high importance.
- Innovation progression index (0.20) – This factor reflects steady advancement in technology through regular upgrade cycles.
- Evaluations given by expert professionals (0.20) – Although based on subjective insights, expert assessments are valuable in forecasting the long-term technological potential.[11].

Explanation of Each Factor and Formula

Technological Potential of Reusability

$$f_1(t)=\ln t - y_0 + 1 \quad [1]$$

- t = year of evaluation.
- y_0 = base year when reusability was initiated.

This logarithmic model represents diminishing returns from maturing technologies.[12].

Scale of Financial Investments (log-scaled)

$$f_2(t)=\ln(F(t)) \quad [2]$$

- $F(t)$ = total capital allocated for development in year (t).

Logarithmic modeling captures saturation in investment impact.[13],[14].

Rate of Research Publications and Patents

$$f_3(t=R(t) \quad [3]$$

- $R(t)$ = number of publications or patents

Indicates growth of technological knowledge and innovation rate.

Innovation Progression Index

$$f_4(t)=1+0.05\cdot(t-2025) \quad [4]$$

Suggests 5% yearly incremental technical improvement based on a fixed 2025 baseline.

Evaluations Given by Expert Professionals

$$f_5(t)=E(t) \quad [5]$$

- $E(t)$ = average rating from aerospace experts (1–10 scale)

Final Composite Model

The technological progress index $T(t)$ is computed by aggregating weighted values of each factor:

$$T(t) = \sum_{i=1}^{n} \omega_I \cdot f_i(t) \quad [6]$$

Where:

- ω_i = assigned weight of factor i
- $f_i(t)$ = computed value of factor i at year t

This model enables year-by-year forecasting of the overall development trajectory of launch vehicle technology, based on transparent and justifiable indicators.[15].

Sample Factor Calculation for Falcon 9

For the year 2025, the reusability factor $f_1(t)$ was calculated using the logarithmic growth function:

$$f_1(2025) = \ln 2025 - 2025 + 1 = \ln(1) = 0$$

This reflects 1 years of continuous reusability advancements.

Other indicators were estimated as follows:

Financial Investment:

$$f_2(2025) = \ln(8000) = 8.987$$

where $8 billion is the estimated annual cost (100 launches × $70M + operational costs).

Scientific Publications:

$$f_3(2025) = 2$$

— derived from relevant studies and databases (e.g., NASA ADS, Google Scholar).

Technical Upgrade Index:

$$f_4(2025) = 1 + 0.05\cdot(2025 - 2025) = 1$$

Expert Evaluations:

$$f_5(2025) = 7.5/10$$

based on online technical forums and performance metrics.[16].

These values were integrated into the composite development score using the following weighted model:

$$T\,(2025) = (0 \cdot 0.25) + (8.987 \cdot 0.15) + (2 \cdot 0.20) + (1 \cdot 0.20) + (7.5 \cdot 0.20) = 3.448.$$

All numerical data used in this article — including the projected financial investments, number of scientific publications, technological upgrade indices, reusability metrics, and expert evaluations for the Falcon launch vehicles from 2025 to 2030 — were derived from publicly available sources. These include official SpaceX data, academic databases such as Google Scholar, NASA ADS, arXiv, and analytical platforms like Reddit, SpaceflightNow, and Everyday Astronaut.[17],[18]. Some forecasted indicators were extrapolated and adjusted based on actual data to fit the modeling approach. For full transparency, all references and data sources are listed in the **"References"** section at the end of the article.

3. Results and discussion

In this study, a quantitative forecasting model was developed to assess the technological advancement of SpaceX's Falcon 9 and Falcon Heavy launch vehicles for the period of 2025 to 2030. The model incorporates five core factors—reusability technology, financial investment, scientific research output, technological upgrade index, and expert evaluations—each weighted according to their influence on technological progress. The table below summarizes the calculated technology development scores for each year, along with the annual growth rate:

Table 2

Forecasting results for falcon 9 (2025-2030)

Year	Falcon 9	Falcon 9 Growth (%)
2025	3.448	0%
2026	4.060	+17.75%
2027	4.599	+33.38%
2028	5.109	+48.17%
2029	5.603	+62.50%
2030	6.077	+76.25%

Table 3

Forecasting results for falcon heavy (2025-2030)

Year	Falcon heavy	Falcon heavy Growth (%)
2025	1.829	0%
2026	2.366	+29.36%
2027	2.617	+43.08%
2028	2.934	+60.42%
2029	3.020	+65.12%
2030	3.309	+80.92%

The results show a clear and steady upward trend in technological development for both Falcon 9 and Falcon Heavy over the forecast period. Falcon 9 is expected to reach a 76.25% increase in its technology development index by 2030 compared to the base year 2025. Similarly, Falcon Heavy shows even stronger relative growth, reaching approximately 80.92% by 2030, which can be attributed to gradual improvements in reusability, upgraded hardware components, and increasing research focus [19].

These values reflect the growing influence of consistent investment, iterative engineering improvements, and accumulated research and development activities. Notably, while Falcon 9 maintains a higher absolute score due to its maturity and higher flight frequency, Falcon Heavy exhibits faster growth because of its potential in heavy payload missions and strategic development efforts in the late 2030s.

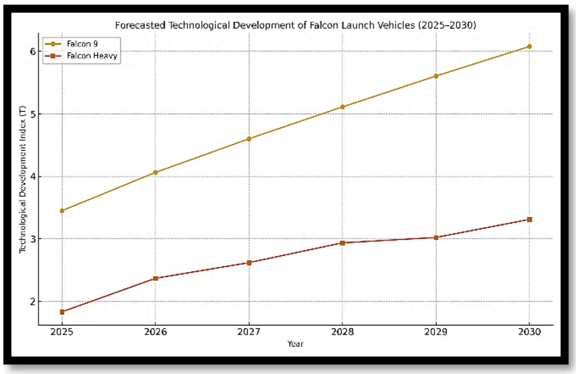

Fig. 1. Forecasted technological development of Falcon launch vehicles (2025 -2030)

From the data analysis, several conclusions can be drawn. Firstly, consistent technological advancement requires the integration of multiple interrelated factors: engineering innovation, budget allocation, academic contributions, and expert validation. Falcon 9's higher maturity level provides a strong foundation for stable incremental progress, while Falcon Heavy, though less utilized, benefits from intensified development efforts.

These trends indicate that future space technologies are likely to evolve not just through increased launches, but through synergistic improvements in design efficiency, resource optimization, and scientific collaboration.

From a practical perspective, such progress has wider implications. For countries like Uzbekistan, the increasing availability and affordability of launch services driven by reusable rockets could open new opportunities in Earth observation, agriculture monitoring, disaster management, and satellite communications. Establishing partnerships or knowledge transfer programs with companies like SpaceX could accelerate the development of domestic aerospace capabilities and support long-term national innovation strategies.[20].

In summary, the model not only projects optimistic growth in Falcon launch vehicle technologies but also highlights how such advancements can extend beyond their origin, offering broader economic and scientific benefits on a global scale.

4. Conclusion

This study focused on forecasting the technological development of Falcon 9 and Falcon Heavy launch vehicles for the period of 2025–2030 using a multi-factor mathematical modeling approach. The results demonstrated a steady and significant technological advancement trend for both rockets, particularly Falcon 9, which benefits from a higher flight frequency and more refined reuse technology.

The modeling incorporated five weighted factors: reuse technology maturity, financial investments, scientific publications, technical innovation index, and expert evaluations. The projected data revealed that Falcon 9's technological development is expected to grow by approximately **76.25%**, while Falcon Heavy is projected to grow by around **80.92%** by 2030, compared to their 2025 levels. This highlights the intensifying focus and investment in launch systems capable of supporting increasingly complex missions and commercial demand.

The study also confirms that multi-criteria modeling can effectively estimate future progress in aerospace technologies, especially when exact empirical data is limited. Such models can guide government bodies, private investors, and research institutions in their strategic planning and resource allocation.

Moreover, the findings underline potential opportunities for countries like Uzbekistan, where the growing commercialization of space and the availability of reusable launch vehicles may open doors to cost-effective satellite deployment, technological cooperation, and national aerospace program development.

Future research may enhance the model by integrating more dynamic variables, such as international policy shifts, unexpected technological disruptions, or new competitors in the launch industry.

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Theoretical approaches to cutting force determination: a review

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Abstract: This article provides a comprehensive review of the main theoretical approaches to determining cutting forces that have been proposed in various scientific studies. Each method is analyzed in terms of its fundamental principles, advantages, limitations, and suitability for application in industrial machining processes. Particular attention is given to the comparison between theoretical calculations and experimental results, which allows for an objective evaluation of the accuracy and reliability of the reviewed models. The paper discusses both classical theories, such as those developed by Merchant and Zorev, and more advanced concepts proposed by researchers like Klocke, Davim, and Astakhov, including energy-based and wave-dependent models. By exploring a wide range of equations and analytical methods, the article highlights how cutting force is influenced by factors such as material properties, cutting speed, depth of cut, and tool geometry. The findings of this review contribute to a better understanding of cutting mechanisms and can be effectively used to improve the prediction of cutting forces, optimize machining parameters, reduce tool wear, and enhance the quality of machined components.

Keywords: machining, cutting force, theoretical methods, cutting force calculation, experimental comparison

1. Introduction

During the cutting process, resistance forces act on the cutting edge of the tool, opposing its motion along the trajectory of the relative working movement. The resultant of these forces is referred to as the cutting force. The study of cutting force is of significant interest, as its values are essential for calculating the mechanisms of feed and primary motion in machine tools. Knowledge of the cutting force enables regulation of the cutting process, including control of machine power consumption, assessment and adjustment of the temperature in the cutting zone, prevention of vibrations, and other related aspects.

Therefore, the considerable interest of researchers in the prediction and analysis of cutting forces is explained by the high relevance of this issue for improving the efficiency of machining processes, optimizing technological parameters, and reducing tool wear [1, 2].

In numerous studies dedicated to cutting force investigation, two main methods for determining its values are commonly used: theoretical and experimental. Both approaches have their own advantages and limitations. Researchers do not rely on a single method but continue to explore new ways of measuring cutting forces. This article focuses primarily on theoretical (analytical) methods for determining cutting force. A wide range of theoretical approaches has been developed for evaluating cutting forces. The present work emphasizes the analysis of existing theoretical methods, their development and practical application in industrial settings, as well as their comparison with experimental results.

2. Research methodology

2.1. Merchant's Circle Diagram and Zorev's Theory

The first theoretical studies on the determination of cutting forces are described in the works of Merchant [3, 4]. In his research, Merchant decomposed the resultant cutting force into several vector components, whose directions are inscribed within a circle. This graphical representation became known as the "Merchant's Circle Diagram" (Fig. 1).

As can be seen, the resultant force R is resolved into the friction force F between the tool and the chip, and the normal force N. The angle μ between the vectors N and R is called the friction angle. On the shear plane, the force R is further decomposed into the shear force F_S, which, according to Merchant, is spent on shearing the metal, and the normal force F_N, which exerts a compressive load on the shear plane.

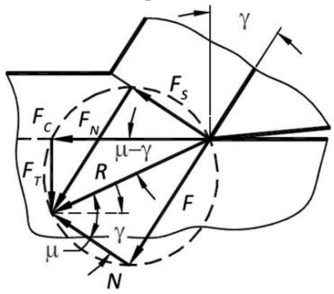

Fig. 1. Merchant's Circle Diagram [3]

Additionally, the force R is resolved along the direction of tool movement into the cutting force F_C and the thrust force F_T acting on the tool. The determination of the cutting force is based on calculating the shear force F_S:

$$F_s = \frac{\tau_y A_c}{\sin\varphi} \quad (1)$$

where τ_y is the shear stress of the workpiece material; φ is the shear angle; and A_c is the cross-sectional area of the undeformed chip.

According to Fig. 1, the cutting force is determined by the following formula:

$$F_c = \frac{F_s \cos(\mu-\gamma)}{\cos(\varphi+\mu-\gamma)} \quad (2)$$

Taking into account equation (1), the final expression for the cutting force can be written as:

$$F_c = \frac{\tau_y A_c \cos(\mu-\gamma)}{\sin\varphi\cos(\varphi+\mu-\gamma)} \quad (3)$$

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A similar calculation scheme for determining the cutting force is presented by N.N. Zorev [5–6]:

$$R_z = \tau_y \frac{ab}{\sin\varphi}\frac{\cos\omega}{\cos(\varphi+\omega)} \quad (4)$$

where R is the chip formation force; τ_y is the shear stress of the workpiece material; *a* is the shear thickness; *b* is the shear width; and ω is the angle of action, i.e., the angle between the force vector R and the cutting velocity vector *v* (Fig. 2).

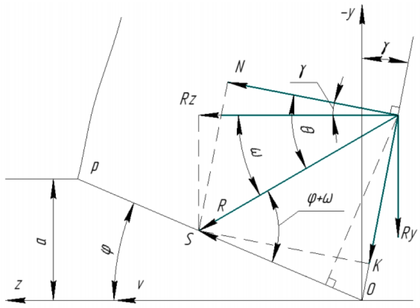

Fig. 2. Zorev's scheme: R – chip formation force; R_z – main (tangential) component of the chip formation force; R_y – radial component of the chip formation force; *a* – shear thickness; ω – angle of action; φ– shear angle; γ – rake angle [5]

It should be noted that neither Merchant's method nor Zorev's method accounts for tool wear and friction on the tool's rake face during the cutting process. When applying these methods in industrial settings, difficulties arise in determining the shear stress τ_y of the workpiece material, the friction angle μ, and the shear angle φ. In his works, Merchant provides an equation for determining the shear angle, which is expressed as follows:

$$\varphi = \arctan\left(\frac{r\cos\gamma}{1-r\sin\gamma}\right) \quad (5)$$

where γ is rake angle; r - chip thickness ratio:

$$r = \frac{t_o}{t_c} \quad (6)$$

where t_o is the chip thickness before deformation, and t_c is the chip thickness after deformation.

Although the equation defining the shear angle appears to provide a complete description of the cutting process, it does not take into account the physical and mechanical properties of the machined material. The shear angle is determined solely based on changes in the geometric parameters of the chip (chip thickness) during cutting and the rake angle of the tool edge.

2.2. Development of Merchant's Theory

Merchant's method was further developed in the works of Kloke [7–9]. In his research, the author focuses on the theory of chip formation and investigates ideal cutting conditions, i.e., assumes an ideally sharp cutting edge. Kloke's circle diagram scheme is shown in Fig. 3.

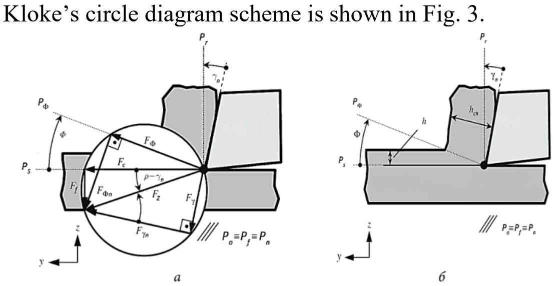

Fig. 3. Kloke's scheme: P_ϕ – shear plane trace; P_r – main plane trace; F_ϕ – shear force; F_c – cutting force; F_f – feed force; F_z – resultant force; Φ – shear angle; ρ – friction angle; h – cutting depth [7]

It is assumed that the shear angle is a function of the shear stress τ_ϕ in the shear plane:

$$\tau_\phi = \frac{|F_\phi|}{A_\phi}; \; A_\phi = b\frac{h}{\sin\Phi} \quad (7)$$

where A_ϕ is the cross-sectional area of the undeformed chip; h is the cutting depth (Fig. 3b); and b is the width of the tool.

The shear force F_ϕ can be expressed through the resultant force F_z as follows:

$$|F_\phi| = |F_z|\cos(\Phi+\rho-\gamma_n) \quad (8)$$

The resultant force F_z can be expressed using all of the above as follows:

$$|F_z| = \frac{\tau_\phi}{\sin\Phi\cos(\Phi+\rho-\gamma_n)}bh \quad (9)$$

The relationship between the cutting force F_c and the resultant force F_z:

$$|F_c| = |F_z|\cos(\rho-\gamma_n) \quad (10)$$

Finally, the equation for determining the cutting force proposed by Kloke takes the following form:

$$|F_c| = \frac{\cos(\rho-\gamma_n)\cdot\tau_\phi}{\sin\Phi\cos(\Phi+\rho-\gamma_n)}bh \quad (11)$$

where h is the cutting depth; b is the tool width; Φ is the shear angle; ρ is the friction angle; γ is the rake angle; and τ_ϕ is the shear stress.

In Kloke's equations, a calculation scheme similar to those of Merchant and Zorev is observed, with the main difference being the notation of the parameters used in the equations.

2.3. Energy-based method for determining cutting force

The energy-based approach to determining the cutting force was proposed by Davim [10–11], and his calculations take tool wear into account, which brings the computations closer to the real machining process. The energy balance within the system is expressed as follows:

$$P_c = F_c v = P_{pd} + P_{fR} + P_{fF} + P_{ch} \quad (12)$$

from which the cutting force is calculated as:

$$F_c = \frac{P_{pd}+P_{fR}+P_{fF}+P_{ch}}{v} \quad (13)$$

where P_{pd} is the energy consumed for the plastic deformation of the removed layer; P_{fR} is the energy consumed due to the interaction between the tool and the chip; P_{fF} is the energy consumed due to the interaction between the tool and the workpiece; and P_{ch} is the energy consumed for the formation of new surfaces.

As follows from the calculations, Davim's method involves summing all the energy components when determining the cutting force. Although the calculations provide a detailed description of the cutting process, this method cannot be practically applied in real conditions due to the labor-intensive nature of computing all energy components.

In his works [10–11], the author also compares experimental and theoretical values of cutting force determination during turning of AISI E52100 steel at a cutting speed v=90 m/min, feed S=0.2 mm/rev, and cutting depth of 2 mm. The discrepancy between calculated and experimental values is approximately 6% (998 N and 940 N, respectively).

2.4. Astakhov's Theory

A fundamentally different approach to determining the cutting force was proposed and experimentally confirmed by V. Astakhov [12–13]. He states that the cutting force exhibits a wave-like dependence on thermal energy and deformation energy. The underlying equation is given as:

$$dW_{in} = dA + dQ \quad (14)$$

where dW_{in} is the internal energy; dA is the mechanical energy supplied from outside; and dQ is the thermal energy dissipated in the system.

A micro-volume of the machined material located at point 2 along the tool path (Fig. 4) is considered at the moment when the tool passes this point. According to the above equation, the change in internal energy dW_{in} within the micro-volume is equal to the sum of the mechanical work of the external forces dA, applied by the tool, and the residual thermal energy dQ, which penetrates into the current position from an equivalent micro-volume located at a neighboring position along the tool path (from point 1, see Fig. 4).

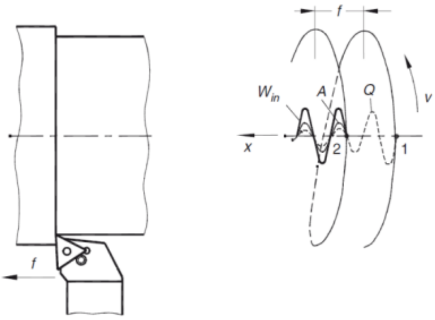

Fig. 4. External turning and tool path trajectory [11]

The residual heat dQ is positive because this heat flows into the micro-volume at point 2 (when the cutting tool reaches it) from a decaying heat source at point 1 (the previous tool position) if and only if the thermal conductivity velocity in the workpiece is equal to or greater than the velocity of the cutting tool movement in the feed direction. Thus, there is no contradiction with the laws of thermodynamics in the energy equation — heat first enters the less heated zone (point 2, see Fig. 4), and then the tool (as a heat source) moves to that zone, thereby causing heat release.

Astakhov provides experimental data. During turning of AISI 4140 steel at speeds ranging from 4 to 345 m/min, the range of cutting force was:

At a cutting depth t= 0.1 mm – 38 to 84 N (approximately 3.8 to 8.5 kgf);

At a cutting depth t=0.5 mm – 169 to 328 N (approximately 17 to 33 kgf);

At a cutting depth t=1.0 mm – 366 to 506 N (approximately 37 to 52 kgf).

Based on these data, a simple dependency is presented:

$$F_z = Ct^x S^y v^n \quad (15)$$

Astakhov then calculates the value of C using the experimental data, while the value of the exponent x is selected from a reference handbook. After substituting the values, the following result was obtained:

$$F_z = 53{,}94v^{-0{,}1} \text{ at } t = 0{,}1 \text{ mm} \quad (16)$$

$$F_z = 193{,}13v^{-0{,}1} \text{ at } t = 0{,}5 \text{ mm} \quad (17)$$

$$F_z = 427{,}79v^{-0{,}1} \text{ at } t = 1{,}0 \text{ mm} \quad (18)$$

The experimental values in the "v – Pz" coordinate system are shown in Fig. 5. Taking into account the wave-like nature of deformations, the author considers these points as sinusoidally periodic data, which can be mathematically represented as a wave-dependent function:

$$F_z = F_{z0} + F_{za} \sin\left[\frac{2\pi}{l_v}(v + v_{ph})\right] \quad (19)$$

where F_{z0} is the sinusoidal function; F_{za}, l_v, and v_{ph} are the amplitude, wavelength, and initial phase of the sinusoid, respectively.

As a result, taking Fig. 5 into account, the following expressions can be written:

$$F_z = 47 + 10\left[\frac{2\pi}{0{,}56}(0{,}050 + v)\right] \text{ at } t = 0{,}1 \text{ mm}; \quad (20)$$

$$F_z = 178 + 11\left[\frac{2\pi}{0{,}50}(0{,}049 + v)\right] \text{ at } t = 0{,}5 \text{ mm}; \quad (21)$$

$$F_z = 422 + 50\left[\frac{2\pi}{0{,}46}(0{,}045 + v)\right] \text{ at } t = 1{,}0 \text{ mm}; \quad (22)$$

It should be noted that at different cutting depths, the wave equations differ, and accordingly, the values of amplitudes and wavelengths also vary.

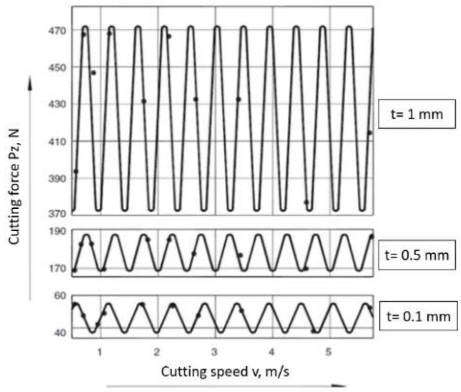

Fig. 5. Dependence of cutting force on cutting speed [11]

A similar wave-like dependence of the cutting force on cutting speed was observed in the studies by Krivoukhov [14] during the machining of titanium alloy. Experimental data were obtained using a VP-4-EI type electro-inductive three-component dynamometer. The results concerning the relationship between the components of the cutting force and the machining parameters during the turning of VT3 titanium alloy are presented in Table 1. Data modeling in the Matlab environment enables graphical representation of these dependencies (Fig.6).

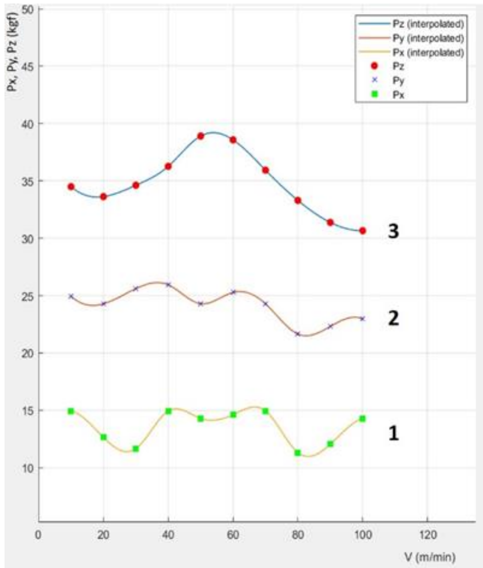

Fig. 6 Dependence of cutting force on cutting speed during turning of VT3 titanium alloy

Table 1

Experimental cutting force data obtained by Krivoukhov [14] during the turning of a titanium alloy

Cutting speed, m/min	Feed rate mm/rev	Cutting depth, mm	Components of the cutting force		
			P_z, kgf	P_x, kgf	P_y, kgf
10	0,11	1,0	34,50	14,95	24,95
20	0,11	1,0	33,63	12,64	24,29
30	0,11	1,0	34,62	11,65	25,61
40	0,11	1,0	36,27	14,95	25,94
50	0,11	1,0	38,91	14,29	24,29
60	0,11	1,0	38,58	14,62	25,28
70	0,11	1,0	35,94	14,95	24,29
80	0,11	1,0	33,30	11,32	21,65
90	0,11	1,0	31,98	12,04	22,31
100	0,11	1,0	30,66	14,29	22,97

As can be seen from Fig. 6, Astakhov's theory, which states that the cutting force has a wave-like dependence on thermal energy and deformation energy, is supported by the dependency graphs. However, it should be noted that the equations proposed by Astakhov were developed based on the machining of AISI 4140 steel, which limits their applicability to other materials. Additionally, the coefficients C, x, y, and n are not detailed, further restricting the practical use of these equations. Nevertheless, a thorough study of Astakhov's theory, in comparison with other research and supported by experimental data, can provide a comprehensive understanding of cutting forces.

3. Conclusion

All the aforementioned methods for determining cutting force are of significant interest not only for further research and practical implementation but also for expanding knowledge in the field of cutting force calculation. Continued study of this topic will not only improve the accuracy of cutting force prediction but also optimize machining processes, reduce tool wear, and enhance the quality of manufactured parts. Moreover, the application of modern calculation methods, including numerical modeling and experimental investigations, promotes the development of new approaches to process control and the selection of optimal machining parameters.

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The problem of classification and justification of the methodology for selecting classes of objects subject to recognition in a multispectral space image

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Abstract: In the article, the specific task of Remote Sensing is being investigated to classify recognizable classes from objects consisting of 12 different types of vegetation soil features. The stages of solving this problem were selected and justified and the territorial areas where the test areas were formed for the development and testing of the classifier were determined. Based on information obtained from satellite and IKONOS, tables are provided that provide quantitative assessments for various class combinations of vegetation objects in the images formed from the satellite image of the studied area. The tables reflect statistical characteristics allow for preliminary assessments of the representativeness of the clusters. The article presents combinations of histograms for various variants of combinations of classified vegetation classes and provides tables of unsuitability using decision rules based on statistical characteristics.

Keywords: Classification, Justification, Methodology, Objects

1. Introduction

To solve the main task of classifying recognizable objects, 12 types of vegetation and soils were identified in the selected study region, the dynamics of changes in the distribution areas of which are indicators reflecting the anthropogenic impact on the study area. Below, in Table 1, some types of vegetation are listed and their names are given.

Table 1

Initial set of classes – vegetation and soil types

Class number	Full name of the plant
Class 1	Marshy reed vegetation
Class 2	Swamp Shrub Tamarisk (Tamarix)
Class3	Coastal zone: semi-desert vegetation
Class 4	Australian false reed (Phragmaties australis)
Class 5	Salsola ericoides
Class 6	Mountain saltwort (Salsola nodulosa)
Class 7	Mountain saltwort (Salsola nodulosa) / Lerch's wormwood (Artemesia lerchiana)
Class 8	Mountain Salsola (Salsola Nodulosa) / Herb
Class 9	Semi-desert vegetation - Caspian potash (Kalidium capsicum)
Class 10	Semi-desert vegetation dominated by Camel Thorn (Alhagi pseudoalhagi)
Class 11	Bare soil
Class 12	Mountain saltwort (Salsola nodulosa) / bare soil

At the first stage, the geographic coordinates measured at the characteristic distribution points of these plants in the studied area are determined, which were geocoded on the space image, and then the areas of the territories are determined, from which the test areas for training and testing the classifier are formed. The image below shows the contours of these areas for some types of selected sets of vegetation classes. The areas with training examples are shown in green, and the areas with testing examples are shown in blue.

Marshy reed vegetation	Swamp Shrub Tamarisk (Tamarix)
Coastal zone: semi-desert vegetation	Australian false reed (Phragmaties australis)
	
Mountain saltwort (Salsola nodulosa)	Salsola ericoides
Mountain Salsola (Salsola Nodulosa) / Herb	Mountain saltwort (Salsola nodulosa) / Lerch's wormwood (Artemesia lerchiana)

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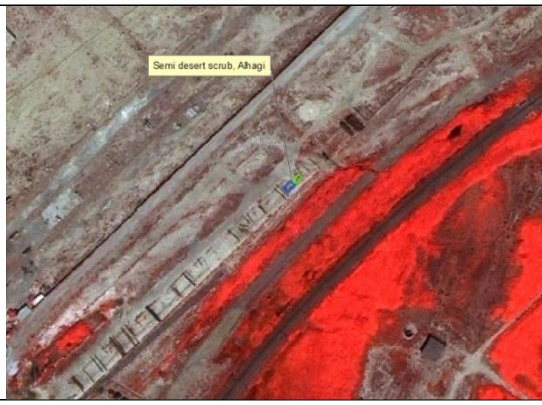
https://doi.org/10.56143/engineer-tstu.v3i2.74 A bridge between science and innovation

Semi-desert vegetation - Caspian potashnik, (Kalidium capsicum)



Semi-desert vegetation dominated by Camel Thorn (Alhagi pseudoalhagi)

Bare soil

Mountain saltwort (Salsola nodulosa) / bare soil

Fig. 1. Vegetation types

2. Research methodology

The capabilities of the designed GIS for recognition and classification of objects allow not only to automate the processes of extracting test examples from a space image within the boundaries of the selected areas, but also to use various algorithms for this[1,2,3] .

In the case under consideration, an algorithm is used that takes into account all pixels that have a slight overlap with the selected areas. In the second case, pixels intersecting with the boundary of the area are added to the set only if the overlap area is more than half the area of one pixel(1 sq.m., in this case).

Below, in Table 2, quantitative data are given on different classes of vegetation cover formed from a space image of the region under study from the IKONOS satellite. The table includes calculated statistical characteristics that allow obtaining preliminary estimates of the representativeness of clusters.

Table 2

Quantitative data are given on different classes of vegetation cover formed from a space image

Class number	Number of examples Procedure 1	Number of examples Procedure 2	Number of examples Procedure 1	Number of examples Procedure 2
Class 1	1215	1113	1487	1368
Class 2	3181	2955	2087	1893
Class 3	97	67	63	33
Class 4	1891	1748	2055	1859
Class 5	234	186	279	176
Class 6	2393	1992	2867	2658
Class 7	690	564	478	388
Class 8	200	182	147	124
Class 9	52	35	49	30
Class 10	40	33	28	21
Class 11	474	242	553	287
Class 12	680	604	579	472
General	11147	9721	10672	9309
Mathematical expectation	928.9167	810.0833	889.3333	775.75
Standard deviation	1036.354	950.3847	976.7583	917.4441

The table shows that the distribution of examples by classes is uneven. This is due to both the total number of examples extracted from different classes of vegetation and soil types presented on the scene, and the nature of the fragmentation of the distribution areas of different plant types [4]. Let's consider some of these estimates and, first of all, let's consider the estimates by their total number:

1. $N_T = 5 * N_W$
2. $N_T = 30 * p * N_O$
3. $N_T = 10 * N_W$
4. $N_T = 30 * N_I * (N_I + 1)$
5. $N_T = 60 * N_I * (N_I + 1)$, where,

N_I - the number of initial neurons, in our case, this is the number of spectral channels of the space image;

N_O - the number of output neurons or recognizable classes.

N_H - the number of neurons in the hidden layer.

Using the given formulas, we determine the minimum and maximum values of the required number of neurons. As a result of the calculations, we obtain;

$$N_H \min = 57, \text{ a } N_H \max = 120.$$

N_W -the number of weighting factors, which is determined by the formula

$$N_W = N_H * (N_I + N_O).$$

Thus

$N_W$min = 8*(4+12) = 684, a $N_W$max = 120*(8+12) = 2400, where

• p is the number of objects/neurons per class and ranges from 3 to 8.

Analyzing the obtained data, we have a wide range of values, which makes it difficult to determine the optimal threshold when choosing the required number of examples. However, it is clear that those estimates that take into account the number of weighting coefficients are reliable. Let us consider the estimates of the distribution of examples by object classes using the formula for determining the interval obtained from the maximum and minimum number of examples:

$$И_{HT} = [N_{av} – \alpha * N_{msd} , N_{av} + \alpha * N_{msd}] , \quad (1)$$

where $N_{av} = (N_T / N_O)$ is the mathematical expectation, N_T is the total number of examples for training or testing; N_O is the number of classes, α is a real number in the range of numbers from one to three, and N_{msd} is the standard deviation of the number of examples in different classes [5,6].

Literature review. The main literature sources used are the monograph “Theory and Methods of Digital Processing of Space Images for Remote Sensing Problems”. The book is in print and will be published in 2024. In addition, materials from articles published in various international publications and SUDEF 24 conferences in 2023-2024 were used.

ICSEGT 2024; 74th International Astronautical Congress 2023 y.

3. Results and Discussion

Statistical tests for representativeness and separability of samples.

Let's consider the general statistical characteristics:

Table 3

Statistical characteristics of training clusters from the "Main set" for four channels

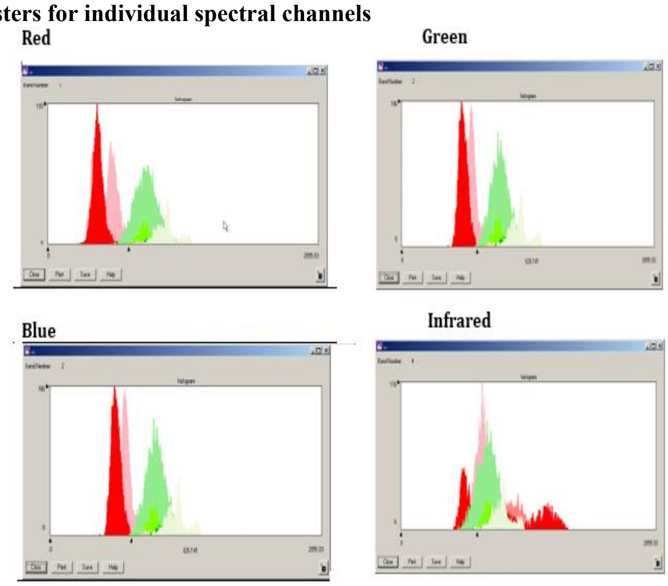
Class name	Red Channel		Green Channel		Blue Channel		Infrared channel	
	Minimum-Maximum	Average ± Stan.Off	Minimum-Maximum	Average ± Stan.Off	Minimum - Maximum	Average ± Stan.Off	Minimum-Maximum	Average ± Stan.Off
Class 1	241 – 655	363.5 ± 40.5	398.0 - 725.0	497.9 ± 31.4	356 - 553	418.0 ± 20.0	466 - 1132	820.5 ± 115.8
Class 2	264 - 738	497.8 ± 65.9	391 - 779	574.4 ± 53.2	354 - 605	468.6 ± 33.9	396 - 821	631.8 ± 52.6
Class 3	555 - 826	704.7 ± 60.4	648 - 878	772.5 ± 56.5	511 - 655	586.1 ± 36.7	481 - 759	649.4 ± 57.4
Class 4	216 - 697	380.7 ± 44.5	362 - 737	498.7± 38.0	329 - 553	424.7 ± 22.4	416 - 1394	806 ± 289.4
Class 5	544 – 981	769.6 ± 95.3	653 - 1008	839.7 ± 77.2	493 - 724	619 ± 50.1	481 - 941	713.7 ± 100.8
Class 6	395 – 1058	743.2 ± 89.7	523 - 1051	799.2 ± 75.9	409 - 760	609.3 ± 42.8	362 - 1000	698.1 ± 87.8
Class 7	554 – 930	729 ± 55.5	631 - 973	780.1 ± 50.7	493 - 691	583.7 – 30.1	534 - 896	700.4 – 50.2
Class 8	597 – 972	784.1 ± 63.5	694 - 994	835.8 ± 51.2	517 - 715	618.6 ± 33.2	541 - 928	738.3 ± 65.7
Class 9	639 – 761	689.0 ± 30.6	684 - 781	722.4 ± 24.4	528 - 598	553 ± 16.1	642 - 783	698 ± 30.2
Class 10	389 – 870	657.1 ± 139.6	520 - 914	742.8 ± 115.7	424 - 672	561.4 ± 70.2	432 - 909	696.8 ± 137.9
Class 11	760 – 1104	941.4 ± 64.6	841 - 1141	1001.8 ± 60.2	607 - 800	709.8 ± 38.0	673 - 1001	851.5 ± 61.1
Class 12	613 – 1047	854.0 ± 75.9	715 - 1078	912 ± 63.3	530 - 768	660.6 ± 40.7	523 - 975	780.0 ± 76.4

It follows from the table that some clusters either intersect or partially coincide. The article considered various combinations of histograms for various combinations of classified vegetation classes. For ease of analysis, the recognizable classes were presented in different colors.

Table 4

Joint histograms of clusters for individual spectral channels

Class 1	
Class 2	
Class 3	
Class 4	
Class 5	
Class 6	
Class 7	
Class 8	
Class 9	
Class 10	
Class 11	
Class 12	



The article analyzes various combinations of histograms, unfortunately the limited volume of the article does not allow us to present the results obtained in full.

Thus, the preliminary tests characterize one of the possible options for modifying the original classification scheme.

For example, the algorithm of the classification scheme is considered, in which an additional set consisting of 7 classes of vegetation types is considered [7].

Using this algorithm, we create new clusters by extracting examples from one or more clusters formed on the basis of the original classification scheme.

The main problem of the initial formation of training examples is the uneven distribution of them across clusters. It is theoretically possible to redistribute the examples so that they are more evenly distributed between the classes [8].

4. Conclusion

We have proposed a technique where the problem statement related to the definition of the structure of the classification scheme was changed. As a rule, the proposed approach is more effective for solving problems of natural resource management, as well as control and aerospace monitoring. When applying this approach, the priority is the selection of recognizable indicators for assessing the situation. After performing the initial tests, an option was proposed for combining classes with similar characteristics and new classification schemes were created.

This allows us to improve the results of training the classifier for classifying objects of recognizable classes. The approach we proposed, combining the methods of modern information technologies and data models on which the proposed methodology is based, always allows us to find the optimal set of indicators - classes and solve the problem [9,10].

Calculation of confusion tables using decision rules based on statistical characteristics.

After conducting statistical tests and evaluations, we created two additional sets from the original 12-cluster set, consisting of 7 and 5 clusters, respectively. Additional sets were compiled before the training procedure of the neural classifier in order to determine the boundaries of possible changes in the classification scheme.

In order to minimize the risks associated with the uncertainty of the training procedure, it is necessary to form representative sets of training examples. Before the training process of neural classifiers, sets of sets of training examples are tested based on the calculation of confusion tables using decision rules based on statistical characteristics.

In this paper, confusion tables are compiled using the maximum likelihood rule on clusters from the maximum 12-class set of examples. Each set has two types: sets of training examples and examples for testing, called training and test clusters. The full version of the article provides tables for the two types of sets, as well as a table of inaccuracies in the classification of examples.

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Engineering and geological investigations for construction and rehabilitation in saline soil regions of Uzbekistan

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Abstract: This article provides information on conducting engineering-geological studies in the design and construction of buildings and structures in the saline soil regions of our Republic. A number of scientific studies related to the assessment of emergency situations of buildings and structures that occur during the use of saline soils are being conducted in the world. In our country, certain achievements are being made in conducting engineering-geological and hydrogeological research works for the safe and efficient operation of buildings and structures in the areas where saline soils are spread.

Keywords: buildings and structures, design, construction, engineering-geological research, hydrogeological research, soils

1. Introduction

Nowadays, large-scale construction work is underway in our country. The projecting and construction of buildings and structures in complex climatic conditions require specific researches. Engineering-geological surveys on soil-based sections with high humidity are carried out according to a special program specified in the terms of reference. The software and terms of reference are developed jointly by the project and exploration organizations. The materials obtained as a result of the search should, in general, allow you to:

1. Quantitative assessment of the stability of the foundation;
2. Predict the value and duration of the subsidence of the base in the consolidation process.

In general, these materials should be evaluated to ensure that the high-moisture layer can be used as the lifting base material.

The program can be edited after receiving the current information by the project organization during the search. In the projecting and construction of buildings and structures in complex climatic conditions, engineering-geological surveys can include the following types of work:

1. Collection, analysis and summarization of search and previous years materials;
2. Obtaining and decoding aerospace survey materials;
3. Recognition inspection in conjunction with aerial and route observations;
4. Crossing mountain carvings;
5. Geophysical study of the area;
6. Field inspection of soils;
7. Hydrogeological research;
8. Stationary observations;
9. Study of soil and water in the laboratory;
10. Predicting possible changes in engineering-geological conditions;
11. Processing of materials in the room;
12. Preparation of technical report (conclusions) [1].

Literature review. During the operation of buildings and structures built on saline soils, man-made levels of underground water are formed under the structure due to natural and artificial factors. The rise of the underground water level and the wetting of the foundation soils cause the uneven settlement of the structure, which leads to emergency situations, as a result of which excessive costs are incurred. Major researchers of the world and our country engaged in the study of the effect of the amount and type of salts in the saline ground base on its physical and mechanical properties: M.D. Braja, G.P. David, W. Kuhn, B.G. Neal, A.R. Arutyunyan, I.L. Bartolomey, V.M. Bezruk, P.B. Babakhanov, A.A. Glaz, A.I. Grot, R.S. Ziangirov, N.P. Zatenaskaya, M.F. Уerusalimskaya, M.O. Karpushko, A.K. Kiyalbaev, A.A. Kirillov, N.A. Klapatovskaya, У.V. Kuznesov, A.D. Kayumov, T.Kh. Qalandarov, S.S. Mordovich, A.A. Mustafayev, N.S. Naletova, A.E. Oradovskaya, V.P. Petrukhin, B.P. Rakhmanov, У.D. Rozhdestvensky, A.L. Rubinshtein, У.M. Sergeyev, A.V. Sukhorukov, M.N. Terleskaya, B.T. Teltayev, N.N. Florov, R.M. Khudaikulov, V.P. Shulgina, I.K. Aimbetov, I.A. Agzamova and others[2,3].

2. Research methodology

In collecting, analyzing and summarizing the research materials of previous years, it is necessary to pay attention to the history of development of geology of the region in the Quaternary period and data on the analogy of the district. Special attention should be paid to the generalization of data on anthropogenic impacts leading to groundwater level rise and swamping in the construction area, as well as the development of swampy, lake, lagoon, alluvial and mixed genesis deposits during route monitoring. It is necessary using different methods of geophysical research in the study of the strength of soils in the maximum volume to study the distribution and thickness of soils in high humidity, as well as in the upper part of the surface. Processing of search materials in the room should be carried out during the field work for timely editing of the survey, as well as in the

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process of drawing conclusions to obtain information about the high-moisture soil layer at the base of the projected lift.

Data on the presence of high-moisture soils, their properties, distribution and properties are collected taking into account the data of previous years and the construction experience in the given area. It is necessary to use aerial photography and space survey data. In the absence of sufficient information on the distribution, genesis, thickness, composition, condition and properties of soils, as well as hydrogeological and geomorphological conditions of the study area, a reconnaissance search is established.

The composition and scope of exploration work in the plan and depth according to RST Uz 20522-95 to distinguish engineering-geological elements, normative and calculated values of soil properties, including strength and deformation characteristics; hydrogeological measurements, measurements of the intensity of development of geological processes, as well as the aggressiveness of groundwater should be sufficient to determine.

It is recommended that the scale of engineering-geological surveys be 1: 10000-1: 2000. A scale of 1: 1000 and smaller can be obtained based on the search program, respectively. The results of geophysical studies of soil thickness at high humidity first supplement the data obtained during the reconnaissance study on the inhomogeneity of its structure, the direction and velocity of groundwater, the variability of physical and mechanical characteristics of soils at high humidity.

The main types of work to be carried out at this stage of the project are: engineering-geological survey, route monitoring, geophysical surveys, sampling of wells and drilling of wells on the ground with high humidity.

It is proposed to carry out engineering-geological survey on a scale of 1: 10000-1:5000. Electro-intelligence and seismoacoustic profiling, georadiolocation are proposed as the main method of geophysical research. Drilling wells will be drilled in the form of a 50x50 m net, depending on the size of the study area, based on aerial photography, at a distance of 150 m on both sides of the route axis. Samples are taken from high-moisture soils every 0.5-1.0 m in depth when passing sounding drilling wells. Materials on the hydrogeological order of the stratum are collected. Salinity often accumulates salts of sulfuric, hydrochloric, and carbonic acids, and in some cases, sodium and potassium salts of nitric acid in the desert. This is very harmful for most species.

3. Results and Discussion

The main factor in the formation of saline soils is the mineralized groundwater and saline rocks lying close to the surface. Therefore, saline soils are found in impermeable plains, deserts and hilly areas. The description of salinity is directly related to the hydrogeological and geomorphological conditions of the site. The foothills are composed of carbonate rocks, usually unsalted soils. In the soils of the foothills and valleys, water-soluble sulfates and partially chlorides are found. As the areas deepen, the amount of salt in the soil increases, in particular, under conditions of loose drainage and when the groundwater lies nearby. The importance of chlorides in the salt content of the lower reaches of river valleys is significant. As we move away from the mountains, the carbonate rocks are replaced by non-carbonate ones, followed by chloride-sulphate, sulphate-chloride, and finally chloride-type saline areas[4, 5].

The strength and compaction of soils should also be taken into account when projectinging and constructing buildings and structures in saline areas. Sedimentary rocks are compressed by external forces, resulting in a decrease in their porosity and volume [5, 7].

The compression process is represented by the compression resistance, the compression coefficient, and the compression modulus.

The compression limit of rocks is equal to the value of the force expended for their maximum compression, expressed in MPa. When soils are compacted by external forces, their particles condense and their porosity decreases.

Under the influence of external forces of soils, compression without lateral expansion is called compression compression. Compression is determined by reducing the volume of the soil as a result of the gradual increase of forces in the hydroproject copying device of the sample taken from the soil [8].

4. Conclusion

Thus, when the amount of calcium carbonate in the soil is less than 5%, it is not decided as necessity, and when it is between 5% and 25%, the soil is called calcified. Typically, large amounts of carbonates occur in dusty soils of various origins. Ground salts can dissolve under the influence of water and other solutions and spread within the soil. The release of soluble salts from the soil is called quantity or salt leaching or chemical suffocation. When the soil is exposed to certain solutions of salts as well as acids and alkalis, it is possible to completely remove not only weak and moderately soluble, but also difficult-to-dissolve salts from the soil.

In addition, strong and moderately soluble salts (chlorides and sulphates), weakly soluble compounds (carbonates, sandstones, iron oxides) are also released as a result of long-term exposure to saline soils. They are the natural cements of soils, which determine their strength and deformation properties. Therefore, the removal or weakening of such natural cements changes the composition and structure of the soils and determines the change in their properties. In saline dusty soils with a content of easily soluble salts less than 5%, suffocation subsidence is low and of practical importance [11, 12].

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Assessment of the influence of strength and deformation characteristics of saline soils on the foundations of buildings and structures

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Abstract: In the article, the results of scientific research related to the assessment of the impact of strength and deformation properties of saline soils on the foundation of structures, the evaluation of emergency situations of buildings and structures that occur during the use of saline soils in the world and in our country, emergency situations taking into account the change in the level of salinity due to the long-term influence of water monitoring, information on carrying out engineering-geological and hydrogeological research works for the safe and efficient operation of buildings and structures in areas where saline soils are scattered in our country. In the construction of buildings and structures in the countries of the world where saline soils are distributed, during the period of their use as a basis, the issues of forecasting and reducing the consequences of emergency situations that may occur due to changes in engineering-geological and hydrogeological conditions are of great importance. The studies of the assessment of emergency situations expected during the use of saline soils serve the socio-economic, sustainable development of countries with areas where such soils are distributed. Certain progress is being made in carrying out engineering-geological and hydrogeological research works for the safe and efficient operation of buildings and structures in areas where saline soils are scattered in our country. In particular, in the regions of Bukhara, Jizzakh, Syrdarya, Khorezm, Fergana and the Republic of Karakalpakstan, saline soils have been thoroughly studied and evaluated based on the determination of engineering-geological and hydrogeological factors.

Keywords: soils, saline soils, strength, deformation, physical-mechanical properties, coefficient of filtration, constructions, underground water, hard-to-dissolve salts, sulfate-chloride salinity, chloride-sulfate salinity, sulfate salinity, sodium salt

1. Introduction

In the construction of buildings and structures in the countries of the world where saline soils are distributed, during the period of their use as a basis, the issues of forecasting and reducing the consequences of emergency situations that may occur due to changes in engineering-geological and hydrogeological conditions are of great importance. In this regard, measures are being taken to assess and forecast emergency situations through comprehensive research and to reduce them in the areas where saline soils are spread. The studies of the assessment of emergency situations expected during the use of saline soils serve the socio-economic, sustainable development of countries with areas where such soils are distributed [1,2].

A number of scientific studies related to the assessment of emergency situations of buildings and structures that occur during the use of saline soil are being carried out in the world. Special attention is paid to the assessment of emergency situations, taking into account the change of the salinity level due to the long-term influence of water, to the improvement of measures that ensure the safe use of buildings and structures during their use.

Certain progress is being made in carrying out engineering-geological and hydrogeological research works for the safe and efficient operation of buildings and structures in areas where saline soils are scattered in our country. In particular, in the regions of Bukhara, Jizzakh, Syrdarya, Khorezm, Fergana and the Republic of Karakalpakstan, saline soils have been thoroughly studied and evaluated based on the determination of engineering-geological and hydrogeological factors [3,4,5].

2. Research methodology

To date, theoretical and practical studies on the study of the amount and type of salts contained in saline soils on the basis of buildings and structures, as well as modeling of their effect on accounting indicators, have been widely studied by scientific centers, universities and scientific research institutes of leading countries. During the operation of buildings and structures built on saline soils, man-made level of underground water is formed under the structure due to natural and artificial factors. The rise of the underground water level and the wetting of the foundation soils cause uneven subsidence of the structure, leading to emergency situations, resulting in excessive costs. Based on this, taking into account the specific engineering-geological and hydrogeological conditions of saline soils, the research of changes in physical-mechanical properties of soils due to their wetting is one of the important issues of today [4, 8].

3. Results and Discussion

Major researchers of the world and our country have

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conducted research on the effect of the amount and type of salts in the saline ground base on its physical and mechanical properties. The results of their scientific research are included in several regulatory documents aimed at ensuring the integrity and safe operation of buildings and structures in areas with saline soils. However, in the developed regulatory documents, changes in their physical and mechanical properties due to leaching of salts contained in saline soils have not been fully studied and paid attention to. The analysis of the emergency situation of some objects in the conditions of Uzbekistan shows that the factors affecting the change in the values of the physical and mechanical properties of the foundation soils used in the calculation of the stability of buildings and structures (for example: long-term water seepage, salt content, etc.) are not sufficiently taken into account. At the same time, as a result of the conducted research, it is shown that the actual subsidence of the existing structures increased by 1.5-2.0 times compared to the design when saline soils were wetted and water seeped for a long time. Taking into account that the construction of many buildings and structures in the conditions of Uzbekistan, where saline soils are widespread, these scientific research works are aimed at assessing the changes in engineering-geological and hydrogeological conditions as a result of the leaching of salts contained in the soil during the moistening of these areas, the issues related to the strength of buildings and structures and their safe use allows to solve. Saline soils are divided into the following types: chloride, sulfate-chloride, chloride-sulfate, sulfate and soda, as well as according to the degree of salinity: low salinity, medium salinity, strong salinity and extremely strong salinity [5, 6]. Scientific novelty of research is is the following:

- the changes in the salinity of soils under the influence of natural and man-made factors in the research object were determined, schematic maps of their hydrogeological and engineering-geological conditions were made, and the change in the filtration coefficient was evaluated;
- the strength, deformation and seismic properties, the decrease of the initial plastering and alkalinity level from the engineering-geological indicators of saline soils were determined under the influence of moisture;
- the dependence of soil strength and deformation indicators on the types of salinity, the level of initial plastering and alkalization was determined, and their mathematical expressions were developed;
- as a result of leaching of saline soils in Pakhtakor district of Jizzakh region and long-term exposure to water, the conditional resistance is reduced by 1,2-1,6 times and the additional settlement of the foundation increased by 1,5-2,0 times in dependent on such conditions.

Table 1 shows the amount of salinity of saline soils by district in Jizzakh region of the Republic of Uzbekistan.

Table-1

Classification of soil salinity by districts in Jizzakh region, % (according to V.M.Bezruk)

№	Regions	Weak salted (from 0,3 - to 1,0)	Moderately salty (from 1,0 to 5,0)	Strong salted (from 5,0 to 8,0)	Extra salted (>8,0)
1	Jizzakh	2,4	1,2	-	-
2	Sh.Rashidov district	-	2,7	3,1	-
3	Pakhtakor district	1,2	17,5	24,3	26,7
4	Zafarabad district	2,1	13,1	14,3	12,9
5	Dostlik District	2	12,1	12,2	11,9
6	Arnasoy district	2,6	12,8	13,5	12,8
7	Mirzachol district	1,6	13,7	12,9	12,3
8	Forish district	-	2,6	1,8	1,2
9	Ghallarol district	3,2	2,5	-	-
10	Bahmal district	-	-	-	-
11	Zomin district	-	-	-	-
12	Zarbdar district	1	1,1	-	-
13	Yangiabad district	-	-	-	-

In different natural conditions of Uzbekistan, in the areas of the Mirzachol plains, saline soils of different quantities and composition are found. The most common salts in soil are the following: $NaCL$, $Na_2SO_4 \cdot 10H_2O$, $MgSO_4 \cdot 7H_2O$, $MgCL_2 \cdot 6H_2O$, $CaCL_2 \cdot 6H_2O$, $NaHCO_3$, $Na_2CO_3 \cdot 10H_2O$, $CaCO_3$ ва $CaSO_4 \cdot 2H_2O$. The amount and quality of these slightly soluble salts determine the physical and mechanical properties of soils. Sources of salinity of saline soils are mineralized waters that evaporate and release a certain amount of salt, the process of enriching the composition of rocks with salts. In the territory of Uzbekistan, in particular, in the desert regions of the Jizzakh region, there are mainly sources of two types of salinity, that is, strong and extremely strong. At the same time, salinization of soils without the influence of groundwater from saline rocks is also observed. From Table 1 above, we can see that the amount of highly saline (24.3%) and extremely saline (26.7%) soils in Pakhtakor district of Jizzakh region is much higher than in other regions. In recent years, deformation of civil and industrial buildings built on saline soil due to the increase in the construction volume of buildings and structures in arid and semi-arid regions has been observed a lot. A distinctive feature of saline soils is the change in the physical and mechanical properties of such soils during the process of water saturation and alkali leaching of salts. Today, in the desert regions of Jizzakh region, especially in Pakhtakor district, saline areas are rapidly expanding. From the experience of building industrial and civil structures on saline soils, as a result of wetting and long-term seepage of water from the foundation, unacceptable deformation of the foundation and loss of bearing capacity are observed. Due to leaching of salt from them and changes in mechanical properties, the bearing capacity of the base decreases (Figure 1,2).

Fig. 1. Sinking of the structure as a result of water seepage into the foundation of school 14 in Pakhtakor district, Jizzakh region

Fig. 2. The crest of the base of the structure as a result of the salinity

The most salinization of irrigated lands is observed in this district, therefore it was considered appropriate to conduct research in this area. It should be emphasized that there have been no systematic studies on the influence of groundwater on the engineering-geological properties of soil in Pakhtakor district of Jizzakh region. Based on the results of this scientific research, the standard value of the volumetric weight of the particles of saline soils depending on the salinity description is presented in Table 2.

Table 2

The standard value of the volumetric weight of the particles of saline soils depending on the description of salinity

Amount of salts, %	Volumetric weight of soil particle, g/sm^3, in types of salinity						
	NaCI	*$NaSO_4$*	*Na_2CO_3*	*$MgCl_2$*	*$MgSO_4$*	*$CaCI_2$*	*$NaCl + MgSO_4$*
0	2,67						
3	2,66	2,67	2,65	2.65	2,67	2,67	2,67
5	2,66	2,67	2,64	2,64	2,65	2,65	2,65
7	2,64	2,64	2,62	2,62	2,64	2,63	2,64
10	2,64	2,61	2,59	2,59	2,62	2,61	2,62

The leaching of salts and the rate of its continuation are closely related to the properties of saline filtration. Many studies on the filtration properties of saline soils show that the process of changing the filtration coefficient is complex due to the dissolution and leaching of salts. Methods for determining the filtration coefficient of soils in laboratory conditions are carried out according to GOST 25584-2016. Filtration coefficient: represents the permeability characteristic of the soil with respect to a certain amount of filtered water. Also, the linear filtration law is equal to the uniform pressure gradient and the filtration rate of water. The process of determining the filtration coefficient of soil samples is presented in picture 3.

Fig. 3. Procedure for determining the filtration coefficient of soil samples

In laboratory conditions, it was found that the filtration coefficient is correlated with the plastic number and porosity coefficient of the soil as follows:

For porosity coefficient $0{,}65 \leq e_0 \geq 0{,}85$ and values of plastic number $0.65 \leq I_p \geq 17$:

$$K_f = -1{,}05 \cdot 10^{-7} + 1{,}86 \cdot 10^{-6} / I_p, \quad (sm/sec). \qquad (1)$$

For porosity coefficient $0{,}55 \leq e_0 \geq 0{,}65$ and values of plastic number $3 \leq I_p \geq 14$:

$$K_f = 9{,}02 \cdot 10^{-9} + 2{,}33 \cdot 10^{-7} / I_p, \quad (sm/sec). \qquad (2)$$

For porosity coefficient $0{,}55 \leq e_0 \geq 0{,}65$ and values of plastic number $3 \leq I_p \geq 14$:

$$K_f = 3{,}50 \cdot 10^{-9} + 2{,}55 \cdot 10^{-7} / I_p, \quad (sm/sec). \qquad (3)$$

On average, the following expression was adopted based on the results of all experiments (the range of variation of porosity coefficient $0{,}45 \leq e_0 \geq 0{,}85$, the range of variation of plasticity number:

$$K_f = 8{,}73 \cdot 10^{-9} + 2{,}37 \cdot 10^{-7} / I_p, \quad (sm/sec) \qquad (4)$$

For sandy soils, the filtration coefficient depends on the amount of particles smaller than 0.1 mm. The following relationship was determined for values of porosity coefficient e=0.65÷0.75:

$$K_f = 2{,}64 \cdot 10^{-4} - 6{,}33 \cdot 10^{-6} \cdot G \quad (sm/sec), \qquad (5)$$

here: G- the percentage of particles smaller than 0.1 mm in size.

The linear approximation of the results of the experiments conducted on sandy soils with a porosity coefficient of 0.45 to 0.55 (the content of clay particles smaller than 0.1 mm in size from 4.5 to 8.5 %) was determined by the following expression:

$$K_f = 10^{-5} - 1{,}488 \cdot 10^{-7} \quad (sm/sec) \qquad (6)$$

In saline areas, subsidence and suffocation may occur due to the use of the structure or changes in the underlying hydrogeological conditions. Easily and moderately soluble salts can also be washed away, and the type of ground changes due to the release of salts from the foundations of structures (for example, when examining the ground of the foundation - solid soils, when examining the structure in a state of emergency - loose soils). As a result of water saturation and alkali leaching of such soils, the values of their deformation and strength characteristics are significantly reduced. The analysis results of the studies show strong salinity of the subsoil and leachate soils. This situation can be explained by the rise of mineralized underground water to the surface of the earth through the capillaries in them. In such conditions, an increase in the amount of salt in the surface layers of soils is observed.

4. Conclusion

In a number of areas of Uzbekistan where saline soils are spread, we can observe the decrease in the strength of the foundation soils as a result of the rise of groundwater and flooding of the area, as a result, the increase in the emergency condition of buildings and structures. It is desirable to conduct experiments related to studying the laws of changes in their strength during filtration washing of saline soils based on observed buildings and structures, as well as studying the microstructure of saline soils. It is necessary to give recommendations and suggestions aimed at ensuring the strength of the foundation of the developed structures and stability to deformation based on the results of researches on determining the deformation and strength of saline soils. It should be noted that when designing structures in such soils, it is necessary to take into account the decrease in strength and deformation characteristics caused by the wetting of the foundation of the structure and the leaching of easily, moderately and difficultly soluble salts. The main risk of construction on saline soils is dissolution of salts due to water filtration, deterioration of soil structure, and decrease in strength, as a result of which uneven settlement occurs. It is necessary to take into account not only the amount of salinity of the soil with the permissible quantitative criterion of salts on the basis of the structure, but also the change of indicators of their water-chemical and physical-mechanical properties due to wetting and alkali leaching. As a result of our research, the following conclusions were reached:

1. These studies indicate early damage to buildings and structures as a result of changes in the engineering-geological conditions of saline soils in the territory of our country, and require a thorough and deeper study of the properties of soils.

2. Alluvial-proluvial soils are mainly distributed in the studied areas, their salinity ranges from 1.2% to 1.8% in sands, from 1.5% to 15.8% in supes, from 2.4% to 18.5% in loams. , it was determined that it varies from 1.25% to 5.8% in clays. The groundwater level is 1.2-2.8 meters deep. Under their influence, the strength indicators of the foundations of buildings and structures decrease from 20 to

50%.

3. When water seeps from hard-to-dissolve saline soils, especially gypsum, for a period of 12 to 24 months, their strength values and the amount of salts in them, that is the degree of salinity, decrease by 70-80%, which in turn leads to a decrease in the stability of the foundation of buildings and structures and subsidence.

4. Based on the fact that the conditional resistance calculated as a result of leaching of saline soils and long-term exposure to water may decrease by 1.2-1.6 times and the additional settlement of the foundation may increase by 1.5-2.0 times under such conditions, an appropriate measure to ensure the strength of buildings and structures - it is recommended to use events.

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Quality management system in the healthcare system of developed countries

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Abstract: This article analaysis the implementation of quality management systems (QMS) within the healthcare systems of developed countries, focusing on their impact on service quality, patient safety, and operational efficiency. QMS plays a critical role in minimizing medical errors, optimizing resource utilization, and ensuring the consistent delivery of high-standard medical care. The study analyzes successful practices from the United States, the European Union, and Japan, highlighting their use of standardization, accreditation systems, evidence-based protocols, and continuous improvement processes. Special attention is given to how these countries have institutionalized quality through regulatory frameworks and organizational culture. By comparing different models and identifying common success factors, the article offers a comprehensive overview of effective QMS strategies. In the concluding section, the potential for adapting and applying these international best practices in the context of Uzbekistan's healthcare system is examined, taking into account local needs, capabilities, and reform initiatives aimed at improving healthcare delivery and patient outcomes.

Keywords: quality management system, healthcare, developed countries, patient safety, Kaizen, accreditation, standardization

1. Introduction

Quality management systems are aimed at improving the quality of healthcare services, covering all aspects of medical care provided to patients [1]. Quality management systems, on the one hand, are aimed at increasing the effectiveness of treatment processes, and on the other hand, include a set of measures aimed at ensuring the safety of patients [2]. These systems aim to provide high-quality services to patients through the continuous improvement and standardization of the activities of healthcare organizations. The main goal of quality management systems is to minimize errors in the provision of medical services, rational use of resources, and increase patient satisfaction [3].

Quality management in the healthcare systems of developed countries has a long history, these countries have accumulated extensive experience in the field of quality management and have successfully implemented it in practice [4]. The development of quality management has resulted from efforts aimed at continuous improvement, standardization, and patient safety in the healthcare sector. Developed countries have significantly improved the quality of medical services, reduced costs, and improved patient outcomes through the implementation of quality management systems [5].

2. Research methodology

These countries widely use a patient-centric approach, evidence-based medicine, and standardized protocols, which contribute to ensuring high quality and efficiency in the provision of medical services [6]. Patient-centered approach means prioritizing patients' needs and desires, ensuring their active participation in the treatment process, and providing personalized services. Evidence-based medicine involves the use of the latest scientific research results in making clinical decisions, optimizing treatment methods, and ensuring best practices for patients. Standardized protocols help regulate the activities of medical personnel, reduce errors, and ensure the uniformity of medical services [7].

Quality management systems have led to reduced healthcare costs and improved patient outcomes, which confirms the effectiveness of these systems and encourages their widespread use [8]. This is achieved through cost reduction, rational use of resources, optimization of treatment processes, and minimization of errors. Improvement of patient outcomes is achieved through improved treatment methods, a personalized approach to patients, and ensuring their active participation in the treatment process [9]. As a result, patients recover faster, their quality of life improves, and the overall effectiveness of the healthcare system increases [10].

3. Results and Discussion

In the USA, quality management in the healthcare sector has a long history and various models are used, which reflects the specifics of the US healthcare system and contributes to its constant improvemen[11]. In the USA, quality management is carried out through various initiatives, programs, and standards aimed at ensuring high quality and safety in the provision of medical services. These models regulate the activities of healthcare organizations, increase their responsibility, and provide reliable guarantees for patients.

Programs such as "Medicare" and "Medicaid" are aimed at improving the quality of medical services, which is one of the main goals of these programs and contributes to increasing their effectiveness [12]. The "Medicare" program provides medical care for Americans over 65 years of age and with disabilities, while the "Medicaid" program provides medical care for low-income Americans. These programs finance various measures aimed at improving the quality of medical services, monitor their effectiveness, and encourage healthcare organizations to provide quality services.

The experience of the USA shows that standardization

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and accountability play an important role in improving quality, which confirms the influence of these factors on the effectiveness of the healthcare system and encourages their widespread use. Standardization ensures uniformity in the provision of medical services, helps reduce errors, and provides best practices for patients. Accountability increases the responsibility of healthcare organizations for their activities, motivates them to provide quality services, and provides reliable guarantees for patients.

EU countries have strict standards and accreditation systems for quality assurance in the healthcare sector, which contributes to ensuring the high quality of the European healthcare system and provides a reliable guarantee for patients. The European Union develops various directives, regulations, and recommendations aimed at ensuring quality in the healthcare sector, which are mandatory for EU member states to comply with. Accreditation systems provide an independent assessment of the activities of medical organizations, confirm their compliance with international standards, and provide reliable guarantees for patients.

Standards such as ISO 9001 regulate the activities of medical organizations, which confirms the impact of these standards on the effectiveness of the healthcare system and encourages their widespread application. The ISO 9001 standard is an international standard for quality management systems and helps medical organizations manage quality, continuously improve, and improve patient satisfaction. This standard regulates the activities of medical organizations, increases their responsibility, and provides reliable guarantees for patients.

Accreditation provides an independent assessment of medical services and provides a reliable guarantee for patients, which confirms the role of accreditation systems in improving the quality of the healthcare system and encourages their widespread use [6]. Accreditation means the assessment of the activities of medical organizations by independent experts, confirming their compliance with international standards and providing reliable guarantees for patients. Accreditation also helps medical organizations improve their activities, improve quality, and increase patient satisfaction.

In Japan, the Kaizen principle is widely applied in the field of healthcare, which reflects the specifics of the Japanese healthcare system and contributes to its constant improvement. The Kaizen principle is aimed at the introduction of small improvements by medical workers in their workplace, and the combination of these improvements leads to large results. Kaizen also increases the responsibility of medical workers for their work, develops their creative abilities, and helps improve the overall culture of the healthcare organization.

Quality control frameworks ensure the active participation of medical personnel and contribute to the identification and resolution of problems, which confirms the influence of these frameworks on the effectiveness of the healthcare system and encourages their widespread use. Quality control circles are subgroups created for medical workers to identify problems that arise at their workplace, solve them, and make proposals for improving quality. These circles ensure the active participation of medical workers, enhance their knowledge and skills, and contribute to improving the overall culture of the healthcare organization.

The experience of Japan shows that continuous improvement and employee engagement are an important factor in improving quality, which confirms the influence of these factors on the effectiveness of the healthcare system and encourages their widespread use. Continuous improvement is carried out by eliminating identified shortcomings in the processes of providing medical services, introducing new technologies, and improving the qualifications of medical personnel. Employee involvement increases the responsibility of medical workers for their work, develops their creative abilities, and contributes to the improvement of the overall culture of the healthcare organization.

Quality management systems help reduce errors and ensure patient safety, which confirms the impact of these systems on the effectiveness of the healthcare system and encourages their widespread use. Quality management systems include a set of measures aimed at predicting possible risks in the provision of medical services, eliminating them, and preventing harm to patients. This will be achieved by improving the qualifications of medical personnel, introducing new technologies, and complying with standardized protocols in the provision of medical services.

Standardized protocols and guidelines regulate the activities of medical personnel and prevent misconduct, which helps to reduce errors in the provision of medical services and ensure the safety of patients. Standardized protocols define the sequence of steps for diagnosing and treating a specific disease, provide clear guidance to medical personnel, and facilitate their decision-making. Instructions, on the other hand, contain instructions on the correct use of methods, techniques, and means used in the provision of medical services. These documents regulate the activities of medical workers, improve their knowledge and skills, and prevent misconduct.

Improving patient safety strengthens patient confidence and increases the demand for medical services, which contributes to improving the overall effectiveness of the healthcare system. Improving patient safety, reducing errors in the provision of medical services, preventing harm to patients, and providing them with high-quality services. This strengthens patients' confidence in medical services, increases their enthusiasm for treatment, and increases the demand for medical services.

The experience of developed countries shows that the implementation of SCS contributes to reducing healthcare costs, rational use of resources, and increasing the efficiency of medical services. In addition, SMT leads to an increase in the recovery rate of patients, a decrease in disability, and an increase in life expectancy.

Continuous improvement (Kaizen) is one of the main principles of quality management. Kaizen is a Japanese word meaning "improvement." According to this principle, medical organizations should constantly strive to improve their activities, improve processes, and introduce new technologies.

This principle is constantly aimed at improving processes and increasing efficiency. The Kaizen principle helps medical organizations achieve great results through small but constant changes. This principle implies the active participation of medical workers, taking their opinions into account, and searching for opportunities for improvement in their work.

The Kaizen approach helps to achieve great results through small but constant changes. The Kaizen principle helps medical organizations reduce costs, rationally use resources, increase the efficiency of medical services, and improve patient satisfaction. In addition, the Kaizen principle contributes to increasing the level of job satisfaction of medical workers and their professional development.

International cooperation and exchange of experience contribute to the study of best practices of developed countries and their adaptation to the conditions of Uzbekistan. International cooperation and exchange of experience contribute to the study of best practices of developed countries and their adaptation to the conditions of Uzbekistan. Uzbekistan can study and learn from the experience of developed countries in implementing quality management in healthcare systems.

Cooperation with international organizations, implementation of joint projects, and conducting seminars play an important role in the implementation of quality management systems. Cooperation with international organizations, implementation of joint projects, and conducting seminars play an important role in the implementation of quality management systems. International organizations can provide technical assistance to Uzbekistan, assist in the training of qualified personnel, and provide financial resources.

4. Conclusion

The experience of developed countries shows that the implementation of quality management systems in the healthcare system allows for ensuring patient safety, improving the quality of services, and reducing costs. In the USA, standardization and accountability, in Europe, accreditation systems and ISO 9001, and in Japan, continuous improvement based on the Kaizen principle have yielded effective results. By applying this experience in Uzbekistan, it is possible to increase the efficiency of the healthcare system, strengthen patient confidence, and ensure quality service in accordance with international standards. International cooperation and the exchange of scientific and technical experience are of great importance in this direction.

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Traffic flows on urban roads and their impact on public transport users

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Abstract: In this article shows the adverse health effects of industrial vibration on workers exposed to hand-transmitted vibration and whole-body vibration. Long-term exposure impairs the nervous, circulatory, musculoskeletal, and skeletal systems. Hand-transmitted vibration can cause Hand–Arm Vibration Syndrome, characterized by numbness, tingling, white-finger episodes, reduced grip strength, and musculoskeletal issues a progression confirmed. Whole-body vibration exposure, commonly experienced by heavy machinery operators, link to back and spinal disorders, fatigue, gastrointestinal issues, and potential cardiovascular complications. Also, the article gives protection measures based on occupational health regulations, including ERGONOMIC ENGINEERING CONTROLS, administrative practices like work-rest rotations and health monitoring, and use of anti-vibration equipment . These interventions align with European Directive 2002/44/EC, which mandates risk assessments and exposure monitoring. The study concludes that an integrated approach combining technical controls, organizational strategies, and personal protection is essential to mitigate vibration hazards and safeguard workers' health in industrial settings.

Keywords: transport, passenger transport, public transport sector, education, system

1. Introduction

Modern production processes are based on high technologies, and various mechanisms, equipment, and automated systems are widely used to increase labor productivity, improve product quality, and meet market demands. However, the human factor still plays an important role in these processes. Employees working in production are forced to work in various working conditions, and in some cases, they are exposed to factors that negatively affect their health. One such factor is vibration [1].

Vibration is a frequently repeated vibration of bodies or a medium. It occurs naturally in many mechanical devices, motor vehicles, electrical appliances, and production equipment. Workers working in workplaces, especially in heavy industry sectors, are more susceptible to vibration. In such conditions, long-term exposure can lead to serious health problems for workers, such as cardiovascular diseases, nervous system disorders, diseases of the musculoskeletal system, excessive fatigue, and constant stress [2].

According to international standards, compliance with occupational safety and sanitary and hygienic standards is one of the main requirements in production. However, practice shows that in many manufacturing enterprises, the impact of vibration on human health is still not sufficiently taken into account. A system of measures for the timely detection, assessment, and elimination of vibration risk factors has not yet been fully formed or the existing systems are not sufficiently effective. In this regard, the study and solution of this problem is a very urgent issue, especially in developing countries, including in the industrial sectors of Uzbekistan. The health and working capacity of the workforce directly affects the economic efficiency of the enterprise. If negative factors in the work environment are reduced, this will have a positive impact not only on the health of workers, but also on the overall efficiency of production. Therefore, the study, assessment, and development of effective mechanisms for preventing the impact of vibration arising in production processes is one of the important tasks facing modern science and practice [3].

Despite many technological achievements, the problem of protecting human health in the context of modern industrial development has not yet been fully resolved. To reduce the negative impact of vibration, control this factor, and ensure the safety of workplaces, it is necessary to introduce innovative technologies, intelligent monitoring systems, personal protective equipment, and ergonomic designs. At the same time, maintaining the health of workers under regular medical supervision is also an integral part of this issue [4].

The main goal of the research devoted to the topic is to identify various forms of vibration arising in the production process, analyze their impact on the health of workers, and develop measures aimed at reducing this problem. To achieve this goal, a number of scientific and methodological approaches were used, including experimental observation, statistical analysis, laboratory measurements, analysis of medical data, and modern monitoring tools. The study also compared foreign and domestic experience and analyzed the practical measures being implemented to reduce vibration based on advanced technologies [5]. Their effectiveness, impact on labor productivity, and economic advantages were considered. In the fight against vibration, the role of high technologies, in particular artificial intelligence, intelligent sensors, and analytical programs, is increasing [6].

2. Research methodology

The literature used in this study to study the impact of vibration arising in the production environment on the health of workers is based on various approaches and scientific schools. The analyzed scientific sources are mainly divided into two groups - studies created by national (Uzbek scientists) and international (foreign specialists).

The works of Uzbek scientists are largely based on practical observations, medical examinations, occupational safety standards, and experimental studies conducted in the

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existing production environment. For example, in his work, S.Kh. Turaev studied the effects of vibration on the human body through observations and laboratory measurements conducted under production conditions. They analyzed factors such as working conditions, physical properties of air, and equipment vibration frequency, determining the relationship with changes in workers' health [7].

Uzbek scientists typically use a hybrid methodology: in addition to medical and physiological data, technical measurements (vibration strength, frequency, transmission rate) are also used. They also rely on the local characteristics of the enterprise's conditions when developing recommendations for the implementation of innovative technologies.

Foreign scientists are mainly based on theoretical analysis, experimental research, and statistical modeling methods. For example, M.J. Griffin, in his work "Handbook of Human Vibration," analyzed the relationship between the human body and vibration from a biological, physiological, and physical point of view. Its methodology is based on experimental laboratory tests, ergonomic analysis, and statistical modeling, which is distinguished by its high scientific accuracy [8]. In studies conducted by such scientists as Bovenzi, Seidel, Palmer, the long-term effect of vibration was determined through long-term observations, medical diagnoses, and clinical experiments conducted on various working groups. They assessed the risk of vibration-related diseases based on the cohort method, weighted regression analysis, and healthcare statistics [9].

In international methodologies, in particular, when assessing the impact of vibration on the human body based on the ISO 2631-1:1997 standard, the types of vibration transmitted through the entire body and hand are distinguished. This approach has not yet been fully implemented in Uzbek research, but is based on internationally accepted norms [10].

Thus, while Uzbek scientists use an approach based more on practical enterprise conditions, relying on local medical and technical indicators, foreign scientists prefer a methodology based on large-scale statistical and theoretical research. The combination of both approaches serves to effectively study and prevent vibration hazards [11].

3. Results and Discussion

During this study, based on observations, measurements, and medical examinations conducted at several production enterprises, the impact of vibration on the health of workers was thoroughly analyzed. More than 100 workers working in metallurgy, machine building, cement production, and car assembly workshops were involved in the research. Information was collected on their working conditions, the availability of technical means, protective equipment, and their health status. The level of vibration was determined using special meters (for example, through vibrometers). According to the results, it was established that the level of vibration in some workshops is 1.5-2 times higher than the established sanitary and labor standards. It was noted that workers who have worked with vibration equipment for many years often suffer from diseases related to the nervous system, blood circulation, joints, and bones.

Table 1

Relationship between vibration level and health problems (based on 100 workers)

Vibration level (m/s2)	Number of workers	Nervous system disorder (%)	Hand tremor (%)	Joint pain (%)
Up to 1.5 (norm)	30.	10%	5%	7%
1.6 - 2.5	40.	28%	15%	22%
2.6 - 3.5 and higher	30.	43%	30%	38%

As can be seen from the table above, as the level of vibration increases, the frequency of health problems also increases. Especially in workers working in highly vibrational environments, complaints related to the nervous system (fast fatigue, insomnia, distractibility) are significantly more common.

In addition, it was found that the indicators of the use of protective equipment are also at a low level. In some workshops, it was observed that 60% of workers do not use protective gloves and special vibration-reducing coatings. This further increases the risk to health.

Table 2

Level of protective equipment use and vibration disorders

Presence of protective equipment	Number of workers	Vibration-related disease conditions
Regularly used	35.	12%
Occasionally used	30.	26%
Unavailable	35.	39%

As can be seen from this table, the risk of diseases is much higher if the level of use of protective equipment is low. Therefore, it is important not only to carry out technical modernization at production enterprises, but also to provide workers with the necessary personal protective equipment.

Similar conclusions have been drawn in foreign literature on the topic under discussion. For example, in laboratory experiments conducted by Griffin (1990), it was proven that if the vibration exceeds 1.5 m/s2, a constant stress state, muscle fatigue, and weakening of bone tissue are observed in the human body. Bovenzi (2005) noted circulatory disorders (Raynaud syndrome) in workers subjected to prolonged hand vibration. Local scientists, including Turaev (2018) and Kholboev (2019), conducted practical observations confirming the negative impact of industrial vibration on the body. In their research, changes in blood pressure, heart rhythm disorders, and diseases of the peripheral nervous system were especially widely studied.

Another important point revealed during the discussions is that men are more exposed to the negative impact of vibration than women, because they are more involved in workshops that work directly with heavy machinery. Also, these effects were more pronounced in workers over 40 years of age, as the body's compensatory mechanisms slowed down.

At the same time, the fact that workers do not pay attention to their health, do not undergo regular medical examinations, and have a low level of health culture contributes to the deepening of the problem. Many workers seek late treatment, perceiving symptoms of vibration sickness as simple fatigue. At foreign enterprises, modern technologies such as vibration-reducing shoes, gloves, shock absorbers on machine handles, and ergonomic workstations have been widely implemented. This serves to effectively reduce vibrational risks.

4. Conclusion

In this study, the influence of vibration arising at production enterprises on the health of workers was deeply analyzed. Based on observations, laboratory measurements, and medical examinations, it was established that vibration is one of the most dangerous physical factors in the work environment, which has a significant negative impact on the nervous system, circulatory system, musculoskeletal system, and general health.

In the course of the research, it was established that in some workshops of industrial enterprises, the level of vibration exceeds the normative indicators, and workers do not sufficiently use protective equipment. Workers who have been exposed to vibration for a long time often experience fatigue, nervousness, hand tremors, joint pain, and other vibration diseases. This leads to negative consequences not only for human health, but also for production efficiency. Compared with international literature, in particular, with the research of such scientists as Griffin, Bovenzi, Seidel, it was noted that the level of combating this problem at production enterprises in Uzbekistan is low. While abroad vibration hazards are controlled through artificial intelligence-based sensory systems, ergonomic workstations, and modern personal protective equipment, measures in this area are still insufficient in our country.

It has also been established that personal protective equipment plays a significant role in the fight against vibration. Regular use reduces the risk of vibration-related diseases by 2-3 times. This is one of the real and cost-effective solutions for creating a healthy and safe working environment at production enterprises.

Based on the research results, the following practical recommendations were developed:

- Establishment of a permanent monitoring system for the detection and reduction of vibration sources.
- Providing workers with modern personal protective equipment and its mandatory use.
- Organization of regular training sessions on occupational hygiene and safety.

Conducting regular medical examinations of workers exposed to vibration and strengthening control over their health.

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Studying and analyzing the traffic intensity of vehicles

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Abstract: The study of vehicle traffic intensity plays an important role in the development of modern cities and infrastructure. Traffic intensity represents the distribution of traffic flow in time and space. Today, the increase in the number of vehicles in large cities and industrial centers leads to traffic congestion, environmental problems, and a decrease in logistics efficiency. Therefore, a deep analysis of the intensity of movement is necessary for the development of effective management measures. As a result of the research, the daily and weekly traffic intensity of vehicles, the hours of peak load were determined, and recommendations for optimal routing and signaling systems were developed. Based on the data obtained, it is possible to modernize traffic management systems, reduce traffic congestion, and improve the environmental situation. The study is also of practical importance in modeling the state of roads and traffic flow.
Keywords: traffic intensity, traffic congestion, analysis, logistics, routing, modeling, management

1. Introduction

One of the most important directions of the current conditions, socio-economic and political development of the republic, as well as the development of transport infrastructure, is the development of a network of main highways, on which domestic and transit links with neighboring states are carried out. Uzbekistan took a direct part in the UN program "Expanding trade through the development of cooperation in transit cargo transportation" and began to revive the "Great Silk Road." Uzbekistan's "Great Silk Road" is considered one of the central pillars of the ancient highway of interaction and cooperation between European and Asian countries [1,2].

It is necessary to distinguish between the work of road transport, the work of drivers, and the organization of traffic and pedestrian movement on the road. The first two issues are mainly handled by motor transport companies, while the latter are handled by road management, traffic safety departments, and government representatives. Based on the foregoing, the main goal of traffic organization is to ensure the safe passage of various vehicles at high speeds across different sections of the road in any weather conditions of the year [3].

The quality of transport routes and the provision of modern infrastructure will lead to an increase in the speed of cargo transportation and ultimately ensure the growth of the country's gross domestic product [4]. During the crisis in international financial markets and the resulting economic difficulties for developing countries, the practical implementation of the experience of developed countries in mobilizing temporarily unused labor resources in other sectors of the economy for the development of the country's transport infrastructure will lead to expected results. Therefore, we consider it expedient to further intensify large-scale work in the field of construction and operation of highways in our country at the expense of the existing road fund [5].

When organizing road traffic, the flow of vehicles is aimed at ensuring a safe traffic regime and high throughput capacity on various sections of the road, maximizing the use of the geometric dimensions of the road, which consists of a system of measures aimed at the efficient movement of vehicles. The principles of traffic organization are aimed at: correctly directing traffic flow, if necessary, grouping them by speed, establishing rational speeds for each section of the road, and timely informing drivers about the direction of movement and road conditions [6-8].

Pedestrians occupy a special place in road traffic. Their thorough knowledge of traffic rules and adherence to them allows them to ensure traffic safety in real road conditions.

In the organization of safe traffic, the study of indicators characterizing the movement of vehicles and pedestrians is a priority task. Below we will dwell on the basic concepts about them [9].

Traffic volume (intensity) - the number of vehicles passing through any cross-section of the road per unit of time (vehicles/day or vehicles/hour).

Traffic composition is an indicator that determines the ratio of different modes of transport in the traffic flow, measured in percentages or shares. This indicator has a great influence on the speed and density of the traffic flow.

2. Research methodology

K. Nagel and M. Schreckenberg's "Road Design" textbook is dedicated to exploration and road design. The first part describes the main requirements for road elements in plan and profile, methods for ensuring the stability of the roadbed, determining the thickness of the road surface and laying the axis of the road on the ground, and calculating small water-conducting structures [10].

U. Yuldashev and others wrote in the textbook "Labor Protection" based on the general rules of labor protection, industrial sanitation, equipment safety techniques, fire safety issues, as well as regulatory documents adopted in the Republic of Uzbekistan.

K.H. Azizov, S. Hoogendoorn and P. H. L. Bovy in the manual "Fundamentals of Organization of Traffic Safety," in the current period when Uzbekistan is moving towards the global economy, the leadership of our republic pays great attention to the "Problem of Ensuring Traffic Safety on Roads." The activities of the Commission for Ensuring Traffic Safety under the Cabinet of Ministers of the Republic

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of Uzbekistan are being shown. Based on the Commission's decision, leading scientists and specialists in this field in our country have developed the concept of "Improving Road Traffic Safety." Work is underway on a set of laws designed to ensure traffic safety. The ultimate goal is aimed at reducing road traffic accidents, the number of deaths and injuries, which are a negative consequence of motorization [2,11].

Due to the sharp increase in the number of cars in our region, the movement of vehicles is accelerating dramatically. Observations show that as a result of the increase in vehicles in the region, conflicts arise between pedestrians, vehicles, and passengers [13]. Additionally, numerous material and moral damages caused by road accidents include high noise levels in city streets and roads passing through populated areas, air pollution, blocking by parked vehicles on streets, vehicle delays, and sharp speed drops [14-16].

3. Results and Discussion

When studying the intensity of vehicles in the Andijan region, we can focus on the following.

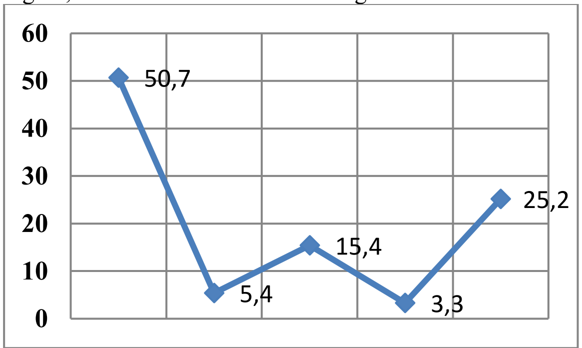

Diagram 1. Percentage of traffic flow during the day

As can be seen from the diagram above, cars make up 50.7%, trucks - 5.4%, buses and minibuses - 15.4%, cycling - 3.3%, pedestrians and children - 25.2%.

Traffic volume is a variable indicator in relation to years, months, hours of the day and days of the week, as well as sections of the road. Traffic volume varies depending on the importance of the highway and the economic development of the surrounding regions and districts.

The average daily traffic flow and pedestrian flow are given.

As can be seen from Diagram 2, during the daytime hours, the amount of movement has a high indicator, and at night, the amount of movement has significantly lower indicators.

Speed of movement is the main indicator of road traffic, which manifests itself in the form of the main goal of movement on the road. The most objective indicator on the route is a graph showing the change in traffic speed throughout the entire route. This creates certain difficulties in practice and in most cases is not feasible. Therefore, in practice, when organizing traffic, the ability to draw conclusions by measuring the instantaneous speed of vehicles on characteristic sections of the road has been developed.

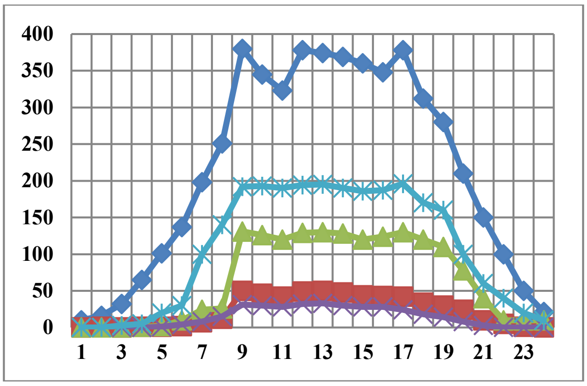

Diagram 2. Traffic volume of vehicles in motion during the day

In general, as mentioned in previous sections, the speed of movement of vehicles and the flow largely depends on the system, and the choice of speed is carried out according to two criteria: 1) minimum time expenditure; 2) ensuring traffic safety. In this case, of course, the driver's skill, work experience, psychophysical state, and purpose of movement influence the choice of speed. Also, the technical condition of the vehicle, the state of the environment, and pedestrian movement have a great influence on the change in speed.

4. Conclusion

We recommend making the following changes based on the results observed in the region:

- It would be advisable to install surveillance cameras in busy areas of the streets of the region, to install a speed-determining radar camera;
- In some areas of the region's streets, there is currently insufficient street lighting during evening walks, resulting in various accidents. For this, it is necessary to equip the street with modern lighting;

If drivers, pedestrians, and children follow the above rules, we can prevent accidents.

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Selection and justification of a technology for improving the wear resistance of ball mill liners

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Abstract: Under conditions of intensive abrasive and impact wear, typical of ball mill operation, the use of conventional high-manganese steel 110G13L as a lining material proves to be insufficiently effective. This study substantiates the feasibility of using M1-grade chromium-molybdenum steel as an alternative material for mill drum lining. Laboratory investigations of the composition, microstructure, and properties of M1 steel were conducted, along with an analysis of the production technology and heat treatment. The results confirm the potential of the proposed alloy in enhancing wear resistance and operational reliability of the lining.
Keywords: chromium-molybdenum steel, mill lining, wear resistance, ball mill, abrasive wear, heat treatment

1. Introduction

Ball mills are widely used in the mining and metallurgical industries for fine grinding of ores and other abrasive materials. A major factor limiting the service life of such equipment is the wear of the lining, which is subjected to cyclic impact and abrasive loads. The most commonly used lining material is high-manganese steel 110G13L; however, under increasingly aggressive operating conditions, this material shows insufficient resistance to wear. Therefore, there is a pressing need to identify new structural materials that offer a combination of superior mechanical and performance properties. One promising candidate is chromium-molybdenum steel, known for its high strength, resistance to abrasive wear, and thermal stability [1-3].

2. Research methodology

K. Nagel and M. Schreckenberg's "Road Design" textbook is dedicated to exploration and road design. The first part describes the main requirements for road elements in plan and profile, methods for ensuring the stability of the roadbed, determining the thickness of the road surface and laying the axis of the road on the ground, and calculating small water-conducting structures [10].

U. Yuldashev and others wrote in the textbook "Labor Protection" based on the general rules of labor protection, industrial sanitation, equipment safety techniques, fire safety issues, as well as regulatory documents adopted in the Republic of Uzbekistan.

2.1. Material

The primary material used in this study was M1-grade chromium-molybdenum steel, produced under laboratory conditions (Figure 1) at the Academic Foundry of NUST "MISIS". The chemical composition of the studied steel is presented in Table 1 [4-5].

Fig. 1. Melting process of M1-grade chromium-molybdenum steel

Table 1
Chemical composition of chromium-molybdenum steel, %

No.	Material Name	C	Si	Mn	P	S	Cr	Mo	Cu
1	M1 grade	0.35	1.11	0.31	0.009	0.009	1.07	0.57	0.50
2	Obtained steel	0.12	0.10	0.18	0.018	0.024	0.36	0.39	0.50

2.2. Melting Procedure

The steel was melted in a laboratory induction crucible furnace using a graphite crucible. The alloying sequence was as follows: iron and carbon were added first, followed sequentially by silicon, manganese, chromium, and molybdenum. Copper was added at the final stage to minimize evaporation losses. The melting temperature was maintained in the range of 1550–1600 °C [6-8].

2.3. Heat Treatment

To achieve the desired microstructure (martensite + carbides), the following heat treatment regime was applied [9]:

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– quenching: Heating to 870–900 °C, holding for 1 hour, followed by oil cooling.

– tempering: Heating to 500–550 °C, holding for 2 hours, followed by air cooling.

2.4. Metallographic Analysis

The microstructure was studied using optical microscopy. Samples were ground and polished, then etched in a 4% nitric acid solution in ethanol [10]. The microstructure of M1 steel after heat treatment is shown in Figure 2.

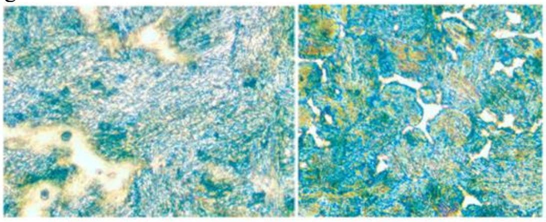

Fig. 2. Microstructure of M1 steel: a) 800× magnification; b) 200× magnification

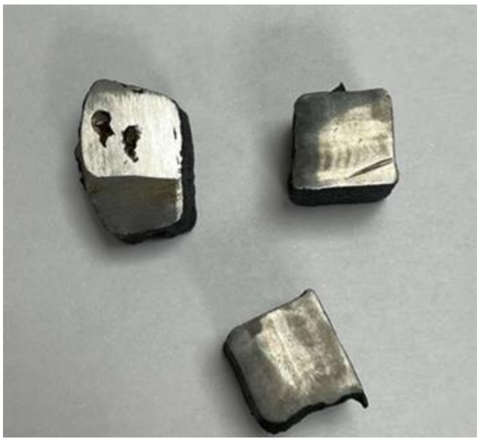

Fig. 3. Sample surface after grinding

3. Results and Discussion

Metallographic analysis showed that after quenching and tempering, the structure of M1 steel consists of martensite with uniformly distributed carbides. This contributes to increased hardness and wear resistance.

The measured hardness reached 450–520 HB, significantly exceeding the typical values of conventional rubber or low-alloy steel linings. This combination of strength and toughness is particularly important under conditions involving intensive interaction between the lining, metal grinding balls, and abrasive ore.

Due to the presence of chromium (0.8–1.2%) and molybdenum (0.8–1.2%), stable carbides are formed in the steel structure, enhancing resistance to both abrasive and impact wear. The additional alloying with copper improves corrosion resistance and reduces susceptibility to cracking.

4. Conclusion

The conducted study confirms the promising potential of using M1-grade chromium-molybdenum steel as a lining material for ball mills. Based on the analysis of chemical composition, microstructure, and heat treatment, the following conclusions can be drawn:

1. M1 steel possesses a combination of properties ensuring high wear resistance and impact toughness under abrasive conditions.

2. The martensitic structure strengthened by carbides provides hardness in the range of 450–520 HB, surpassing conventional lining materials.

3. The proposed technology can be recommended for implementation at industrial facilities operating ball mills in highly abrasive environments, particularly at JSC "AGMK".

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