This paper reports a study of the main principles for the formation of public passenger transport service quality standards. The object of the research is public passenger transport services. The task of the study is the development of conceptual foundations for the formation of quality standards using modern innovative technologies. It has been established that the main factor in achieving the quality of public passenger transport services is taking into account innovative technologies and compliance with the criteria and norms of EU standards.

Features in the functioning of public passenger transport in the world have been studied, including the use of information platforms for tracking the movement of transport routes, Internet applications, ensuring safety and compliance with environmental requirements. The criteria that serve as indicators of improving the efficiency of the quality of services have been defined, among the main ones are the availability of transportation, comfort, frequency of traffic, and waiting time, quality of service, as well as safety. A system of forming the quality of public passenger transport services has been proposed, which involves determining the needs and requirements of consumers of public passenger transport services, ensures the development of measures to improve the quality of services and their certification.

A comprehensive approach to the formation of the quality of public passenger transport services based on the introduction of innovative technologies has been formed, which could make it possible to determine the level of their innovative development, as well as ways to improve it. This approach takes into account the relationship between implemented measures, measuring the level of service quality and the distribution of obligations to ensure the level of services determined by quality criteria. This makes it possible to determine the required level of quality of public passenger transport services and to form a relationship between the level of innovative technologies and the stages of the approach.

The practical significance of the results is the design of tools that would ensure the improvement of the quality of public passenger transport services

***Keywords:** public passenger transport (PPT), service quality standards, quality criteria, innovative technologies*

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DEVELOPMENT OF CONCEPTUAL PROVISIONS FOR IMPLEMENTING INNOVATIVE TECHNOLOGIES TO QUALITY STANDARDS OF PUBLIC PASSENGER TRANSPORT

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1. Introduction

Under modern conditions, high-quality passenger service has become a priority in the process of providing transport services to the population of cities. Improving the quality of road passenger transport in the city system is one of the most important directions of the functioning and development of public transport. The quality of urban automobile passenger transportation is a complex concept that is constantly developing and improving. World trends indicate that the quality of transport services should meet the needs and expectations of consumers [1].

Improving the quality management system of transport services is one of the most important directions for ensuring the growth of transportation volumes, a stable sales market, and stable profit [2].

It is expedient to solve quality management problems at transport enterprises with the help of modern innovative tools. Quite a few transport companies use a combination of the three innovation paradigms discussed above. However, they are not

able to cover the entire complex of problems of ensuring the quality of transport services under modern conditions [3].

Improving the quality of passenger service is a priority area in the process of providing transport services to the population. It is necessary to develop quality standards of public transport that would make it possible to clearly define the main requirements and norms that must be observed by carriers providing public transport passenger services. The growth of competition between transport operators puts ever greater demands on the quality of service.

The quality of transportation characterizes the degree of public utility of transport products and services. The need to improve the quality of transport services to modern requirements, which is specified in the quality standards, is one of the main tools for the functioning and development of public passenger transport. Within this framework, the development of standards for the application of innovative technologies will provide an opportunity to adapt public passenger transport services to European standards. Improving the quality of public passenger transport services with the introduction of innovative technologies will make the transition to "smart" solutions easier while the introduction of mobility will be able to solve a number of problems and at the same time open wide opportunities. With digital platforms, journey planners, Internet of Things (IoT) technologies and ticketing solutions to fully achieve this transition, a new way of thinking and innovative MaaS platforms and system integration must be adopted. That is why the stable growth of the need for transportation and their coordination, the introduction of fundamentally new management tools based on innovative technologies at transport enterprises are becoming particularly relevant. Research into the issue of the formation of a system for ensuring the quality of transport services and the implementation of quality standards for public passenger transport services are needed. Therefore, research on the development of quality standards for public passenger transport based on the implementation of innovative technologies is a relevant task as it contributes to improving the quality of public transport services, ensuring competitiveness, and meeting high customer expectations.

2. Literature review and problem statement

A methodology for measuring the impact of urban transport on society through three factors: first, the impact on the environment – climate change, engine emissions, resource consumption for the production of vehicles and land use. Secondly, the social impact – public health, traffic accidents, social exclusivity of car owners. Thirdly, the economic impact is the dependence of the transport sector on the increase in fuel prices, traffic jams in cities, which is proposed in paper [4]. However, issues related to the quality management system of public passenger transport services remain insufficiently addressed. It is also appropriate to consider the peculiarities of the functioning of individual components of public passenger transport in accordance with the conditions of its functioning.

The authors of work [5] determine that the quality of services, in general, consists of five different dimensions, the first two: material (physical premises, equipment, appearance of personnel); reliability (ability to perform the promised service reliably and accurately). The next three are responsiveness (willingness to help customers and provide prompt service); confidence (the knowledge and courtesy of employees and their ability to inspire trust), and empathy (the company's care or individual attention to its customers). In this context, it is appropriate to ensure the flexibility of transport enterprises depending on changes in the external environment, as well as the formation of rational processes based on the principles and standards of service quality.

The reliability of public transport systems is mentioned in the scientific literature as an important factor in assessing the quality of urban transport services. Work [6] identified five factors affecting the reliability of public transport: the number of stops for boarding and disembarking passengers, outdated and faulty vehicles. It is also traffic jams, frequent breakdowns of vehicles, and the number of available vehicles as such. However, issues regarding the quality of service provision remained unaddressed because it is especially important for transport companies to constantly monitor the dynamics of their activity indicators under the influence of changes in the quality parameters of the provision of public passenger transport services.

The authors of paper [7] covered a global review on the problem of designing a transport network. However, the work does not define the mechanism and limit possibilities of public passenger transport for improving the quality of passenger service.

In work [8], a new high-quality service of public passenger transport is proposed. Owing to the use of interactive integrated information platforms, such as the use of the Internet and telephony, it is possible to order an individual bus for groups of passengers. This service is very attractive to citizens in most Chinese cities, as a result, there is a significant increase in the level of public transport use. However, it is not highlighted how several technological processes can be combined together and how, on their basis, the quality of public transport services for passengers is ensured.

In work [9] it was determined that certain aspects of the work of public transport can be expressed quantitatively, that is, in numerical values. Numerical values do not give information about how good or bad the result is. In order to interpret these values, it is necessary to compare them with the standard values set by default within service levels A to F. It is assumed that users report significant differences in quality between the two levels of transport services. What users consider to be the best quality of service is often not cost-effective, and operators must balance service quality with affordability. This study has shown that there are both positive and negative deviations from the traffic schedule. That is why there is an urgent need to develop appropriate quality standards for public transport services and their compliance with certain criteria.

In the scientific work [10], the mode of ratio of price and quality of public passenger transport services is defined. This makes it possible to ensure that the operators provide the best level of service according to the needs of the stakeholders and especially the objectives of the government. However, the work does not propose a system of price and service quality criteria.

The authors of paper [11] applied an approach to measuring the level of quality using the quality index of transport services through passenger-demand and efficiency-cost functions (by measuring profitability and economic efficiency (total productivity ratio). The most important indi-

cators are fare, delivery time, and time accessibility (time of approach to the stop, waiting time, because according to the schedule, the bus can depart at intervals of 15, 30, and even 60 minutes). This will make it possible to form sustainable long-term competitive advantages and increase the level of competitiveness of the transport enterprise.

In our review of the literature, it was found that the issues of developing the conceptual foundations of the introduction of innovative technologies to the quality standards of public passenger transport services remained unresolved, which indicates the feasibility of conducting our research.

3. The aim and objectives of the study

The purpose of our study is to devise a conceptual approach to the introduction of innovative technologies into the quality standards of public passenger transport. This will provide an opportunity to contribute to the increase in the mobility of services and the constant modernization of the technological state of passenger transport. The development of standards for the quality of public passenger transport must take into account the requirements and preferences of consumers, comply with European norms and standards, and also contribute to the competitiveness of public passenger transport enterprises.

To achieve the goal, the following tasks were set:

– to investigate the peculiarities of public passenger transport in the world;

– to form a high-quality system of providing public passenger transport services;

– to develop criteria for the quality of public passenger transport services;

– to devise quality standards for public passenger transport services on an innovative basis.

4. The study materials and methods

The object of our study is the process of forming quality standards of public passenger transport services based on the application of innovative technologies. The research hypothesis assumed that the formation of public passenger transport service quality standards directly determines the need to develop a conceptual approach, in particular based on innovative technologies. This will contribute to the increase of the company's profitability, effective functioning on the market, will ensure the modernization of its technological state, and will make it possible to obtain sustainable competitive advantages. The assumptions adopted in the study necessitated the use of certain methods, which can be divided depending on the directions of our research: theoretical; analytical. The theoretical group of methods was used in the study in the development and justification of the implementation of public passenger transport service quality standards. Analytical method – to determine and generalize trends regarding the level of application of quality standards of public passenger transport services on a global scale. A complex of general scientific and special methods of cognition is used, namely: system analysis and synthesis, theoretical generalization, and comparison. These methods were used to devise quality criteria for public passenger transport services.

5. Results of the study on ensuring the quality of public passenger transport services using innovative technologies

5. 1. Investigating the peculiarities of public passenger transport in the world

The quality of public passenger transport services is one of the components of the quality of life in cities. As the level of motorization increases, quality public transport services become an alternative to the use of private cars and improve the ecology of cities. The countries of Western Europe, the USA, Australia, etc. followed this path.

An acute problem of high-quality service for passengers by public transport appears in Ukraine due to the accumulation of a number of social problems associated with a large number of preferential categories of passengers, which leads to a certain degradation of public passenger transport. On the other hand, during the last decade, restrictions on the import of old cars from Europe and the US were lifted, which contributed to the country's mass motorization, but caused serious traffic congestion and exhaust emissions in cities. That is why it is necessary to develop appropriate quality standards for public passenger transport services and prescribe all the basic requirements and norms that carriers must adhere to. However, when developing standards, it is necessary to use modern innovative technologies so that the standards meet the challenges of modern times. On a global scale, each country develops its own quality standards for public transport services, and each country has its own characteristics. For Ukraine, it is necessary to meet the economic and environmental criteria, the need to develop software for real-time integration. This is done by importing and comparing all existing timetable data. The passenger receives multimodal information about the entire route, including possible transfers to public transport.

In the UK, service reliability and value for money are important needs for public transport users. A new step in improving the quality of services was the introduction of the post of road safety officers to combat anti-social behavior. With £2.5m of funding, specially trained officers will improve public safety and help prevent violence against women and girls in and around public transport [12].

For the USA, the main indicators of the quality of services for passengers, authorities, and carriers are the division into communities: motorist, transit agency, passengers. To measure the quality of public transport, it is proposed to divide each indicator into 5–7 numerical gradations [13]. Features of public passenger transport are illustrated in Fig. 1.

Australia has issued and applies Public Transport Infrastructure Guidelines, which prescribe all the features of services, tariffs, and rules [14]. The Government of Ireland has issued an Official Guide for the Small Public Transport Industry, which outlines the specificity of providing public passenger transport services [15].

Many transport models have been developed. For example, in Austin, Texas, the "Node-Place-People" model is used to evaluate 133 future transit-oriented development sites according to the new regional transportation development plan [16].

Based on statistical data, an assessment was made of how effective and high-quality the passenger service system is in public transport. The sample consisted of 22 European cities meeting indicator 11.2.1 of the Global Sustainable Develop-

ment Indicator, which measures the proportion of the population with convenient access to public transport. It has been established that in a number of cities of different sizes and regions, especially southern European ones, public transport systems organize their networks of stops more efficiently, as they provide convenient access for the population, than in northern cities. In order to achieve the efficiency standard of DEA (Data Envelopment Analysis), inefficient public transport systems need to reorganize the network of stops and increase public access to public transport by an average of 58 % [17].

There are a number of measures to improve the operation of public transport to quickly respond to short-term changes in passenger demand for transport services. However, if the realized level of service (LoS) may differ significantly from the expected one, demand management measures are required. These can be recommendations for passengers to use certain routes to reduce traffic jams and travel time (social reorientation). It can also include implementing certain proposals for the population together with measures to improve LoS in different time scales [19].

The use of digital technologies allows the enterprise to carry out centralized management at all stages of the life cycle of the manufactured product (or the service provided). Namely, digital design and modeling, digital manufacturing, digital supply chain, logistics and digital adaptation for the consumer after its delivery [21].

There are barriers and their impact on daily travel, especially in densely populated areas characterized by high levels of car use, insufficient pedestrian areas, and limited connections to other modes of transport. To minimize the negative impact, it is advisable to develop a questionnaire for self-filling, as well as to conduct a survey to collect answers from passengers who use public transport at various transport hubs. Results from structural equation modeling (SEM) showed a positive correlation between instrumental attractiveness (IA) and facility design and operation (FDO) with daily commutes. Conversely, service and information (SI) together with environmental comfort (EC) showed a negative correlation with daily trips [22].

Stakeholders		Stakeholder Interest Areas	Performance measure examples	
COMMUNITY	PASSENGER	TRAVEL TIME	Transit-auto travel time	Transfer time
		AVAILABILITY	Service coverage Service denials	Frequency Hours of service
		SERVICE DELIVERY	Reliability Comfort	Passenger environment Customer satisfaction
		SAFETY AND SECURITY	Vehicle accident rate Passenger accident rate	Transit crime rate Safety device inventory
		MAINTENANCE / CONSTRUCTION	Road calls Fleet cleaning	Spare ratio Construction impact
	TRANSIT AGENCY	ECONOMIC	Ridership Average fleet age	Cost efficiency Cost effectiveness
		TRANSIT IMPACT	Economic impact Employment impact	Environmental impact Mobility
	MOTORIST	CAPACITY	Vehicle capacity Person capacity	Roadway capacity Volume-to-capacity ratio
		TRAVEL TIME	Delay	Average system speed

Fig. 1. Quality indicators of public passenger transport services in the USA [13]

The use of integrated public transport networks will improve the quality of services if they are implemented strategically and taking into account the experience of service users. When building urban transport, managers of enterprises need to pay attention to certain aspects, including security (provision of cameras, patrols and help desks). As well as provision of infrastructure (barriers protecting users from vehicles and provision of shelters) during the implementation of such projects [18].

Analyzing transport activities and comparing the structural efficiency of more than 7,000 official and unofficial bus routes in 36 cities in 22 countries of the world, it was established that unofficial transport organizes itself at the level of efficiency of centralized services, higher than the official one. It exhibits fewer detours, more unified routes, and remains more profitable without the heavy subsidies typical of the Global North [6].

In South Africa, the growing dominance of taxis gradually undermined other existing modes of transport and contributed in part to the decline of the public transport system. Symptoms of the dysfunction of South Africa's public transport system include declining share of formal services (rail and road), fierce market competition on congested routes. Also, the low quality of services of paratransit types of transport (especially aggressive behavior of drivers and unsuitable vehicles) and weak law enforcement and regulation [6].

In Ukraine, public transport consists of minibuses, only in large cities there are electric transport and large buses. The situation is similar in developing countries. In Dakar, the capital of Senegal, a large number of minibuses are owned by informal operators who operate locally under the Tata name. Since 2000, the public bus company Dakar Dem Dikk has been established, and public transport has been replaced and reorganized. However, this new offer still coexists with older, more or less informal forms of transport. In terms of public passenger transport (PT) in Dakar, 58 % customers used Tata or DDD buses, 52 % – other informal means of transport PPT [23].

Investigating the peculiarities of public transport in Ukraine, it is possible to ascertain the presence of a number of problems, including irrational distribution of modes of transport, unsatisfactory condition of the road surface. It is also the absence of a single coordination center, the absence of a detailed traffic scheme on the route with an indication of the time of arrival [24, 25]. Evaluating the quality of public passenger transport services in Zaporizhzhia, it was determined that the following indicators have the greatest weight: availability of passenger transport (0.12), speed of movement on the route (0.17), and time. These are also indicators of the time spent on movement (0.115) (the indicator is inversely

proportional), the interval of movement on the route (0.11), reliability (0.10), and the cost of services (0.108).

The study into the peculiarities of the functioning of public passenger transport in the world showed that the use of innovative technologies in service contributes to the processes of modernization of the transport and road complex. It also contributes to the activation of attracting investments in the implementation of strategically important projects of an innovative nature in the transport sector with the aim of expanding the scope of providing quality transport services to both sectors of the economy and the population. The use of innovative technologies and processes, the development and introduction of innovative products allow the company to occupy a leading position on the market. This provides products (services) with a high level of scientificity and novelty, thereby making them competitive in the world market [26].

5. 2. Formation of the quality system of public passenger transport services

Implementation of the quality management system of public passenger transport services will ensure the continuity of the process of development and improvement of services.

The implementation of modern quality management systems that meet ISO 9001:2015 standards contributes to the optimization of processes and the formation of a system aimed at constantly improving the quality of transport services.

The quality management system of public passenger transport services is based on the study of current and prospective demand for transport services. During the development and improvement of the transport services quality management system, the requirements of current standards, consumer requirements, scientific and technical data, and certification results are taken into account. The quality management system of public passenger transport services should consist of a complex of interconnected processes that ensure compliance with the requirements of quality standards.

The most complete indicators of the quality of public passenger transport are defined in EU standards [27, 28]:

– DSTU EN 13816:2002 Transportation. Logistics and services. Public passenger transport. Definition, purpose, and quantitative assessment of the quality of services provided (2002);

– DSTU EN 15140:2006 Public passenger transport (GPT). Basic requirements and recommendations for systems of quantitative assessment of the quality of provided services (2006), hereinafter – Standards. In Ukraine, these standards entered into force on February 1, 2023.

The overall quality of public passenger transport is assessed by a large number of criteria. The criteria reflect the consumer's view of the service provided, and in these standards, they are divided into 8 categories.

Categories 1 and 2 describe the PPP offer in more general terms, categories 3, 4, 5, 6, and 7 provide a more detailed description of the quality of services, and category 8 describes the impact on the environment of the community as a whole. The criteria for the quality of services are given in Table 1.

Each criterion is further divided into 3 levels. For example, the "Availability" criterion includes five criteria at level 2:

1. 1. Types of transport.
1. 2. Network.
1. 3. Transport operations.
1. 4. Eligibility.
1. 5. Reliability.

At the level of 3 criteria, 1. 2. The network includes:

1. 2. 1. Distance to the landing place.
1. 2. 2. The need for translations.
1. 2. 3. Covered territory.

In general, the standard offers 30 criteria at level 2 and 100 criteria at level 3. The description of criteria for the PPP service requires the implementation of such a complex system of evaluation and management of the service quality system and the organization of certain activities [29].

The general principles of the service quality cycle are outlined and illustrated in Fig. 2, while the requirements and recommendations of the standard based on the quality cycle principle are set out in clauses 4 and 5 of the EU standards (EN 13816:2002).

Table 1

Quality criteria of public passenger transport services according to EN 13816:2002

No.	Category	Description
1	Availability	The scope of the offered services in terms of geography, time, frequency, and mode of transport
2	Accessibility	Access to the PPT system, including the interface with other modes of transport
3	Information	Systematic provision of knowledge about the PPT system to assist in travel planning and execution
4	Time	Time aspects relevant to travel planning and execution
5	Customer service	Service elements have been introduced that ensure the maximum possible correspondence between the standard service and the requirements of each individual client
6	Comfort	Service elements have been introduced to make PPT travel relaxing and enjoyable
7	Security	The sense of personal security experienced by customers resulting from the measures actually in place and the activities aimed at ensuring that customers are aware of these measures
8	Environmental impact	Impact on the environment as a result of the provision of the PPT service

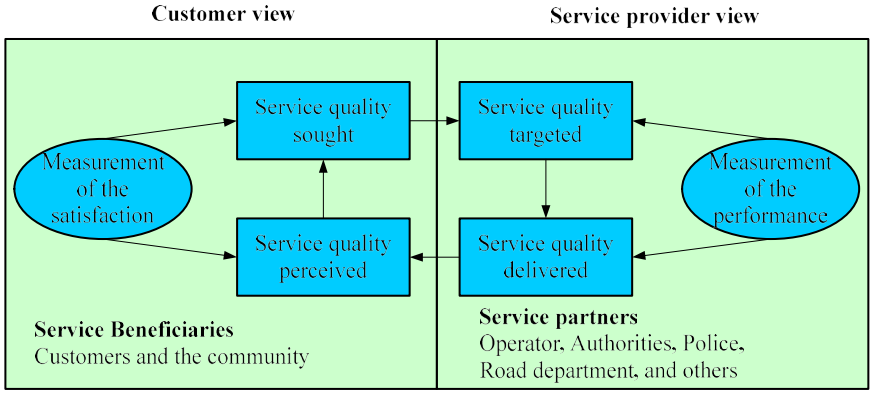

Fig. 2. Service quality cycle

The main components of the formation of the quality system of public passenger transport services are the fulfillment of the following requirements:

Requirement 1. Desired quality of services. This is the level of quality that is explicitly or implicitly required by the customer. The quality level can be considered as the sum of a number of weighted quality criteria. The relative weight of these criteria can be assessed using qualitative analysis.

Requirement 2. Target quality of services. This is the level of quality that the service provider aims to provide for consumers.

Requirement 3. Quality of provided services. This is a level of quality that is achieved on a daily basis. Delivered quality is measured from the customer's point of view.

Requirement 4. Perception of service quality. This is the level of quality perceived by the consumer. The consumer's perception of the quality of the provided service depends on his/her personal experience of using the service or related services, on the information he receives about the service.

The main advantage of the EU standards (EN 13816:2002) is that they focus the quality assurance process on the needs of the customer rather than on the needs of the supplier, emphasizing that it is the service (transport route) that must comply with the standard. In this regard, customer satisfaction research is an important additional quality management tool, along with the ISO standard. This can play a supporting role in the management of service quality by using appropriate service levels that are easily and objectively measured [25].

Implementation of the quality management system of public passenger transport services will ensure a continuous process of development and improvement of services. The most difficult part of this work is the definition of specific quality criteria within categories 1–4 of the standard criteria, where the main characteristic indicators of the system are described only in general terms: availability, accessibility, informing. They must be determined using formulas or comparative calculations that quantify the level of each category within the range of the specified categories.

At the same time, it should be noted that establishing an objective level of quality of public passenger transport services can only be determined on the basis of survey results, which is a difficult and time-consuming task for large cities.

The main indicators characterizing the development of the route network are density of the route network, route coefficient, frequency, and interval of bus traffic on the route. It is recommended to calculate these indicators according to certain formulas. It is these indicators that further determine the efficiency of the created transport system and form the most important indicators of service quality for the consumer. Among which are the average distance of the passenger's walking distance to the stop on the route; the time spent on walking to the stop; for a transfer from the destination to the purpose of the trip. It is also the time spent in the vehicle; total travel time on the route network; reliability of transport service, and other indicators of quality, safety, convenience, and comfort within categories 5–8 of the criteria provided by DSTU EN 13816:2022.

5. 3. Calculation of quality criteria for public passenger transport services

The main problem of determining the quality of passenger transportation is the lack of a single evaluation methodology. It is possible to objectively evaluate the quality of passenger transportation provided that a system of criteria for assessing the quality of services is developed, which would take into account the influence of various factors on the quality of service.

It is proposed to single out the following main groups of criteria for the quality of public passenger transport services:

1. Density of the route network (km/km)^2:

$$\delta = \frac{\sum L_M}{F}, \tag{1}$$

where L_M is the length of the route network, km;

F – built-up area of the city, km^2.

The density of the route network affects the time a passenger spends on the road to the stop. Reduction of travel time is ensured by optimization of 3 elements:

1) location of bus stops;

2) the time passengers spend on the road to stops;

3) time for transfer.

The density of the route network is determined depending on the population. If the density of the route network is lower, then the level of development of the route system in the city cannot be considered effective. Exceeding the regulatory density of the route network leads to an increase in the number of route intersections, and as a result, the speed of movement on the routes and their carrying capacity decrease.

2. Route coefficient:

$$k_M = \frac{\sum L_M}{\sum L_B}, \tag{2}$$

where L_M is the length of the route network, km;

L_B – the length of all streets through which routes pass, km.

The route ratio characterizes the duplication of routes on the network and quantitatively measures the number of route kilometers per kilometer of the route network. The recommended values of the route coefficient for cities are km=1.5...3.5. The growth of the route coefficient, on the one hand, indicates a decrease in the number of transfers, but, on the other hand, it increases the intervals of traffic for the same passenger capacity of the rolling stock or stimulates the use of buses with a smaller capacity. A negative consequence is the predominance of relatively small-capacity rolling stock on existing bus routes.

3. Operational speed on the route, km/h:

$$V_e = \frac{2L}{T_{tr}}, \tag{3}$$

where L is the length of the route, km;

T_{tr} – bus turnover time on the route, h.

4. Bus turnover time on the route, hours:

$$T_{tr} = t^1 + t_K^1 + t^2 + t_K^2, \tag{4}$$

where t^1 and t^2 – travel time in forward and reverse directions, hour;

t_K^1 and t_K^2 – idle time at the final stops of the route, hours.

5. Interval of buses on the route:

$$I = \frac{T_{tr}}{n_b}, \tag{5}$$

where T_{tr} is the bus turnover time on the route, h;

n_b – the number of buses on the route.

6. Actual frequency of buses on the route, buses/min:

$$h = \frac{n \times 60}{T_{tr}}, \quad (6)$$

where n is the number of buses on the route;

T_{tr} – bus turnover time on the route, h.

7. Required number of buses on the route. It is calculated based on passenger survey data:

$$n_M = \frac{T_{tr} \times Q_{\max}}{60 m_g}, \quad (7)$$

where T_{tr} is the bus turnover time on the route;

$Q_{\max}$ – the maximum passenger flow on the busiest section of the route during rush hour;

m_g is the maximum capacity of the bus.

8. Indicator of passenger traffic of buses on the route:

$$k_M = \frac{L_M}{L_{ad}}, \quad (8)$$

where L_M is the length of the route, km;

L_{ad} – the average distance traveled by a passenger, km.

The passenger turnover rate of buses is used to analyze the efficiency of buses on the route.

9. Capacity utilization rate of rolling stock:

$$\gamma = \frac{Q_{paskm}}{Q_{total\ seat\ km}}, \quad (9)$$

where Q_{paskm} is the actual number of passenger-kilometers traveled by the vehicle(s), pass-km,

$Q_{total\ seatkm}$ – the total number of seat-kilometers provided in the vehicle, seat-km.

The coefficient of use of the total capacity of the vehicle characterizes the degree of its filling. The total passenger capacity of the vehicle is determined by the sum of seating and standing places. The norms of usable space for one passenger are 0.315 m^2 for a seated passenger and 0.125...0.2 m^2 for a standing passenger. For calculations, it is recommended to use the standard – 5 passengers/m^2.

Tip: ensure a passenger capacity utilization factor of 0.7–0.8 during peak hours on the busiest sections of the routes and no more than 0.3 on an average working day.

Reduction of travel time is ensured by optimizing the location of stops and time for passengers to walk and change the mode of transport (transfer).

10. Average passenger travel distance:

$$L_{dist} = \frac{P}{Q}, \quad (10)$$

where P is annual passenger traffic, pass-km;

Q – number of transported passengers, pas.

11. Time spent in the vehicle, minutes:

$$T_{veh} = \frac{60 \cdot L_{trip}}{V_{speed}}, \quad (11)$$

where V_C is the speed of the car on the route, km/h;

L_{trip} – average distance traveled on the route, km.

12. Total travel time on the route network:

$$T_{total} = 2 \cdot T_{walk} + T_{wait} + T_{veh}, \quad (12)$$

where T_{total} – total travel time on the route network, min;

T_{walk} – time spent walking to the bus stop, moving from the destination to the place of travel, min;

T_{wait} – waiting time for boarding the vehicle, min;

T_{veh} – time spent in the vehicle, min.

The analysis of the travel time of passengers suggests that it can be considered 40 minutes for cities with a population of more than 1 million inhabitants. For cities from 500 thousand to 1 million – 35 minutes, for cities from 250 to 500 thousand – 30 minutes. And for cities with a population of less than 250 thousand inhabitants – 25 minutes (Table 2).

Table 2

The optimal travel time depending on the size of the city

No.	City size, thousand inhabitants	Travel time, minutes
1	Above 1000	40
2	500–1000	35
3	250–500	30
4	Less than 250	25

13. Mobility of the population (mobility coefficient):

$$b = \frac{Q}{N}, \quad (13)$$

where Q is the number of transported passengers per year;

N is the population of the city.

It is used to calculate the transport system of cities, united territorial communities, and regions.

14. Accessibility coefficient characterizes the share of buses for the transportation of population groups with reduced mobility:

$$k_{access} = \frac{Q_{eq\ veh}}{Q_{veh}}, \quad (14)$$

where $Q_{eq\ veh}$ is the number of vehicles equipped with auxiliary means during boarding or disembarking from the vehicle for persons sitting in a wheelchair, units.

Q_{veh} is the total number of vehicles, units.

15. Reliability of transport services (coefficient of traffic schedule):

$$k_{schedule} = \frac{Q_{schedule\ trips}}{Q_{trips}}, \quad (15)$$

where $Q_{schedule\ trips}$ is the number of trips performed in compliance with the time set by the schedule or within the limits of permissible deviations from the schedule, trips;

Q_{trips} – total number of trips.

Customer care is the service elements implemented to achieve the best match between the standard service and the requirements of each individual customer: convenience, comfort, travel safety and environmental impact of the PTC service.

Some elements of these quality categories are characterized by coefficients that are calculated according to certain formulas.

16. Share of vehicles equipped with devices for informing passengers:

$$k_{inform} = \frac{Q_{inform\ veh}}{Q_{veh}}, \quad (16)$$

where $Q_{inform\ veh}$ is the number of vehicles equipped with means of informing passengers on public routes, units;

Q_{veh} – number of vehicles on public routes, units.

17. Share of vehicles equipped with a cashless fare payment system:

$$k_{payment\ system} = \frac{Q_{payment\ system}}{Q_{veh}}, \quad (17)$$

where $Q_{payment\ system}$ is the number of vehicles equipped with a cashless fare payment system, units;

Q_{veh} – number of vehicles on public routes, units.

18. Share of vehicles equipped with working interior heating and ventilation systems:

$$k_{heat} = \frac{Q_{heat}}{Q_{veh}} * 100(\%), \quad (18)$$

where Q_{heat} is the share of vehicles equipped with interior heating and ventilation systems, units;

Q_{veh} – number of vehicles on public routes, units.

An important factor in ensuring the quality of passenger service is the presence of a mechanism for comprehensive evaluation of the effectiveness of its results. At the same time, the assessment should be carried out not only by quantitative, but also by qualitative methods.

The qualitative assessment is based on the results of passenger surveys using developed questionnaires, as well as on the results of observation. The quantitative assessment is obtained by calculating the integral indicator of the quality of service. According to the results of quality measurement control, the degree of deviation from the planned quality level is revealed.

5. 4. Devising quality standards for public passenger transport services on an innovative basis

Under modern economic conditions, it is impossible to achieve significant competitive advantages without building a modern strategy for the innovative development of transport enterprises. Formation of quality standards of public passenger transport services on an innovative basis creates a number of competitive advantages: increasing demand for transportation, reducing costs (due to anti-crisis innovations). This is an increase in the quality of service (due to organizational and management innovations), an increase in income (due to product innovations).

There is a trend towards the introduction of innovative technologies into the activities of transport enterprises, which will contribute to increasing their competitiveness and operational efficiency.

Strengthening the innovative component of the development of public passenger transport will make it possible to modernize the transport system and increase the efficiency of its functioning. It also contributes to increasing the carrying capacity of the transport network, accelerating the pace of integration of the domestic transport system into the European and world transport systems, and increasing the level of transport safety. The development and implementation of innovations is carried out through the application of fundamentally new technologies in transport, which leads to effective transformations and its modernization.

In order to form quality standards of public passenger transport services, it is necessary to define in detail the methodological approaches to the requirements for quality criteria and their assessment. As well as give examples of defining service quality criteria, methods and techniques for their quantitative assessment and management of the service quality system.

To implement this recommendation, experts consider two approaches to determining the quality of public passenger transport services: one is based on the operational parameters of the system's functioning. The second is based on the use of sociological research methods, through a systematic survey of consumers in order to determine their expectations regarding giving preference to certain indicators of quality criteria.

National standards provide for the simultaneous use of both approaches to determining the quality of services, which creates a cyclical quality management system that ensures the continuity of the process of improving public passenger transport services. However, for carriers, conducting examinations and surveys of consumers on a regular and permanent basis seems questionable due to the complexity and significant cost.

The service quality standard is the basis for developing plans for the development of public passenger transport and the route network. This standard helps the developers of the route network to determine the location of the stopping points, the capacity, and the frequency of the routes in order to establish the number of passengers per 1 m^2 of the bus floor that does not exceed the established standard.

Implementation of national standards is impossible without carrying out certain organizational and preparatory work. The implementation of the requirements of national standards, taking into account local features and opportunities, is illustrated in Table 3.

Given that the requirements of national standards apply to all types of public passenger transport, it is advisable to pay special attention to road transport, given its fragmentation, lack of direct sectoral subordination and management, as well as lack of official statistics. At the same time, it is advisable to take into account and use the experience of the European Union, which had similar problems. That is why the road sector in the EU is one of the most strictly regulated, while it has the corresponding features of the permit system and the technical regulation system.

In this context, it is proposed to apply a comprehensive approach to the development of public passenger transport service quality standards, which should consist of the following stages:

Stage 1. Creation of a single Methodological Center with the authority to coordinate work related to the implementation of standards requirements.

Stage 2. Determination of responsible and competent performers in cities and local communities.

Stage 3. Development of local regulatory and legal acts, which should create a regulatory and legal basis for the implementation and operation of standards using innovative technologies.

Stage 4. Amendments to some current legal acts, which should stimulate carriers to achieve a certain level of quality criteria.

Stage 5. Creation and training of groups of independent experts to conduct examinations.

Stage 6. Implementation of corrective measures based on research results.

Stage 7. Introduction of voluntary certification of compliance of services with the requirements of the standards.

Table 3

Priority measures recommended to ensure the development of national standards for public passenger transport services (pt)

No. of entry	Measure content	Performance indicator (result of actions or regulatory act ID)
Activities at the national level		
1	To approve the Action Plan for the implementation of national standards DSTU EN 13816:2022 (EN 13816:2002, IDT) and DSTU EN 15140:2022 (EN 15140:2006, IDT) in the field of public passenger transport services	Order of the Ministry of Infrastructure on measures to implement the requirements of national standards DSTU EN 13816:2022 (EN 13816:2002, IDT) and DSTU EN 15140:2022 (EN 15140:2006, IDT) during the provision of public passenger transport services
2	Create a Coordination and Methodological Center under the Ministry of Infrastructure for coordination and methodical support of the implementation of national standards of public passenger transport services	Order of the Ministry of Infrastructure on the establishment of a Coordination and Methodological Center for the support of the implementation of national standards of public passenger transport services
3	To ensure the development and adoption of methods of implementation of national standards for each type of transport	Methods of implementing the requirements of national standards for each type of transport have been approved
4	Provide initial and periodic professional training of experts to conduct consumer surveys and assess the level of services provided	Order of the Ministry of Infrastructure on initial and periodic professional training of experts on conducting consumer surveys and assessing the level of service provision
5	To encourage carriers to achieve a certain level of quality of public passenger transport services, confirmed by a certificate of conformity issued to the carrier by the relevant certification body	The quality criteria of public passenger transport services are included in such resolutions of the Cabinet of Ministers of Ukraine as the Procedure for conducting a competition for the transportation of passengers on a public bus route (approved by the resolution of the Cabinet of Ministers of Ukraine dated December 3, 2008) and the Rules for the provision of passenger road transport services (approved by the Cabinet resolution of Ministers of Ukraine dated February 18, 1997)
6	Ensure the creation of bodies for voluntary certification of public passenger transport services and the development of the procedure for such certification	Bodies of voluntary certification of public passenger transport services have been established. A voluntary certification procedure has been developed
Activities at the local level		
7	Adopt a decision of the local self-government body to implement the requirements of national standards regarding the quality of public passenger transport services in the relevant territory (city, territorial community)	Decision of the local self-government body on the implementation of the requirements of national standards regarding the quality of public passenger transport services in the relevant territory (city, territorial community)
8	Create a methodological office or appoint a tender committee to manage the implementation of national standards for public passenger transport services	Order of the local self-government body on the creation of a methodical cabinet
9	Make changes to the terms of tenders, which provide for the inclusion in contracts of specific levels of service quality that the carrier must provide, as well as incentives provided to the carrier in the event of achieving the quality indicators determined by it	The conditions for conducting tenders with carriers are approved by the local self-government body, which determines the terms of service contracts with specific levels of service quality to be provided by carriers, as well as incentives provided to carriers in the event that they achieve the specified quality indicators
10	Include quality criteria indicators for the tender winner in the contract	Quality criteria are included in the contract with the winning carriers on specific routes
11	Approve the Plan of measures for conducting a survey of passengers on the routes regarding their satisfaction with the services provided and determining the criteria and level of services that passengers expect	The plan of measures for conducting a survey of passengers on the routes regarding their satisfaction with the service was approved, which is approved by the local self-government body
12	Create and train a group of experts to introduce a systematic survey of consumers	Adoption by a local self-government body of an order on the creation of expert groups, with a list of experts
13	Ensure systematic passenger surveys, analysis of results and development of corrective measures	1. Expert reports with conclusions based on the survey. 2. Corrective measures approved by the government. 3. Indicators of quality criteria are developed for each route. 4. Route network quality criteria were developed, and numerical indicators of these criteria were determined
14	Develop specific service quality criteria for each public passenger transport route based on passenger survey results	The concept of improving the quality of public passenger transport services for the territorial community, approved by the decision of the relevant local self-government body

For the formation of quality standards of public passenger transport services, it is necessary to ensure the relationship between implemented measures, measurement of the level of service quality and the distribution of obligations to ensure the level of services determined by the criteria.

The block diagram of actions regarding the management of the quality system of public passenger transport services is shown in Fig. 3.

The proposed block diagram of the quality management of public passenger transport services makes it possible to form a

number of characteristics or properties of services that ensure the measurement of the level of quality of services provided by the service provider. They also determine its ability to satisfy the established and predictable needs of consumers, such as: reliability, trustworthiness, accessibility, communicativeness, attentiveness. Important for improving the quality of public passenger transport services and increasing demand for them is the introduction of innovative technologies that increase the comfort of receiving them.

The use of modern innovative technologies can facilitate monitoring, planning, and management of processes affecting the quality of public passenger transport services. This can be manifested through the provision of up-to-date information for passengers regarding schedules, delays, and changes in the operation of transport. It can also be various communication channels, including websites, mobile applications, and information boards, which will make passengers' journeys more punctual and convenient.

In order to implement the proposed measures using innovative technologies, a necessary condition is the creation and implementation of the following projects on public passenger transport:

1. Development and implementation of technical and technological means for the implementation of a single electronic ticket.

2. Increasing the efficiency of transportation management due to the use of modern navigation systems.

3. Optimization of the designs of motor vehicles used in urban passenger transportation using smart technologies.

4. Organization and implementation of events aimed at increasing the level of public safety in public passenger transport, installation of video surveillance cameras in public passenger transport with the function of an emergency call.

The introduction of innovative technologies in public passenger transport will improve the quality of service and ensure the satisfaction of customer needs, safety and an extensive system of routes.

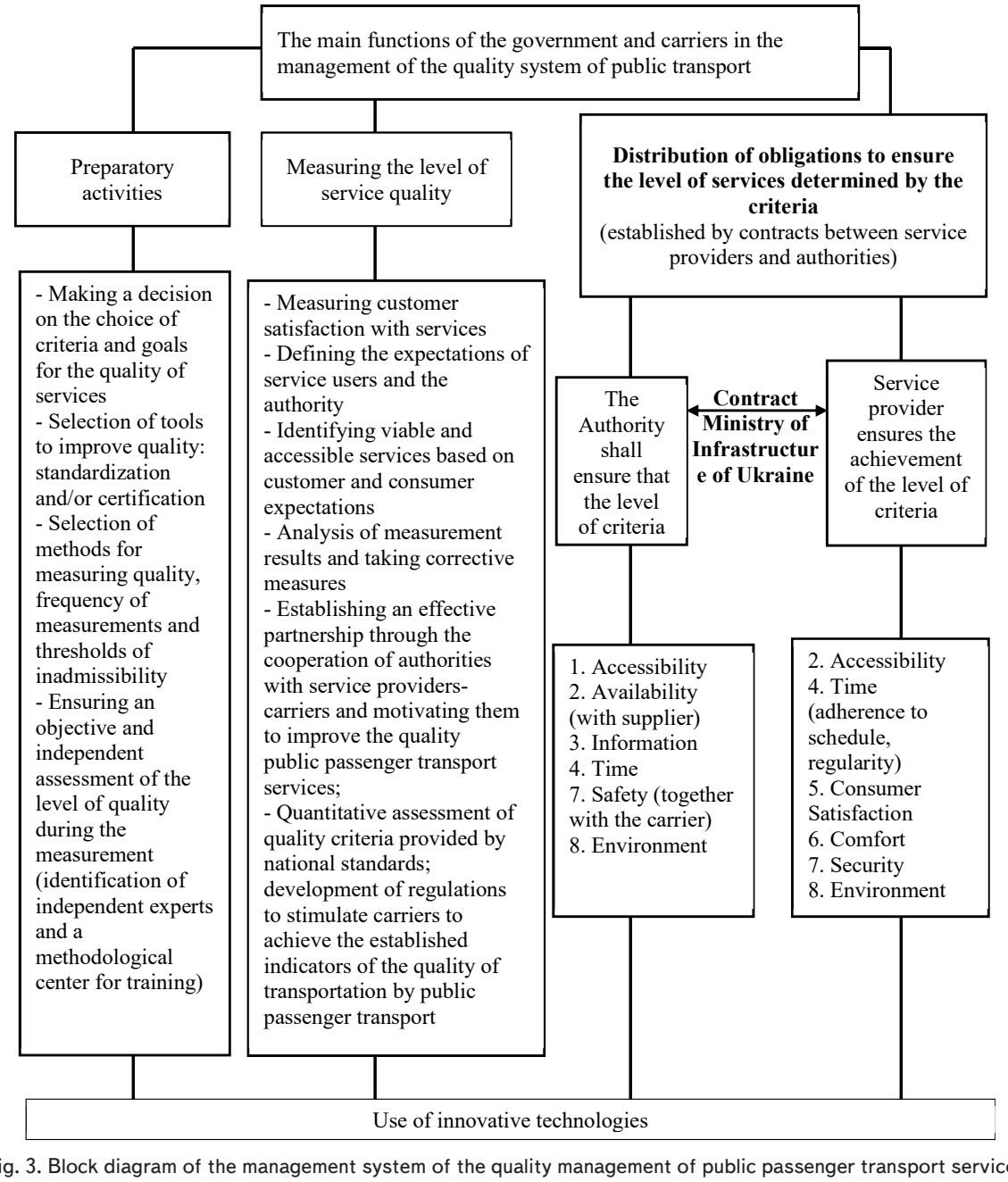

Fig. 3. Block diagram of the management system of the quality management of public passenger transport services

6. Discussion of results of the development of conceptual foundations for the introduction of innovative technologies into the quality standards of public passenger transport services

There is a large number of methods for improving and forming a system of transport service quality standards, which have been proposed by modern researchers [4–11]. All of them are mostly based on the general principles of the quality system, and do not take into account the peculiarities of public passenger transport. The study of the features of public passenger transport in the world showed that it is necessary to meet economic and environmental criteria, the need to develop software for real-time integration. One of these examples is the USA, with the development of a system of indicators of the quality of public passenger services (Fig. 1).

To ensure the quality of public passenger transport services, a system of criteria for the quality of public passenger transport services was formed in accordance with EN 13816:2002 (Table 1), which is based on the study of current and prospective demand for transport services. The influence of innovative technologies on the implementation of quality standards of public passenger transport services makes it possible to determine the effect of the modernization of the technological composition of transport, to ensure a new level of service, and to reduce inefficient routes.

The determination of requirements and recommendations for the development of standards are based on general principles regarding the quality cycle of passenger service (Fig. 2) and must comply with clauses 4 and 5 of the EU standards (EN 13816:2002). The main indicators characterizing the development of the route network are density of the route network, route coefficient, frequency, and interval of bus traffic on the route. It is recommended to calculate these indicators according to formulas (1) to (18). At the same time, it should be noted that establishing the objective level of quality of public passenger transport services can be determined only on the basis of the results of passenger surveys using developed questionnaires, as well as on the results of observation.

In contrast to existing approaches, this paper proposes a comprehensive approach to the implementation of public passenger transport service quality standards on an innovative basis. This approach consists of seven stages, which makes it possible to establish qualitative and quantitative characteristics that determine the degree of effectiveness of public transport management and functioning. Within the framework of the approach, in order to form quality standards for public passenger transport services, it is necessary to ensure the relationship between implemented measures, measurement of the level of service quality, and the distribution of obligations to ensure the level of service determined by the criteria (Fig. 3).

It has been established that service quality standards are the basis for the development of plans for public transport and the route network. Measures recommended for ensuring and implementing standards of passenger transport services are proposed in Table 3.

Therefore, it can be argued that the current state of development of public passenger transport with the use of innovative technologies makes it possible to draw a general conclusion about the weak level of their innovative activity. The further application of innovations in the formation of quality standards of public transport services will make it possible to increase the efficiency of operation and to form further ways to increase the innovative potential.

However, in our research on the implementation of innovative technologies for the formation of public transport service quality standards, only general purpose transport was used. This, accordingly, limits the field of research in terms of practical use and outlines the scope of further research in the direction of applying the proposed methods and practical recommendations for enterprises in other industries.

The disadvantage of the study is that the effectiveness of the proposed recommendations and their practical implementation in the activities of public transport enterprises requires significant funding for the application of innovations and innovative technologies in all production processes.

In the future, it is advisable to investigate the impact of innovative technologies on general purpose transport enterprises with the calculation of their financial indicators and further ways and opportunities to ensure sustainable competitive advantages.

7. Conclusions

1. Features of public passenger transport in the world have been studied. Our analysis revealed that the use of innovative technologies in public transport services contributes to the modernization of the transport and road complex. It also contributes to the activation of investment attraction in the implementation of strategically important projects of an innovative nature in the transport sector with the aim of expanding the scope of providing high-quality transport services to the population. At the same time, such aspects of the introduction of innovative technologies in public passenger transport services as: allocation of funding for the development of innovations, increasing the investment attractiveness of enterprises, attracting specialists from the IT industry, and the use of modern technologies are highlighted.

2. The proposed quality management system for public passenger transport services, which should include current and future demand for transportation. The main requirements for the formation of a transport service quality management system are compliance with service quality standards, consideration of consumer requirements, and certification results. The most important for the formation of the quality system of public passenger transport services is the observance of specific quality criteria within the standards, where the main characteristics consist of availability, accessibility, information.

3. The main criteria of the quality of public passenger transport services characterizing the development of the route network have been highlighted, such as the density of the route network, the route coefficient, the frequency and interval of bus traffic on the route. These indicators further determine the efficiency of the created transport system and form the most important indicators of quality customer service.

4. It was determined that the formation of quality standards for public passenger transport services on an innovative basis creates a number of competitive advantages: increasing demand for transportation, reducing costs, improving the quality of service, and increasing revenues. In this context, it is proposed to apply a comprehensive approach to the development of quality standards for public passenger transport services, which takes into account the relationship between implemented measures, measurement

of the level of service quality and the distribution of obligations to ensure the level of service determined by quality criteria. The developed stages of the approach provide an opportunity to rationally use time when describing the connection between the results of the application of innovative technologies and measures to achieve them during the development of standards and their certification.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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