Digitization of Accounting in the Innovative Management of Autonomous Robotic Transport

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Abstract: The digitization of economic processes is advancing across all sectors, contributing to the development of Industry 5.0. A key element of this fifth industrial revolution is the activation of robotic economic activity. Recently, advancements in autonomous robotic transport have been implemented in practice. However, both the practical application of unmanned vehicles and scientific developments in this field have shown low efficiency in the implementation of projects for the autonomous transportation of goods and passengers. This inefficiency stems from insufficient attention to the accounting and management aspects of autonomous robotic transport operations. The scientific and practical novelty of this study lies in improving accounting and management practices in the context of digitalization, specifically by addressing the fundamental transformations in economic processes caused by the use of autonomous vehicles. The key organizational factors influencing accounting for robotic transport operations include the type of transported objects, fuel and energy resource consumption, human involvement, the capacity and number of goods (or passengers) transported at one time, continuous operation, maintainability, software update capabilities, autonomous interaction with other transport means, and communication and information sharing with customers of transport services. A method for digitizing the accounting of fuel and energy costs, personnel wages, social activity deductions, depreciation, operational costs, and other costs related to the functioning of autonomous robotic transport has been developed. This method leverages IoT data and considers the organizational prerequisites mentioned. The use of two-dimensional calculation units, such as "kilogram-kilometre" and "passenger-kilometre" units, for the digitalization of cost calculations for passenger and cargo transportation via autonomous robotic transport has been proposed. Additionally, the procedure for determining the cost of transport services for end users and the formation of information arrays for the innovative management of transport enterprises has been refined. The elimination of organizational restrictions in managing autonomous transport operations, alongside the need for information synchronization between transport enterprises and other business entities within the information ecosystem of a smart city, highlights future research prospects in this area.

Keywords: digitalization of accounting, innovative management, costing, autonomous transport, robotic vehicles, unmanned aerial vehicles, electronic transactions.

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1. Introduction. The latest trend in the development of transport infrastructure is active research in the field of artificial intelligence technologies. The implementation of developments in the field of full automation in various sectors of the economy has led to the emergence of a new phenomenon – robotic economic activity. Robotizing the implementation of business and information processes made it possible to design autonomous (without operation by specialists) equipment. For example, unmanned vehicles are being actively implemented in all areas of business. The market size of autonomous vehicles was estimated at $2 trillion USD in 2023, and it is projected to exhibit a compound annual growth rate (CAGR) of over 13.5% during the period from 2024-2032 (Autonomous Vehicle Market Size). The mass adoption of autonomous robotic transport will reduce the number of accidents, fuel consumption, travel time, and environmental emissions. However, the scope of autonomous transport usage extends far beyond individual transportation, and consequently, the potential benefits of robotizing transportation systems can be diverse. According to the Autonomous Vehicle Market Size study, in 2023, although the majority of autonomous vehicles were used for personal transportation (42%), there was a gradual increase in the share of commercial use of robotic transport in public transportation (25%) and goods transportation (19%).

The use of robotic transport in various spheres of economic activity has led to fundamental transformations in the economic sphere of modern enterprises. Active research is being conducted on the benefits of using robotic transport in passenger and freight transportation. However, positive transformations also occur at the enterprise level for those using autonomous transport. There is a need to shift the scientific focus from the functioning of autonomous transport to the economic activities of transport enterprises, which are rarely the subject of scientific research and applied development. Since accounting is the informational basis of socioeconomic processes in the activities of enterprises using autonomous transport, its methodology and organization are undergoing significant changes, which determines the relevance of research in this area. Moreover, the accounting and management aspects of investigating the prospects for digitalizing the operations of robotic transport enterprises remain outside the focus of contemporary researchers. Accordingly, the hypothesis of the scientific research lies in the fundamental transformation of the methodology and organization of the accounting of the functioning of transport enterprises in the conditions of their digitization as a result of the change in the economic mechanisms of providing transport services via autonomous robotic transport. Changes in the implementation of traditional economic processes in the production, trade, logistics and management of transport enterprises, accordingly, have led to the transformation of methodological and organizational provisions for accounting for the operation of robotic transport under the conditions of digitalization. The problem of digitalization of accounting for the functioning of autonomous transport is not sufficiently developed in scientific space. In practice, the implementation of autonomous transportation technologies is only being developed by leading corporations, and the existing developments have not been successful because the importance of the digitization of accounting as an important component of autonomous robotic transport management has been neglected.

Accordingly, the purpose of this article is to develop a methodology for the digitized accounting of costs for the operation of robotic transport and to substantiate the impact of the organizational features of passenger and cargo carriers on the innovative management of autonomous vehicles. Achieving the established goal involves the implementation of tasks: systematize the organizational factors of autonomous transport operations to identify their impact on accounting and management, which will help to reveal positive changes in the functioning of transport enterprises; clarify the mechanism for the automatic collection of accounting data on the operation of robotic transport vehicles to create an information array that can be used for the digitalization of transport cost accounting; digitalization of expense accounting and cost management for passenger and freight transportation services via unmanned aerial vehicles and autonomous road transport with the implementation of innovative cost calculation units for prompt stakeholder notification of transport service costs; improving the methodology for forming accounting information on the operation of autonomous transport for innovative management in the financial and economic activities of transport enterprises.

The object of the research is accounting information about the activity of autonomous robotic vehicles, which is used to account for costs and form the cost of transport services. Research results and applied developments will be useful for developers of technical means of autonomous transportation of passengers and cargo, as well as scientists in the field of accounting and management of the activities of transport enterprises. The research consists of: introduction (establishing the relevance of the topic, presenting the hypothesis and objectives), review of the scientific literature and applied developments, research methodology (defining research methods, information processing techniques, and specifying information resources and software), research results: analysing the impact of organizational factors on the functioning of autonomous transport in accounting and management, developing an innovative methodology for digital accounting of the expense and cost management of transportation services, limitations and discussion, conclusions, and further research is needed.

2. Literature Review. Industrial research and development of autonomous vehicles is most actively carried out by Apple, Google, Volvo, Nissan, Robot Car UK, General Motors, Tesla and others. In particular, in 2012, Google received the first licence for the use of unmanned vehicles in the USA (Self-driving Car Logs More Miles, 2012). In cooperation with Toyota, the experimental cars Toyota Prius and Lexus RX with autonomous control were created. The electric car manufacturer Tesla is also interested in cooperation with Google, which has released software for cars with autonomous functions and developed autonomous taxis to move passengers in modern cities (Stoklosa, 2020). Another well-known car company, Nissan, which was one of the first to produce a mass-produced electric car, has long been implementing autonomous technologies in vehicles (Nissan's Path to Self-Driving Cars, 2017). Instead, Volvo focused on the production of autonomous trucks, and since 2017, it has been actively producing self-driving vehicles every year. The international taxi corporations Uber and Volvo are developing unmanned passenger transportation services (Uber self-driving cars allowed back on California roads, 2020). By 2030, 12% of all registered vehicles are expected to be equipped with fully autonomous functions (autonomous vehicles – global market penetration from 2021-2030, 2022). The share of semiautonomous vehicles will gradually decline in favour of fully robotic transport systems. These trends are relevant for cargo and passenger transport (Fig. 1).

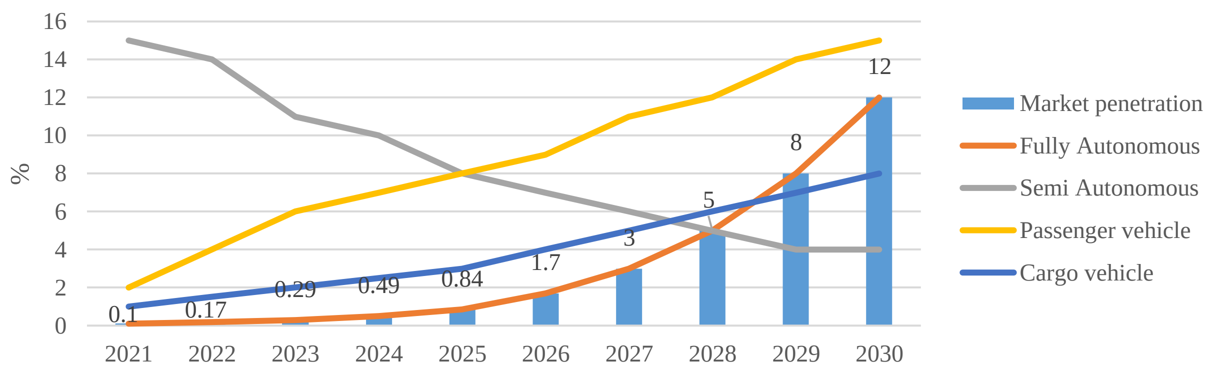

Figure 1. Share of autonomous robotic vehicles for the period 2021-2030
Sources: Developed by the authors based on (Autonomous vehicles – global market penetration 2021-2030, 2022).

The German companies Audi, BMW and Mercedes are also in the final stages of designing autonomous robotic transport. Despite large investments in the Titan project, Apple has not yet launched the production of unmanned vehicles, which is explained by the technological complexity of scientific and technical developments in this area. Therefore, all automotive companies involve a significant number of technological corporations working in the fields of visual and graphic orientation techniques, navigation technologies, wireless and telecommunication interactions, road infrastructure and artificial intelligence (Autonomous Vehicle Market, 2022) in the process of developing autonomous transport. Today, the robotic transportation of passengers using only rail transport, the routes of which are determined in advance, is relevant. For other types of passenger transport, autonomous management in the conditions of the need to permanently consider road and weather conditions is complicated.

The situation is somewhat better in the field of cargo delivery via autonomous robotic means. The leading companies Amazon, Starship Technologies, JD.com, and Alibaba Group use courier robots, and DroneUp, Watts Innovations and other trade and logistics companies use unmanned aerial vehicles to deliver small goods to end consumers (Delivery of the future, 2024). However, such autonomous vehicles are dependent on weather conditions, adequate road infrastructure and effective traffic management systems in urban areas. Scientists also emphasize the complexity and need for complex developments in the field of autonomous robotic transport (Fig. 2).

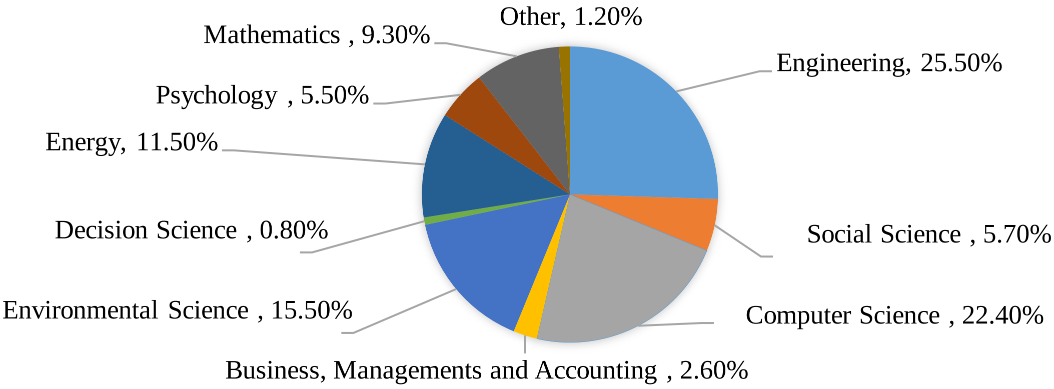

Figure 2. Research directions in the field of autonomous transportation in the Scopus database for 2021-2024

Sources: Developed by the authors on the basis of SciVal analytical resources.

According to the SciVal analytical service, the majority of scientific papers in the Scopus database on autonomous transportation are focused on engineering (55.5%). Only 12.6% of the articles are dedicated to research on business processes related to the use of autonomous transportation, specifically in improving accounting and enterprise management. Scientific developments by researchers on the economic aspects of transportation robotization have traditionally focused on three areas: transformation of the transportation sector under the influence of robotic transport; the impact of the organizational features of transport operations on a company's business processes; improving information processes in enterprises via autonomous transportation. The majority of scientific research within the first area of applied studies on the transformation of the transportation sector due to robotic transport focuses on the macro level. In particular, Bellone et al. (2021), describing the experience of implementing autonomous transport technology in the public transport of EU countries, noted the insufficient efficiency of transport flow management due to insufficient attention to the economic aspects of the digitalization of the information processing of transport enterprises. Cordera et al. (2022) carried out information modelling of unmanned traffic flows in cities and allocated a separate place for economic information in management. Konecka et al. (2020) highlighted the relationship between the development of autonomous transport networks and the economic component of the sustainable development of countries. Similarly, Stradner & Brunner (2019) and Bellone et al. (2021), among the disadvantages of the use of autonomous transport, described the difficulty of building an economic model of the functioning of transport enterprises and digitizing their management. Serafin (2021) developed a system for evaluating the effectiveness of the use of autonomous transport in various types of industrial activity.

At the macroeconomic level, studies on the use of autonomous transport have been conducted by additional researchers: Thorhauge et al. (2022) examined the use of autonomous transport in value creation logistics chains within the economy; Tomaszewski (2017) developed a new EU transport policy considering the prospects of autonomous transport; Booth et al. (2024) explored the potential for urban economic growth through the use of robotic transport; Katebi Hooshang (2023) analysed the convergence of autonomous transport with the economic potential of transport infrastructure in the post pandemic resilience of the economy; and Booth et al. (2023) discussed expected scenarios for integrating autonomous transport with other modes of transportation on a global scale. However, these macroeconomic-level studies do not address the microeconomic processes that arise from the implementation of autonomous transport in enterprise operations, necessitating a shift to the next research level.

The second group of researchers includes Ko et al. (2024), who developed an algorithm for optimal food delivery via drones while considering the variable parameters of transport routes and time intervals. Kaplan & Heaslip (2024) researched the most effective ways to deliver robotic goods with rural areas in mind. The method of forming cargo delivery schedules simultaneously via drones and robotic trucks was developed by Yamada et al. (2024). Cheng et al. (2024) focused on the management of autonomous transport while taking into account environmental conditions. Pillai et al. (2024) addressed the important issue of ensuring the personal and information security of customers with the delivery of goods via unmanned aerial vehicles and autonomous vehicles.

At the organizational level, research on autonomous transport has also been conducted by Hamadneh & Esztergár-Kiss (2024), who examined the impact of multimodal transportation involving robotic vehicles on transport mode choice and optimal route modelling; Pigeon et al. (2021), who studied factors of acceptability, adoption, and usage in the development of autonomous transport; Hamadneh et al. (2024), who explored passenger actions in regulating traffic flows in smart cities; Klinkhardt et al. (2023), who investigated various ways to provide passenger transport services in public transit; Tscharaktschiew & Evangelinos (2022), who looked into the reasons for the increase in transportation costs due to the application of robotic vehicles; and Yuen et al. (2022), who examined public perceptions of autonomous transport across various sectors and fields of application. However, organizational-level studies on the use of robotic transport only partially cover the information and management transformations occurring in enterprise operations.

Scientists who have improved information processes in the management of transport enterprises belong to the third scientific direction. For example, Hjalmarsson Anders et al. (2018) and Wang & Wang (2022) explained the impact of the use of unmanned transport and the financial performance of transport enterprises on the basis of the optimization of logistics routes. Zadorozhnyi et al. (2022) offered autonomous technical support to vehicles to collect information about the functioning of the smart city passenger network. For proper information exchange between autonomous transport systems, Muravskyi et al. (2022) suggested the use of sixth-generation cellular communication within the framework of the formation of a universal traffic flow management system. At the information-management level, research on autonomous transport has been conducted by Baliyan et al. (2022), who studied the role of artificial intelligence technologies and the Internet of Things in collecting data from autonomous vehicles; Ali et al. (2023), who analysed fully decentralized management of robotic transport within autonomous cooperative transport systems; Kortekaas et al. (2023), who focused on configurable management of combined passenger and freight transport by robotic vehicles; Nagappan et al. (2023), who developed context-dependent cluster-based management of traffic flows in intelligent autonomous transport networks; and Shafiei et al. (2023), who explored pricing based on agency theory for managing autonomous transport networks. Despite the significant achievements in improving the information management of business activities in the autonomous transportation sector, the potential for digitizing accounting processes – key information generators at the enterprise level – remains largely unexplored. Even more scientific works are focused on separate aspects of the use of autonomous vehicles in the transportation of goods and passengers without establishing a relationship with complex information and management processes in the activities of transport companies.

Thus, the macroeconomic, organizational, and information-management levels of research on the use of autonomous transport are closely interconnected. Together, they form a pyramid of paradigm development in the management system of transport enterprises, where each level builds upon the previous level (Fig. 3).

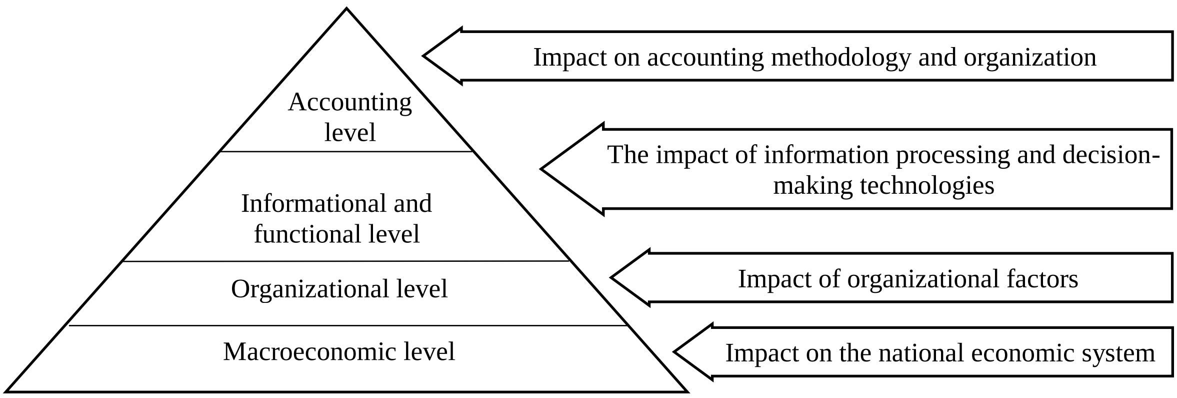

Figure 3. Multilevel scientific research in the field of commercial use of autonomous transport
Sources: developed by the authors.

At the top of the pyramid lies the accounting level, which serves as the informational foundation for positive changes in managing autonomous transport. However, this level remains under researched in the scientific literature. Undervaluing the importance of accounting for robotic transport operations jeopardizes the success of business projects aimed at implementing autonomous transport in both passenger and freight transportation. A summary of the opinions of scientists regarding the impact of autonomous transportation on socioeconomic processes is given in Table 1. Despite the significant advantages of using autonomous robotic transport, the scientific environment still lacks research in the field of accounting as the main information resource of autonomous transport management.

Table 1. Influence of the use of autonomous transport on socioeconomic processes

The influence of autonomous transport	Justification of the impact
Cost of vehicles	- decrease due to the lack of drivers and insufficient wages; - reduction of breakdowns and accidents, which optimizes the costs of the enterprise; - growth due to depreciation of valuable equipment and maintenance of robotic transport.
Environment	- minimization of the impact on the environment due to zero emissions of harmful substances.
Transportation	- improvement of road infrastructure; - improvement of the transportation comfort; - reduction of time for transporting goods and passengers..
Employment	- unemployment among drivers due to the lack of jobs; - high demand for autonomous transport maintenance specialists.
Social sphere	- creation of various new types of vehicles; - accommodation and performance of functional duties in transport.

Sources: developed by the authors.

Insufficient attention to accounting and informational processes regarding the functioning of autonomous transport is the reason for the insufficient pace of implementation of projects on the implementation of economic activities in the field of unmanned transportation, which determines the methods of this research.

3. Methodology and research methods. A systematic approach is used to substantiate the information connection between the accounting system of the functioning of autonomous transport and the management system of transport enterprises. Using an innovative method, the organization and methodology of accounting has improved in the context of its digitization for the management of autonomous vehicles. The methodological tools used in the research included bibliographic and comparative analysis methods. The empirical study utilized a bibliometric approach, specifically “word co-occurrence analysis,” which was based on search phrases such as “autonomous transport”, “unmanned transport”, and “accounting” within the “ResearchGate” information resource. Additionally, the SciVal analytical resource was used to determine the share of scientific developments in robotic transport across various scientific fields, with the search query “autonomous transport” based on data from the Scopus database for 2021-2024. All the scientific works were sorted into three research directions, macroeconomic, organizational, and information management, which allowed for the formulation of a multilevel concept for the development of robotic transport in entrepreneurial activities. To empirically substantiate the research hypothesis, cross-analysis of statistical data in the field of robotic transport technologies was applied. A forecast of market capitalization indicators in the robotic transport sector by 2030 was made via predictive functions on the basis of previous data, with polynomial trend analysis conducted in MS Excel. The results of the forward-looking analysis indicated significant future growth in the share of autonomous vehicles compared with other types of transport. The study on minimizing labor costs due to the use of robotic transport is based on average wage indicators in the transportation sector of EU countries (Poliak et al., 2019). The average wage was calculated as the mean wage in the transport sector across all EU countries. The allocation of overhead costs takes into account the following: one driver can operate two unmanned vehicles; one supervisor can oversee 40 traditional or 10 unmanned and autonomous vehicles; and one technical staff member can manage 10 traditional or 4-5 innovative vehicles. Wages for medical and other service staff were not allocated, as they are less dependent on the type of vehicle. Calculations were performed via MS Excel to evaluate the economic feasibility of introducing robotic transport in freight and passenger transportation.

To compare different methods of calculating vehicle depreciation, the automatic monthly depreciation calculation service (calculator for calculating the depreciation of fixed assets, 2024) was used, assuming a fixed asset value of 20,000 USD and a useful life of 5 years. Depreciation for autonomous transport was calculated via straight-line, cumulative, accelerated depreciation, and production methods. Graphs of annual depreciation charges were constructed via MS Excel, which demonstrated that the production method aligned most closely with the organizational implementation of transport enterprise operations. To analyse fuel and energy resource costs, the regulatory document Basic Norms of Consumption (supplement with the “Methodical recommendations on norming consumption of fuel, electric energy, lubricants, other operating materials by cars and machinery)” (2023) was utilized. The increase in fuel and energy costs was empirically demonstrated through an analysis of the remaining battery charge of an unmanned aerial vehicle covering a distance of 1 km with a payload of 1-5 kg, as well as diesel fuel consumption for a 24-seat bus transporting 1-20 passengers over a distance of 1 km. The calculation methodology and estimated values were drawn from a similar scientific study by Rahmani et al. (2024). The greatest economic benefit from using autonomous transport, according to the analysis, occurs with increased weight and transport distance. However, overuse of autonomous vehicles (transporting more than 5 kg of cargo or more than 20 passengers) significantly reduces their efficiency, raising questions about the feasibility of implementing robotic systems that must operate under intensive conditions. The study results were presented through graphical analysis via MS Excel to construct analytical graphs.

4. Results.

4.1. The impact of the organizational factors of autonomous robotic transport on accounting and management

The digitization of accounting is a new stage in the development of the digital economy. Accordingly, the progressive digitization of economic processes of transformation also requires accounting, the peculiarities of which depend on certain prerequisites for the functioning of various types of autonomous transport. The first condition that defines the specific features of accounting at transport enterprises is the type of autonomous transport. Depending on the type of vehicle (aircraft, automobile, rail or sea), the costs of fuel and energy resources may differ. These resource sources include costs for gasoline, diesel fuel, accumulated electricity, and power grid electricity. The share of costs for fuel and energy resources can differ significantly in the operation of different vehicles. The type of transportation (cargo, passenger, or mixed) determines the calculation units operated by the transport enterprises in the calculation of the cost of the provided transportation services. Typically, carriers can simultaneously transport goods and passengers, which maximizes revenues from the provision of complex transport services. Another factor is the participation of the company's employees in autonomous transport operations. All unmanned vehicles can follow a predetermined route, move independently with determination and adjustment of the direction of movement, and be controlled remotely by an operator. If the manned operation of vehicles is minimal, the costs of wages and social deductions of employees of transport enterprises are optimized. However, innovative costs for the development and support of automatic movement technologies are increasing. The level of perfection of algorithms for adapting to road conditions and spatial aspects of movement directly affects the cost of vehicle maintenance. An important criterion, which depends on the organization and accounting method, is the capacity of autonomous transport. Vehicles can transport one unit, several or a significant number of goods (passengers) in one flight. For example, drones can deliver one unit of goods to a recipient in one flight. Transporting additional quantities of goods requires multiple returns to the warehouse for reloading. Self-driving cars can deliver from one to five passengers to a given destination. However, autonomous trains can transport many goods (passengers) in one flight. According to the quantitative factor, the time spent performing technological downtimes in the functioning of autonomous transport changes, and the cost of services per unit of transported cargo (passengers) is also calculated differentially. The permanence of the activity of autonomous transport is also an organizational factor that determines the characteristic features of accounting at transport enterprises. According to the time organizational factor, it is advisable to allocate autonomous transport, which is capable or incapable of twenty-four-hour operation, according to the time-limit organizational factor. For example, drones can deliver goods at any time of the day. However, aircraft or floating transport is highly dependent on weather conditions. The permanent use of autonomous transport maximizes the economic efficiency of its operation. The periodic use of vehicles, depending on weather or seasonal conditions, limits the profitability of the enterprise and requires the use of additional methods for delivering goods (passengers).

Other organizational prerequisites that determine the individual properties of accounting for the functioning of autonomous transport should be recognized as follows: maintainability (unrepairable, repairable by the maintenance services of the transport company, repairs are performed only by the service centre); the possibility of software updating; autonomous interaction with other vehicles; and the ability to communicate with and inform customers of transport services. Organizational factors determine the content and periodicity of accounting data on the parameters of the functioning of autonomous transport. Robotic vehicles are able to independently collect most of the accounting data and transfer it to the accounting and management unit of the enterprise for further processing. The following data should include distance, overtravel, working time and movement between control points; location with connection to geoinformation resources; loading and unloading, weight and quantity of transported cargo and passengers; downtime and stoppages; breakages and damage, etc. It is expedient to use the given data for the digitization of accounting for transport services via autonomous transport. The information scheme of the digitization of the accounting methodology is shown in Figure 4.

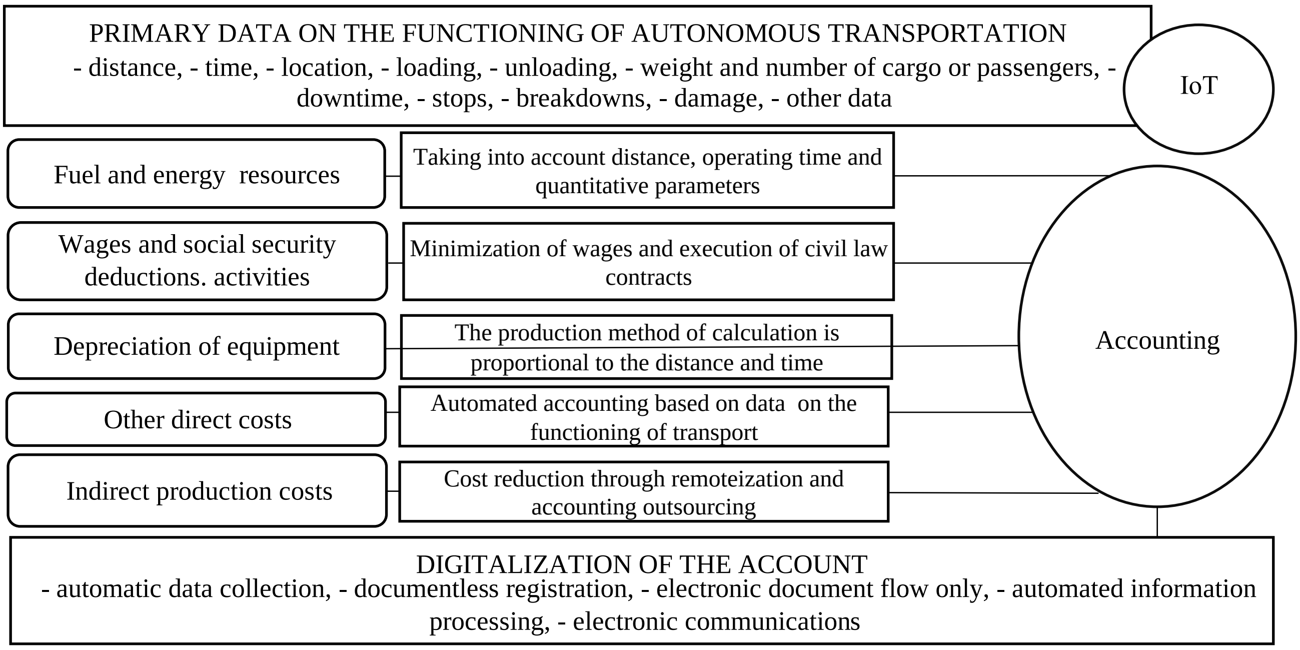

Figure 4. Information scheme for digital accounting for the functioning of autonomous transport
Sources: developed by the authors.

It is advisable to position the transportation of goods via autonomous transport as an integral part of the operational cycle. The sale of finished products or goods takes place not at the manufacturer (supplier) but at the buyer. Since the logistics system of sales involves the transportation of material assets by the enterprise's own autonomous transport, ownership transfer occurs later. Therefore, it is advisable to reflect on the realization of tangible assets in the accounting system only after delivery to the final consumer. Accounting records for the recognition of income from the sale of products (goods) should be formed at the time of their physical delivery to the location, with a video recording of transportation as legal proof of the process. Therefore, it is advisable to inform the buyer at the time of purchase of goods about legal responsibility and consent to delivery by autonomous means of transport. Such an agreement is the legal basis for the accounting display of sales operations. The final registration of the order and legal consent starts the implementation process and information display in the accounting system. The costs of transporting material assets to the final consumer, which are associated with the operation of autonomous robotic transport, should be recognized as sales costs. In the case of loss or damage of material value, which makes their realization impossible, it is advisable to redistribute the costs from the realization in favour of other costs of the enterprise. If the damage can be repaired, then it is advisable to recognize the receipt of goods for sale as income of the enterprise to minimize the impact of extraordinary events on the financial results of autonomous transport operators, it is advisable to create insurance reserves in the form of securing future costs and payments. In this case, it is advisable to compensate for the cost of lost or damaged material assets from the reserve fund for such situations. In the case of the return of material values by the buyer within the period guaranteed by the law or after-sales service, it is advisable to provide for the possibility of return delivery by autonomous unmanned transport. It is expedient to compensate for the costs of cargo transportation from the buyer to the place of storage at the enterprise from the previously formed reserve. The fund can ensure future expenses and payments for the after-sale movement of material assets and their repair (suitable for further use). Another accounting method is used when the provision of transport services via autonomous robotic transport is the main activity of the enterprise. Expenses for the provision of transport services are recognized as expenses of the period, and the cost of services is determined by calculating direct costs such as material costs (primarily for fuel and energy resources), wages of controllers and operators of unmanned transport, social deductions, depreciation of fixed assets and other direct costs.

The cost of services is calculated by passenger carriers to determine the cost of transporting one passenger or a certain number of people for one kilometre of travel. A positive difference that affects the accounting of passenger transport is the prompt determination of the cost of transport services. Depending on the distance and duration of the trip in unmanned vehicles, it is advisable to calculate the cost of passenger transportation and notify each passenger. The cost of a transport ticket is variable and is adaptively adjusted depending on the change in the operating conditions of the carriers. Through an individual calculation mechanism, a reliable method of determining revenues from the provision of passenger transportation services becomes available. After completing each passenger's route, it is possible to inform them about the variable cost of transportation, taking into account variables. The fare can be automatically withdrawn from the passenger's personal or bank account. Owing to Internet of Things (IoT) technology, which is built into autonomous vehicles, variables are subject to automated identification. Each variable indicator, such as range, duration of the trip, zoning of the transport network, number of passengers, luggage, availability of discounts or benefits for transportation, can automatically calculate the ticket price for a passenger. According to a similar method of digitalization, the transport costs of enterprises using autonomous vehicles are determined. The scheme of digitalization accounting for the functioning of autonomous robotic transport is shown in Fig. 5.

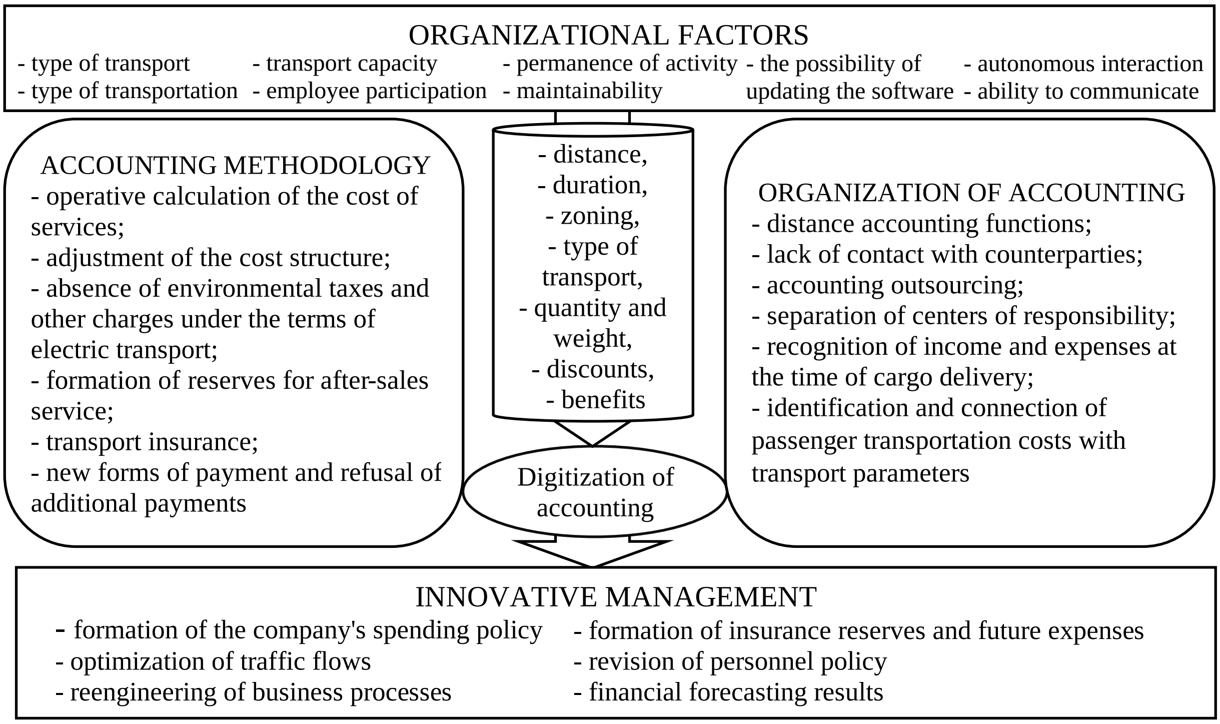

Figure 5. Scheme of the digitalization of accounting in the innovative management of autonomous robotic transport

Sources: developed by the authors.

4.2. Digitalization of expense accounting and cost calculation for transportation services

Fuel and energy resources constitute the largest share of the costs of transport enterprises. It is advisable to use information on the movement of autonomous vehicles to digitalize the accounting of fuel and electricity transportation costs. On the basis of autonomous transport data, it is advisable to automate the cost of the fuel used in accordance with regulatory (forecast) values for production or marketing costs. Electric transport is able to automatically provide electricity residue data in the battery. The difference between this indicator before the movement of the vehicle and after its arrival at the final destination determines the cost of electricity for the performance of the production task. The cost of consumed electricity for each movement of autonomous transport or completed production cycle should be attributed promptly to the production or marketing costs of the enterprise. Additionally, the uniform movement of robotic vehicles by the road optimizes the costs of fuel and lubricants, and the use of electric rolling stock significantly minimizes the cost of the transport services provided. In addition, the transition to renewable energy sources is associated with the absence of emissions of harmful substances into the environment. Moreover, this makes environmental taxes irrelevant for transport companies that use autonomous electric vehicles. The costs of fuel and energy reserves depend significantly on the type of robotic vehicle: unmanned aerial vehicles or autonomous vehicles (Fig. 6).

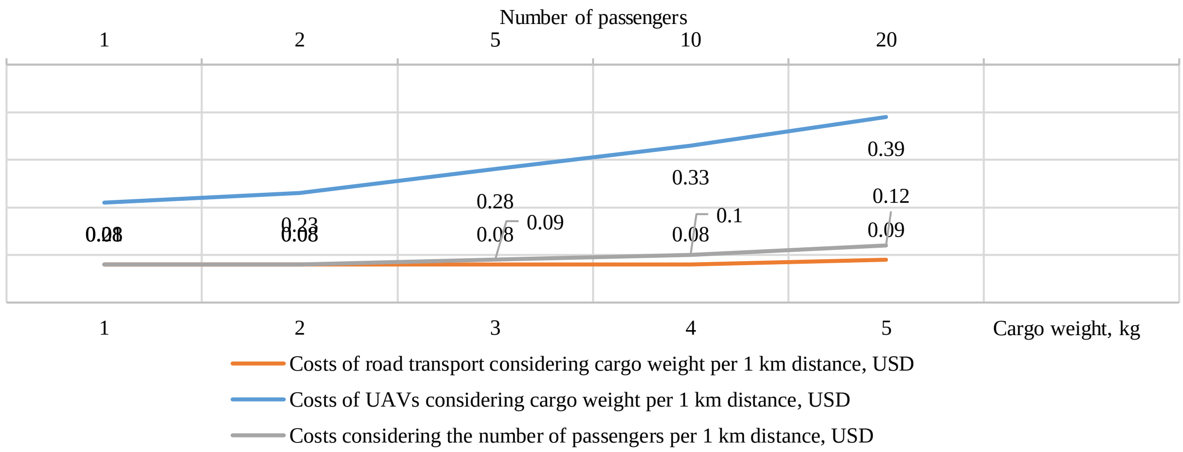

Figure 6. Costs of fuel and energy resources depending on the quantitative parameters of transport services for different types of transport
Sources: developed by the authors based on (Basic cost norms, 2023; Rahmani et al., 2024).

According to the conducted analysis, fuel and energy consumption increases significantly with increasing cargo weight transported by autonomous aerial vehicles. The cost of air transportation of material goods directly depends on the route distance and cargo weight. Specifically, fuel and energy expenses for air transport (drones) increase from 0.21 USD for 1 kg of payload to 0.39 USD for 5 kg per kilometre of distance. The optimal weight for economically feasible air transportation is 2-3 kg. For cargo exceeding 4 kg, alternative modes of transportation are recommended. In contrast, the operation of autonomous road transport is minimally affected by the weight and quantity parameters of the service. For example, only when the cargo weight reaches 5 kg do fuel and energy costs increase by 0.1 USD per kilometre travelled by autonomous vehicles. A significant increase in the number of passengers transported by autonomous road vehicles slightly increases fuel and energy costs (transporting 5 passengers requires 0.09 USD per kilometre, whereas 20 passengers increase the cost to 0.12 USD per kilometre). Therefore, to improve the efficiency of autonomous passenger transport, maximizing vehicle occupancy is essential. For this purpose, transport management should plan the number of vehicles deployed on the route accordingly. The next element that affects the cost of transport services is wages and social events. Employee wages in transport companies can be automatically calculated in proportion to the operational parameters of autonomous transport. It is advisable to link wages to factors such as the distance travelled by robotic vehicles, the number of passengers transported, the weight of cargo, or the duration of time spent at the workplace. IoT technology is capable of identifying these quantitative metrics, which can then be used as a basis for calculating the appropriate wage for each employee.

Moreover, vehicle autonomy means that there are no costs related to personnel's wages. Drivers, controllers, conductors, logics, merchandisers, cargo security, etc., may not be involved in the operation of autonomous robotic transport. Minimizing the participation of a company's personnel in transport operations optimizes payroll and expenses for social measures. However, the amount of savings in terms of labour costs depends on the type of transport (traditional, remotely piloted, fully autonomous (Fig. 7)).

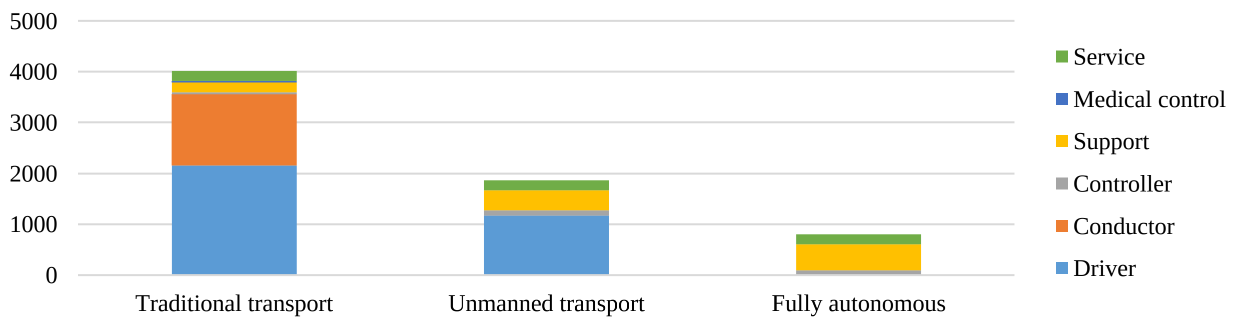

Figure 7. Remuneration funds for personnel related to the operation of transport
Sources: Developed by the authors (The Economic Roadmap, 2024; Poliak et al., 2019).

Notably, the reorientation of transport enterprises to the use of unmanned (remotely piloted) vehicles reduces the payroll by approximately two times. Instead, the total transition to the use of autonomous robotic transport ensures a fourfold minimization of the costs of wages for the personnel of the transport enterprise. Regardless of the type of transport service (passenger, cargo) or means of transport, savings are ensured by refusing the services of a certain type of employee. At the same time, it is possible to increase costs for the functioning of technical, service and other personnel related to transport services by the autonomous transport.

If the transport enterprise in the technological process is not able to abandon the operational staff, it is advisable to attract employees on a legal basis with the execution of civil law contracts, which makes it possible to reduce the costs of paying sick leave, vacation and other compensatory and incentive payments. In addition, the company's employees can operate unmanned vehicles or monitor their operation remotely, and the company's costs for maintaining commercial buildings and premises are reduced. The refusal of different premises for employees automatically minimizes operating costs. These costs include depreciation of outbuildings; heating, power and water supplies; computer equipment; etc. Consequently, the structure of future expenses and payments should focus on after-sales customer service instead of holiday payments. The funds from this reserve can cover probable costs caused by the autonomous functioning of vehicles. On the other hand, the use of unmanned vehicles significantly minimizes road accidents, which creates significant additional insurance reserves. It is possible to refuse to form other types of insurance funds in addition to ensuring the civil liability of vehicle owners. However, the intensive round-the-clock use of unmanned vehicles, which are currently expensive, leads to rapid wear, tear and breakdown. It is important to use accelerated methods for calculating depreciation and periodic maintenance. As a result, the share of these costs related to the operation of autonomous transport in the cost of the provided transport services is increasing. The amount of depreciation, which is included in the cost of the provided transport services, can differ significantly depending on the chosen method of its calculation (Fig. 8).

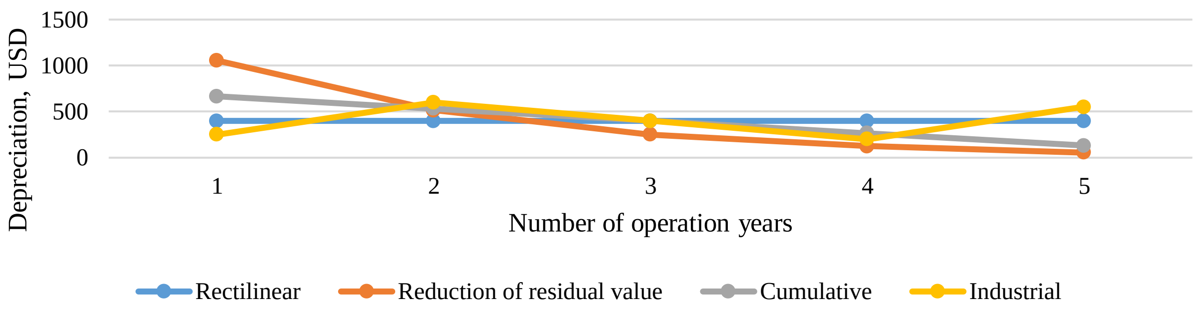

Figure 8. Amount of depreciation with different calculation methods
Sources: Developed by the authors on the basis of (Calculator for calculating depreciation of fixed assets, 2024).

Most methods of calculating depreciation ensure uniform or initially maximum consideration of the wear and tear of vehicles when determining the cost of the provided transport services. This trend followed the example of the calculation of depreciation according to the main methods (straight-line, cumulative, reduction in residual value and production). Among them, only the production method of calculating depreciation is directly related to dynamic changes in the parameters of vehicle operation (Fig. 6 shows a broken curved line with variable amounts of depreciation deductions for different years of operation of fixed assets).

A modified production method for calculating depreciation can be used for a more reliable calculation of depreciation deductions and their operational consideration in the cost of transport services. The production method of calculating depreciation consists of the ratio of the distance travelled by the vehicle or flight hours to the general normative (planned) indicator of the fault-free functioning of autonomous robotic transport. In other words, with each performance of an economic task, the vehicle exhausts the resource of guaranteed activity without the need for major repairs, and its cost is gradually transferred to the cost of the provided transport services. Accordingly, it is advisable to automatically calculate depreciation after the completion of each trip (flight) with reflection on the composition of production (sales) costs. The proposed version of depreciation accounting ensures the determination of the fair value of transporting cargo (passengers) on the basis of data of autonomous transport movement. Similarly, other expenses, such as fuel and energy resources, material costs, and wages, should be associated with the quantitative parameters of autonomous transport operations. Accordingly, all these expenses can be automatically identified, providing a basis for real-time calculation of transport service costs. An example of automatic determination of the cost of a transport service for the consumer is shown in Table 2.

Table 2. Calculating the cost of transporting goods and determining the cost for the end consumer via robotic transport

The cost of transportation of a cargo unit without taking into account the weight			
Type of expenses	**for 1 km**	**Distance, km**	**Cost, USD**
Fuel and energy resources	0.22	11	2.42
Wages and social insurance	0.07	11	0.77
Amortization	0.08	11	0.88
Current repair	0.04	11	0.44
Medical insurance	0.14	11	1.54
Reserves to ensure future expenses and payments	0.06	11	0.66
Cost of freight transportation			6.71
Planned profit from the transport services		30%	2.01
Cost of transportation for the end user			8.72
Cost of cargo transportation including weight			
Type of expenses	**For 1 kg/km**	**Weight and distance, kg/km**	**Cost, USD**
Fuel and energy resources	0.10	$4 \times 11 = 44$	4.40
Wages and social insurance	0.04	$4 \times 11 = 44$	1.76
Amortization	0.03	$4 \times 11 = 44$	1.32
Current repair	0.02	$4 \times 11 = 44$	0.88
Medical insurance	0.06	$4 \times 11 = 44$	2.64
Reserves to ensure future expenses and payments	0.02	$4 \times 11 = 44$	0.88
Cost of freight transportation			11.88
Planned profit from the transport services		30%	3.56
Cost of transportation for the end user			15.44

Sources: developed by the authors.

The largest share of the cost structure of cargo transportation is occupied by costs of fuel and energy resources (0.22 USD), as well as insurance of cargo (0.14 USD) delivered by autonomous robotic transport. However, the identification of cargo weight in the process of cost accounting of transport enterprises ensures full consideration of all parameters of the functioning of vehicles. The ability to review the cost of delivery, taking into account weight meters, is most relevant for the operation of unmanned aerial vehicles. An increase in the weight of the transported cargo necessarily leads to increases in the consumption of fuel and energy resources. Table 2 shows a comparison of the cost of cargo transportation under different conditions when weight meters are considered. The cost of air transportation for a 4 kg cargo over a distance of 11 km is 6.71 USD without considering weight parameters and 11.88 USD when weight is factored in. Thus, disregarding weight parameters in autonomous cargo transportation leads to distorted accounting data. On the basis of inaccurate cost information, the management of a transport company might make erroneous decisions regarding pricing for cargo services. A twofold increase in the cost of the service is a significant argument for implementing digitized accounting that incorporates all the quantitative parameters of cargo transport.

A similar situation is observed for passenger carriers. However, the greater the capacity of autonomous vehicles is, the less significant the increase in the number of passengers will be for the cost of transportation. In particular, for passenger buses, an increase in the number of passengers per person will have almost no effect on the cost of transport services. Table 3 shows an example of calculating the cost of passenger transportation while considering only the distance of the trip, as well as the identification of the number of transported persons. The table shows an example of a radical change in some cost elements in the cost of passenger transportation, taking into account various options for the use of quantitative measures. However, fuel and energy costs remain static indicators in the calculation of transport service costs (0.22 USD) and, as has been demonstrated, hardly change with increasing number of passengers. The amount of depreciation of vehicles, which is associated with an increase (decrease) in passenger flow, depends even more on quantitative measures. According to the cost calculation results, the cost of transporting one passenger over a distance of 4 km is 2.44 USD without considering the number of passengers and 1.58 USD when accounting for all the quantitative parameters of autonomous transport operations.

Table 3. Calculating the cost of passenger transportation and determining the cost for the end consumer via robotic transport

The cost of transportation does not include the number of passengers			
Type of expenses	**for 1 km**	**Distance, km**	**Cost, USD**
Fuel and energy resources	0.22	4	0.88
Wages and social insurance	0.07	4	0.28
Amortization	0.08	4	0.32
Current repair	0.04	4	0.16
Medical insurance	0.14	4	0.56
Reserves to ensure future expenses and payments	0.06	4	0.24
Cost of freight transportation			2.44
Planned profit from the transport services	10%		0.24
Cost of transportation for the end user			2.68
The cost of transportation, taking into account the number of passengers			
Type of expenses	**for 1 passenger / km**	**Quantity and distance, passenger/km**	**Cost, USD**
Fuel and energy resources	0.22	4	0.88
Wages and social insurance	0.03	$2 \times 4 = 8$	0.24
Amortization	0.04	$2 \times 4 = 8$	0.32
Current repair	0.02	$2 \times 4 = 8$	0.16
Medical insurance	0.14	$2 \times 4 = 8$	1.12
Reserves to ensure future expenses and payments	0.02	$2 \times 4 = 8$	0.16
Cost of freight transportation			2.88
Planned profit from the transport services	10%		0.29
Cost of transportation for the end user			3.17/2 passengers = 1.58

Sources: developed by the authors.

Increasing the number of passengers transported simultaneously reduces the cost of transport services for each individual passenger. Unlike cargo transportation via autonomous vehicles, the digitization of passenger transport cost calculations eliminates the possibility of artificially inflating service prices. While the accounting for cargo transportation revealed cases of omitted costs related to moving heavy loads, passenger transport accounting revealed increased transportation costs. To avoid inaccuracies in accounting data, it is advisable to use calculation units that simultaneously consider all the quantitative parameters of autonomous transport operations.

As a result, to ensure the innovative management of vehicles, it is advisable to use complex units of measurement – "kilogram-kilometre" and "passenger-kilometre". Two-dimensional calculation units make it possible to consider not only the distance travelled by autonomous vehicles but also the weight of the cargo and the number of transported passengers. Multiaspect cost accounting of transport enterprises provides parameterization of all aspects of the operation of vehicles that affect the cost of the services provided. The digitization of cost accounting by two-dimensional calculation units also prevents fictitious distribution of costs and inefficient determination of the cost of transport services for end users. In other words, the application of such complex units of measurement on the basis of data collected by autonomous transport ensures reliable, complete and timely accounting of the costs of the activities of transport enterprises.

Moreover, certain specific features of transportation via autonomous vehicles remain overlooked, which highlights limitations for the widespread application of the proposed digital cost calculation methodology for transport services.

5. Discussion. The research was conducted in sequential alignment with the scientific work of other authors. To achieve the goals and objectives of the article, the research was carried out through successive stages corresponding to the research levels: macroeconomic, organizational, information-management, and accounting levels. Each research stage was based on relevant literature from various scholars. At the macroeconomic level, the impact of autonomous transport on socioeconomic transformations within the transport sector was identified. The identification of the impact of organizational factors on the operations of transportation enterprises engaged in autonomous transport was conducted at the organizational level. The innovative aspect of the article at the information-management level lies in the proposed use of data collected by autonomous vehicles for accounting purposes. The final research level encompasses the author's developments in the digitization of cost accounting for autonomous transport operations and the automatic calculation of transport service costs for the innovative management of transportation enterprises. Achieving the accounting level represents one of the first scientific studies in the field of autonomous transport from the perspective of accounting. The research results revealed an anomalous contradiction in the calculation of transportation costs for freight and passenger services when accounting for all the quantitative parameters of autonomous transport operations. For freight transport (particularly the use of unmanned aerial vehicles), the digitization of cost calculations leads to an increase in costs due to the identification of additional transport expenses. Conversely, for passenger transport, the digitization of cost calculations contributes to a reduction in transportation service costs when the number of passengers transported is considered. The final goal of this research is to ensure the accuracy of transportation cost accounting and the calculation of transport service costs, which provides an informational basis for the effective management of transportation enterprises.

6. Conclusions. The active development of artificial intelligence technology has made it possible to develop the concept of autonomous vehicle management. Robotic vehicles are involved in the transportation of passengers and cargo, which forms a fundamental basis for the emergence of innovative transport enterprises. To effectively manage the financial and economic processes of carriers, it is advisable to use autonomous transport to collect primary data that can be useful for accounting. This accounting information includes the distance covered by vehicles, the duration of the journey, the number of transported passengers, the weights of the transported cargo, stops, parking lots, travel routes and other data. The key organizational factors affecting the accounting of the functioning of robotic transport are as follows: the type of transported objects; consumed fuel and energy resources; the participation of people; the capacity and number of transported cargo (passengers) at one time; the permanence of functioning, maintainability; the possibility of updating the software provision; autonomous interaction with other means of transport; ability to communicate with and inform customers of transport services.

Considering the organizational prerequisites mentioned above, it is advisable to digitize the accounting of fuel and energy resource consumption on the basis of information provided by the IoT from autonomous transport systems. It is proposed that fuel and energy resources be promptly written off after each trip on the basis of data regarding the number of kilometres travelled, the weight of the cargo, and the number of passengers transported per trip. Similarly, automatically calculating the wages of all employees involved in service of autonomous transport vehicles for each completed trip is recommended. Owing to the autonomy of vehicles, the labour costs for drivers, conductors, cashiers, and other related personnel are significantly reduced, thereby optimizing the cost of transport services. Accounting for the depreciation and ongoing maintenance of autonomous transport should also be digitized, with the use of the production method for calculating depreciation enabling the establishment of a correlation between wear and tear and the quantitative parameters of autonomous vehicle operations. As a result, all the direct costs associated with the transport of passengers and cargo are subject to automatic identification and accounting.

To account for all operational parameters of autonomous robotic transport, it is advisable to use two-dimensional calculation units such as “kilogram-kilometre” and “passenger-kilometre”, which ensure that the transportation distance, cargo weight, and number of passengers are factored into the calculation of direct transport costs, including fuel and energy resources, wages, social and medical insurance, depreciation, and ongoing maintenance and repairs. The calculations of the cost of cargo and passenger transportation services via complex calculation units yielded opposite results. The transition to two-dimensional calculation units led to an increase in the cost of cargo transportation due to the identification of additional transport expenses, whereas the cost of passenger transportation decreased as a result of optimizing transportation costs with an increase in passenger traffic. The digitization of cost accounting and transport service cost calculations ensures accurate, complete, and timely information for end consumers regarding transportation costs, providing an informational basis for the innovative management of transport enterprises.

Innovative management of transportation flows is based on the accounting information involved: identifying revenues and expenses at the moment of robotic cargo delivery; determining the relationship between passenger transportation costs and transport movement parameters; establishing reserves for post sale service of delivered goods; managing transportation flows; insuring cargo and passengers; eliminating additional compensatory and incentive payments for personnel employed under civil contracts; performing operational cost calculations and minimizing service costs immediately after each instance of passenger or cargo delivery; and optimizing environmental taxes and other levies. As a result, the research hypothesis is confirmed regarding the fundamental transformation of accounting for the operations of transport enterprises due to changes in the business mechanisms of providing transportation services via autonomous robotic transport. Proposals for calculating transportation service costs face organizational and functional limitations.

These limitations include the inability to calculate costs for simultaneous passenger and cargo transport using the same vehicles; the difficulty in counting the number of passengers simultaneously present in a vehicle, requiring entry/exit validation and monitoring technologies; and the inappropriateness of applying proposals for rail and maritime transport owing to their focus on unmanned vehicles or aerial vehicles (drones).

However, given the limitations in the proposed methodology for digitalizing the accounting and cost calculation of transport services, further research is needed to explore the feasibility of the simultaneous transportation of passengers and cargo by shared vehicles; the use of rail, marine, and aviation transport for robotic transportation; and the improvement of transport flow management methods in smart cities.

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Цифровізація обліку в інноваційному управлінні автономним роботизованим транспортом

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Діджиталізація економічних процесів відбувається у всіх галузях економіки, що разом формують Індустрію 5.0. Важливим елементом п'ятої промислової революції є активізація роботизованої господарської діяльності. В останнє десятиріччя практичного втілення набули розробки у сфері автономного роботизованого транспорту. Проте практика використання безпілотних транспортних засобів, а також наукові напрацювання у цій сфері продемонстрували низьку ефективність імплементації проєктів автономного транспортування вантажів та пасажирів. Причиною цього є недостатня увага до обліково-управлінських аспектів функціонування автономного роботизованого транспорту. Науково-практична новизна дослідження полягає в удосконаленні обліку та управління в умовах їх діджиталізації у частині врахування фундаментальних трансформацій господарських процесів, спричинених використанням автономних транспортних засобів. Виокремлено ключові організаційні чинники, які впливають на бухгалтерський облік функціонування роботизованого транспорту: вид транспортованих об'єктів, споживаних паливо-енергетичних ресурсів, участь людей, місткість та кількість перевезеного вантажу (пасажирів) за один раз, перманентність функціонування, ремонтопридатність, можливість оновлення програмного забезпечення, автономна взаємодія з іншими транспортними засобами, здатність комунікації та інформування замовників транспортних послуг. Розроблено методику цифровізації обліку витрат на паливо-енергетичні ресурси, заробітну плату персоналу, відрахування на соціальні заходи, амортизацію, експлуатаційні та інші витрати, пов'язані з функціонуванням автономного роботизованого транспорту з врахуванням наведених організаційних передумов на основі інформації з IoT. Запропоновано використовувати двовимірні калькуляційні одиниці «кілограмо-кілометр» та «пасажиро-кілометр» для цифровізації калькулювання собівартості послуг з перевезення пасажирів та вантажів за допомогою автономного роботизованого транспорту з врахуванням усіх аспектів його функціонування. Уточнено порядок визначення вартості транспортних послуг для кінцевих споживачів та формування інформаційних масивів для інноваційного управління транспортними підприємствами. Важливість усунення організаційних обмежень в управлінні функціонуванням автономного транспорту, а також необхідність інформаційної синхронізації транспортних підприємств з іншими учасниками ділових взаємовідносин в інформаційному середовищі смартміста визначає перспективність подальших досліджень у цій сфері.

Ключові слова: цифровізація обліку, інноваційне управління, калькулювання собівартості, автономний транспорт, роботизовані транспортні засоби, безпілотні літальні апарати, електронні трансакції.