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DEVISING A METHOD FOR ASSESSING THE LEVEL OF TRANSPORT SERVICES IN THE "PEOPLE – TRANSPORT – ROAD – ENVIRONMENT" SYSTEM

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The object of this study is the process of assessing the level of public transport service provision in cities. The task is to devise a method for assessing the level of public transport service provision in terms of the influence of characteristics of the elements within the "People – Transport – Road – Environment" system. It was determined that these characteristics could serve as predictors – parameters and forecasting tools that determine the level of quality of public transport services for city residents. A logistic model has been built, which underlies the method for assessing the level of public transport service provision. This approach could allow for a comprehensive and interconnected study of social and technological factors of transport activity of subjects.

A method for diagnosing the logistic model for adequacy and consistency with empirical data has been proposed, which is based on the application of the Hosmer-Lemeshov agreement criterion and ROC analysis.

The method for assessing the level of public transport service provision was tested using an example of a city of regional significance. The adequacy of the method was confirmed using the Hosmer-Lemeshaw criterion and ROC analysis, which were 8.892 and 0.3428, respectively. Based on the verification results, proposals have been devised to improve the predictors of the activities of urban carriers. The effectiveness of the proposed measures was assessed by the percentage change in the time spent by city residents on travel, which was 17.5 %. This confirms the acceptability of the method devised.

The scope of using the method includes activities of business entities that provide transport services to the people in cities and to local government bodies. The prospect of this study is its application to assessing the level of quality of transport services by other types of passenger transport

Keywords: quality level, logistics model, ROC analysis, Wald test, service predictors

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1. Introduction

The task to manage the quality of public transport services is complex, complicated, and associated with a number of theoretical and practical issues that need to be resolved. No country has yet been able to meet the basic social needs of its residents in transportation at a balanced level. And the need to use additional resources and the growing environmental factor in the "People – Transport – Road – Environment" system only exacerbates social challenges [1–3].

Contradictions in the development of passenger transport systems are largely due to the fact that the needs of people in transportation are dynamic, have characteristic features, and change over time and territory. In addition, the choice of a passenger route is also influenced by the condition of roads, road safety indicators, technical condition of public transport, environmental conditions, etc. This necessitates the need for constant assessment, study, and research of this problem in order to bring the transport service system into line with the requirements and needs of users. This situation is particularly acute in cities [4].

It is known that practically every need for passenger transport services must be satisfied quickly, and sometimes immediately. In many cases, a need that is not met within a certain period of time becomes irrelevant for the consumer, that is, it is necessary to regulate the transport system over time. To this end, technical, economic, and labor resources are involved, which must be consequently managed in real time based on the results of diagnosing the level of service quality and the conditions for its provision. The detected discrepancy means a violation of the level of transport services quality. Therefore, the category of quality of transport services provided to people is decisive [5].

Thus, the integration of a certain body of knowledge about assessing the level of public transport services, in particular in a city within the "People – Transport – Road – Environment" system, is an urgent task. This is due to the fact that the results of relevant studies could make it possible to effectively determine the level of service to people, identify vulnerabilities in transport systems, as well as properly organize them and timely prevent disruptions.

2. Literature review and problem statement

Study [1] determined that transport services are a specific product of activity, the quality of which plays an important role in prosperity, satisfaction of material and spiritual needs of a person. They also characterize the possibilities of changing lifestyles and balanced development of territories [1]. However, the results of study [1] contain only a conceptual subtext for the formation of the "People – Transport – Motorway – Environment" system and relate more to the issues of spatial accessibility of objects for transport users. The results of papers [2, 3] could be used as a basis for forming the characteristics of the system elements but they do not contain methodological approaches to solving the problems of assessing the quality of transport services.

In work [4], it is determined that the modern concept of the development of the transport services sector involves revising state and municipal policies to improve their quality, reduce social inequality in the domain of consumption. The main emphasis of the study is to determine the social justice of public transport. However, in [4], other important aspects of the impact on the behavior of the people in the context of the user of public transport are not considered, such as, for example, the complexity of the route, the quality of roads, the state of the environment, road safety, etc.

Methods for assessing the quality of transport services play an important role in improving the system of rendering them, achieving high standards of consumer protection, in particular from the point of view of stakeholders [5]. However, study [5] is of a survey nature and does not contain proposals for the practical implementation of improving the quality of public transport. To determine the criteria for the quality of public transport services, paper [6] proposed a methodology based on a hybrid hierarchical process analysis and the best-worst method (BWM) criterion analysis methods. However, the representativeness of the survey model in [6] does not make it possible to extend the proposed solutions for managing the quality of services to all types of public transport. In work [7], a model for managing the quality of public transport services was built, which takes into account the opinions of users and experts based on the generation of a quality index and sensitivity analysis. However, the issue of the consistency of service quality indicators that should be used for assessment remained unresolved. At the same time, quality assessment can be carried out using the SERVQUAL methodology [8, 9], six sigma [10], cost-benefit analysis, in particular, time and reliability values [11]. However, the specified approach [8, 9] cannot be applied to all characteristics of the transport system, in particular, to the state of the environment, road quality and the capacity of service companies. The method presented in [10] is inherently process-based, which does not allow it to be used to substantiate the characteristics of the impact on the quality of transport services. It should be noted that the time spent by the consumer on the road plays an important role in assessing the quality of services. However, in study [11], this aspect is considered from the point of view of economic benefit, and not for determining the consumer characteristics of transport services.

In some papers, there is a structuring of quantitative, qualitative indicators, and evaluation criteria [12]. In particular, in [13], attention is paid to the elements of travel duration, their perception by passengers, in [14] – reliability of service, in [15] – convenience of trips at different times of the day. However, study [12] does not contain a methodology for solving the issue of assessing the level of quality of transport services. And papers [13–15] consider only one of the characteristics that affects the public transport service to meet the need for travel.

Based on the analysis of known methods for assessing the quality of services, the need to construct new assessment models is emphasized in [16]. The cited studies [6–16] set specific goals but there is fragmentation of approaches, no unambiguous assessment is achieved, and differences between the capabilities of transport systems and consumer preferences are not taken into account. In modern studies, the assessment of the quality of transport services is associated with service management strategies [17], in particular, the concept of "Mobility as a Service", on-demand service, and vehicle automation [18]. In the process of assessing the quality, the impact of travel time on work productivity and passenger satisfaction [19], the effectiveness of logistics technologies [20], the impact of transport infrastructure on mental health and well-being [21] were studied. However, work [19] is of a survey nature and does not contain clear proposals for specifying the process of assessing the level of service provision to the urban people. Although logistics is of significant importance when choosing a transport service operator by a consumer, study [20] does not consider other characteristics of urban transportation. In particular, paper [21] is more focused on the psychology of the behavior of consumer of transport services, rather than on assessing the quality of functioning of the transport system.

Despite the evidence provided, the results reported in the literature [17–21] are diverse and contradictory, which makes it difficult to reach a generalized conclusion. This indicates the need to devise a method for assessing the level of urban transport services, taking into account the influence of demand factors, transport infrastructure, road network, and the environment.

Thus, the scientific problem addressed is predetermined by the multifaceted nature of the research object and the need to solve the task to substantiate the method for assessing the level of transport services provided to people. These issues are related to the need to achieve a correct understanding of the characteristics that affect transport services, the choice of methods and criteria for assessing the components and factors of influence on the consumer.

3. The aim and objectives of the study

The purpose of our study is to devise a method for assessing the level of public transport services in cities, taking into account factors in the "People – Transport – Road – Environment" system. It is assumed that the method could become a new integrated perspective for increasing the level of transport services for residents and rational organization of the resources of the transport system in settlements. This would make it possible to introduce a new way of thinking for rendering transport services, to create conditions for the formation of a new understanding of the service aspect of passenger transport activities. In practice, this would facilitate the process of identifying reserves of the city's transport system, modernizing its infrastructure, and reducing the duration of residents' travel.

To achieve the goal, the following tasks were set and accomplished:

– to adapt the logistic regression model, identify and analyze the predictors of transport activity;

– to devise a methodological approach to diagnosing the logistic model for adequacy and consistency with empirical data;

– to diagnose the model and verify the method for assessing the level of public transport service provision being developed.

4. The study materials and methods

The object of our study is the process of assessing the level of public transport service provision in cities.

The main hypothesis of the study assumes that determining a set of input data on the consumption of transport services and analyzing the predictors of transport activity of carriers could lead to the effectiveness of the method for assessing the quality of services. The main assumption of the study is to take into account the uniqueness of each individual predictor in the logistic model and its impact on the level of public transport service provision. Since a logistic model was used to interpret the results of the study, the main simplification is to accept the level of quality of transport services as a binary variable with two values.

The research methodology is based on the results of our review of the literature and the provisions for the application of logistic regression. In particular, the research methodology was built in three stages. At the first stage, the research concept was formed based on a critical analysis of literary data that characterize the main achievements and reflect variables that could affect the conditions and level of public transport service provision. The development of a method for assessing the quality of public transport services in a city is based on a statistical binary logistic regression model, which uses an appropriate function to model the dependence of the output variable on a set of inputs [22]. This makes it possible to categorize services provided in the city as those that meet a predetermined indicator of the level of quality of transport services, or as those that do not. To build the concept of adapting the logistic regression model, systems analysis and systems theory approaches were used due to the fact that predictors are characteristics of elements of the transport service provision system. This became the reason for considering the city's transport services in the context of the proposed conceptual system "People – Transport – Motorway – Environment". To devise a method for diagnosing the logistic model for adequacy and consistency with empirical data, the Hosmer-Lemeshow goodness of fit test and ROC analysis (Receiver Operator Characteristic) [23] were used. This makes it possible to determine the degree of acceptability of the model with the proposed parameters for further use.

The second stage included data collection from transport service consumers and other sources regarding analysis of the relationships between consumer respondents, the communication environment, and safety using sociological research and expert approaches. The socio-economic aspects and the level of satisfaction with public transport services were characterized, which made it possible to identify and analyze predictors of transport activity of urban carriers.

At the third stage, model diagnostics and testing of the developed method for assessing the level of public transport services were performed on the example of a city of regional significance with a people of about 262 thousand people. For statistical processing and analysis of real data, the Wald test was used, implemented in the MS Excel environment (USA). The effectiveness of the devised method for assessing the quality of transport services was characterized by the percentage change in delay time, which will be 17.5 % if the proposed measures are implemented.

5. Results of devising a method for assessing the level of quality of transport services for people in cities

5. 1. Adaptation of the logistic regression model, identification, and analysis of predictors of the city's transport system

It is advisable to consider the city's transport services in the context of the interaction of such components as people, transport, road network, and the environment (Fig. 1).

Fig. 1 defines the characteristics of each element in the "People – Transport – Road – Environment" system from the point of view of the impact on the process of providing transport services. These characteristics can serve as predictors (independent variables) [23, 24] – parameters and means of forecasting that determine the function – the level of quality of public transport services for city residents:

$$Y \in f(x_i); i \in [1; k]; k \in N, \quad (1)$$

where Y is the level of quality of public transport services for city residents; x_i are independent variables (service predictors) used in the mathematical model to predict the total volume k; N is a sign of belonging to natural numbers.

The general list of predictors for our study (Fig. 1) was established based on our review of the literature [2, 3, 11–16, 19–21, 25, 26]. This is information about the quantitative parameters of the need for services. In particular, the forms of their provision, road conditions, road safety and road condition, risks of the activities of servicing motor transport enterprises, territorial distribution of demand and conditions for its satisfaction over time, the environment, etc. The predictors were systematized, and their analysis was carried out for interconnection, identity, informativeness, feasibility, originality, and coverage of the operation of transport activities in terms of serving people. However, it should be noted that the list of predictors shown in Fig. 1 is not exhaustive and can be supplemented depending on the tasks of managing the city's transport system.

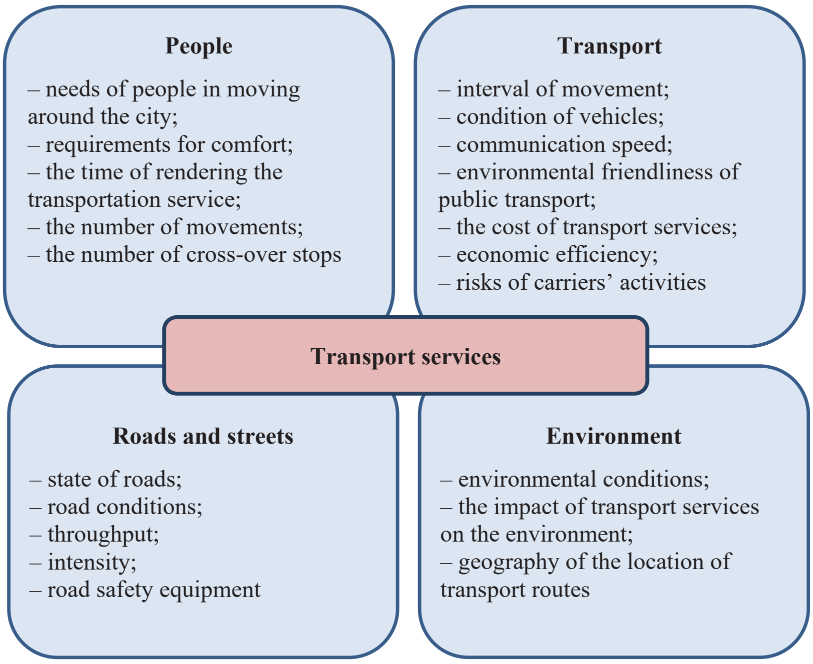

Fig. 1. "People — Transport —Road — Environment" system

To devise a method for assessing the level of transport services using the concept of predictors, the logistic regression model was adapted. This model provides the ability to describe and evaluate the relationship between a dependent variable, which takes only two possible values, depending on whether an event occurred, and independent variables that affect this phenomenon [22, 27]. That is, whether residents are provided with quality transportation to places of work and for cultural and household purposes or not.

In the process of calculating the probability of rendering quality transport services to city residents, it is assumed that the level of service quality means a dichotomous binary variable with two values:

$$Y \in [0;1] \left\{ \begin{array}{l|l} \forall x_i, P(x_i) & Y=1, \\ \forall x_i, \nexists P(x_i) & Y=0, \end{array} \right. \quad (2)$$

where $P(x_i)$ is the probability of providing quality transport services to city residents; 1 is the occurrence of the event of interest to us (quality service – success); 0 is the opposite case (poor quality service – failure).

In this case, the logistic regression model is described by the following equation:

$$P(x_i) = \frac{e^{\beta_0} + \sum_{i=1}^{k} \beta_i \times x_i}{1 + e^{\beta_0} + \sum_{i=1}^{k} \beta_i \times x_i}, \quad (3)$$

where β_0, β_i are logistic regression coefficients, $i \in [1; k]$; $k \in N$; e is the base of the natural logarithm.

To determine the set of predictors that will be used to implement logistic regression in the context of a specific city, a statistical approach can be applied, in particular, a frontal survey of residents, observations, questionnaires of carriers, etc. As a result of collecting statistical data, the sample should be examined for the significance of the relationships between variables and the weight of the drift on the logistic regression model as a whole. To this end, nonparametric methods of statistical analysis can be used (Kruskal-Wallis test, Mann-Whitney U-criterion, chi-square agreement criterion, etc.), as well as an expert approach. The choice of a specific method depends on the characteristics and dimensions of the selected set of predictors. In particular, whether they are qualitative or quantitative.

It is also important to interpret logistic regression in terms of the chances of the event (success) occurring, where the chances of the event $S(A)$ are defined as the probability of the event $P(A)$ divided by the probability that the event will not occur [23]. At the same time, an important aspect in this regard is also the odds ratio "OR". It is expressed as the ratio of the odds that the event $S(A)$ will occur in one group to the same event $S(B)$ that will occur in another, compared group. The "OR" indicator ($OR_{A \times B}$) determines how much greater or lesser the chances of a certain event occurring are:

$$OR_{A \times B} = \frac{S(A)}{S(B)} = \frac{P(A)}{1-P(A)} : \frac{P(B)}{1-P(B)}, \quad (4)$$

where $S(A)$, $S(B)$ are the chances of the studied event (success) occurring in statistical groups A and B, respectively; $P(A)$, $P(B)$ – probability of the studied event (success) occurring in statistical groups A and B, respectively.

To test the hypothesis of the adequacy of logistic regression (3) and to assess the significance of its coefficients, we apply the Wald statistical test:

$$Z_W = \hat{\beta} - \frac{\beta_0}{E_{st}(\hat{\beta})}, \quad (5)$$

where $E_{st}(\hat{\beta})$ is the standard error; $\hat{\beta}$ – average value of coefficient variation.

If the value obtained by the Wald statistical test allows us with sufficient probability to reject the null hypothesis, then the logistic regression model is considered adequate.

To perform the Wald test, it is advisable to represent the parameters of the logistic regression model in the form of a table. This is a template with a set of parameters relative to predictors, which in this case are characterized by the impact on exceeding the normative time spent by the people on travel (Table 1).

In this case, the probability of an increased trip duration is described using a logistic regression model in the following form [28]:

$$P(x_i)_a = \frac{e^a}{1+e^a}, \quad (6)$$

where a is the estimate of the influence of the predictor in the logistic regression.

The next step is to decide whether the model is suitable for further use in practice.

Table 1

Wald test execution template for logistic regression model parameters and their characteristics

Predictor		Estimating the impact of a predictor a	Standard error $E_{st}(\hat{\beta})$	Wald statistics Z_W	Upper limit of variance β 95.00 %	Lower limit of variance β 5.00 %	$P(x)_a$
x_1	Name	a_1	$E_{st}(\hat{\beta})$	Z_W	βmax	βmin	$P(x_1)_a$
x_i	Name	a_i	$E_{st}(\hat{\beta})$	Z_W	βmax	βmin	$P(x_i)_a$
x_k	Name	a_k	$E_{st}(\hat{\beta})$	Z_W	βmax	βmin	$P(x_k)_a$

5. 2. Devising a methodological approach to diagnosing a logistic model for adequacy and consistency with empirical data

According to [23], the Hosmer-Lemeshow goodness of fit test and ROC analysis (Receiver Operator Characteristic) are considered to be effective tools for checking the adequacy of the constructed logistic model and its consistency with empirical data. These are the statistical tests used for binary models, such as logistic regression, proposed in this study.

The procedure for applying the Hosmer-Lemeshow goodness of fit test consists in grouping observations by expected probabilities with subsequent evaluation of the null hypothesis – the difference between the observed (A) and expected events (B).

ROC analysis is a matrix of results that involves evaluating observations by groups (Table 2).

Table 2

Matrix of observation results based on ROC analysis

Model	True	False
Positive	TP	FP
Negative	TN	FN

Table 2 gives the following groups:

– *TP* (True Positives) – the number of true positive results;

– *TN* (True Negatives) – the number of true negative results;

– *FP* (False Positives) – the number of false positive results;

– *FN* (False Negatives) – the number of false negative results.

The next step of ROC analysis is to diagnose the model devised by the so-called "cut-off point". This is the value of the predictor that best divides the studied data set into two groups: the group in which the studied phenomenon occurs and the group in which this phenomenon does not occur. The characteristics of sensitivity and specificity are associated with the cut-off point [25]. In particular, sensitivity, as the ability of the model to detect phenomena with a distinctive feature, determines the number of correctly predicted cases in the set of all observed cases [26]. The specified characteristics are calculated according to the following formulas:

$$SE = \frac{TP}{TP + FN}, \tag{7}$$

$$SP = \frac{TN}{TN + FP}, \tag{8}$$

where SE is the sensitivity of the model; SP is the specificity of the model.

The relationship between the sensitivity and specificity of a given model determines the final result of ROC analysis [22]. In particular, the optimality of dividing the studied data set into two groups (in which the phenomenon occurs and in which it does not occur) is determined using the Youden index (J) [27], according to the equation:

$$J = SE + SP - 1. \tag{9}$$

The success of the implementation of the methodological approach to assessing the level of service provision developed by public transport in practice can be measured by the percentage change in indicators [29].

In this case, for example, for the time spent by city residents on travel, it is determined from the formula:

$$PC = \frac{\Delta t}{t_1} = \frac{t_2 - t_1}{t_1} \times 100\ \%, \tag{10}$$

where t_2 is the time spent by city residents on travel, empirical, or according to sample A; t_1 – time spent by city residents on travel, actual, or according to sample B.

5. 3. Model diagnostics and verification of the method for assessing the level of public transport service provision

In order to establish the values of the model parameters, a sample of data on transport services for the people of a city of regional significance with a people of about 262 thousand people was processed. Transport services are provided by trolleybus, bus, as well as by route and passenger taxis, i.e., various types of transport are represented. The route system consists of 45 bus and 10 trolleybus routes. About 182 buses, up to 60 trolleybuses, and about 700 taxis are used daily. In order to determine the set of predictors of this city, a survey of its residents (397 people) was conducted. By calculating a non-repeated sample for the general people in accordance with the volume of respondents, it was determined that the variance is 0.5; the marginal error of representativeness is 5 %; tabular value, which depends on the value of the marginal sampling error is 2.

An analysis of surveys was conducted, which showed that 39 % of the transport services provided to consumers exceeded the duration of travel relative to the normative values. That is, in a significant part of cases (156 out of 397) the needs of consumers were not met within the normative period, which for settlements of this scale should not exceed 35 minutes (the example of Ukraine; the rules of Terms and Conditions for Transport Services are applied for European countries).

The number of movements and the number of trips are considered important predictors of a given city since they are the primary source of public transport service activity. The number of trips characterizes the realized demand for services, which is less than the number of trips due to the presence of transfers from route to route in the absence of a direct route. It is assumed that people travel over 4 periods of active demand, which differ significantly in the intensity of service, as well as the intensity of traffic flows on the roads along which public transport routes are laid (Table 3).

Table 3

Percentage of excess travel time spent by people

Period characteristics	Period No.			
	1	2	3	4
Daily interval	6.00–10.00	10.00–16.00	16.00–19.00	19.00–23.00
Number of services exceeding the travel time standard (%)	12.2	40.5	18.6	28.7

Analysis of the significance of differences in the averages in the specified periods, conducted using the Kruskal-Wallis test, confirmed that at the adopted level of significance ($\alpha=0.05$) there is no reason to reject the accepted hypothesis ($p=0.3402$) about the convergence of the averages in the studied groups. The analysis of the time spent by the people on travel by periods of the day reveals that the most problematic is the second period, which accounts for more than 40 % of transport services provided with an excess of the normative time spent on travel (Table 3). At the same time, the number of trips with an excess of the normative time spent is lower during peak periods. This may be the result of a greater concentration of resources in the city's transport system, which in the case of such trips is high. In particular, this contributes to improving the quality of services for the consumer and obtaining greater income for transport enterprises. Thus, the number of trips and the allocated travel periods during the day can be predictors that affect the quality of transport services for people.

According to the results of our survey of residents, the number of transfers, depending on the adopted route scheme, varies from 0 to 2, and on the 10th trip, the average is 1.23 (Table 4).

Table 4

Statistical analysis by number of transfers

Number of observations	Average	Median	Minimum	Maximum	Standard deviation	Coefficient of variance (%)
397	1.23	1.22	0.83	1.76	0.28	3.11

The regularity of the difference in time costs by periods of the day was confirmed by the results of the Mann-Whitney U-test ($p=0.000$), which, at the accepted level of significance ($\alpha=0.05$), indicates the need to reject the null hypothesis of equal means in the group [27].

Analysis of the variable relative to the number of trips revealed its significant impact on the timeliness of service provision. It turned out that the level of time cost overrun is higher when the number of trips served during a certain period of the day is greater. This is confirmed by the results of the Mann-Whitney U-test ($p=0.000$), which, at the accepted level of significance ($\alpha=0.05$), indicate the rejection of the null hypothesis being tested.

Traffic congestion, as a predictor, refers to the characteristics of a transport network when there is a possible decrease in its capacity and an increase in the duration of trips, which significantly affects service delays. Traffic congestion on routes is caused both by an increase in the intensity of traffic flow and by random circumstances, in particular, traffic accidents and the condition of highways. According to the analysis of the survey, delays associated with traffic intensity accounted for almost 34 % of trips in the 1st and 3rd periods.

Geo-information aspects of the study indicate that due to differences in the density of settlement of city residents, it is impossible to guarantee the same level of service quality in central and peripheral areas. In particular, changing the travel interval can increase the duration of delivery of city residents and can cause a certain redistribution of consumers by periods. As the analysis showed, the number of transport services provided in peripheral areas of the city with exceeding the standard time costs is higher (almost 37 % of all trips), compared to transport services provided in the central part of the city.

The speed of communication largely characterizes the use of the carrying capacity of vehicles. The assessment according to the specified predictor was carried out with the involvement of 10 experts who came to a joint conclusion about the presence of 19.2 % potential increase in the speed of communication when using the city's bus fleet. The estimated concordance coefficient was $W=0.83$, which indicates a high level of consistency of experts' opinions regarding this predictor.

As a result of substantiating the predictors for a given city, the following logistic regression model was built, the parameters of which were characterized by their impact on exceeding the normative time spent by people on travel (Table 5).

Table 5

Logistic regression model parameters and their characteristics

Predictor		Estimating the impact of a predictor a	Standard error $E_{st}(\hat{\beta})$	Wald statistics Z_W	Upper limit of variance β 95.00 %	Lower limit of variance β 5.00 %	$P(x)_a$
x_1	Number of movements	−0.149	0.009	121.011	−0.167	−0.130	0.000
x_2	Number of trips	0.031	0.004	36.316	0.024	0.038	0.000
x_3	Traffic jams	0.289	0.047	19.14	0.198	0.381	0.000
x_4	Distribution by territory	−0.319	0.048	10.63	−0.416	−0.126	0.000
x_5	Connection speed	−0.285	0.051	9.93	−0.372	−0.118	0.000
x_6	Period 1	0.611	0.092	21.902	0.429	0.791	0.000
x_7	Period 2	0.381	0.081	10.987	0.222	0.541	0.000
x_8	Period 3	0.399	0.076	13.411	0.248	0.572	0.000
x_9	Period 4	0.423	0.073	16.772	0.281	0.569	0.000

All calculated parameters were statistically significant, which was confirmed by the Wald test (5) and the associated probability value $P(x)_a$, which for each row is less than the accepted significance level $\alpha=0.05$. (Table 3). Statistical data processing was performed in MS Excel (USA). The Wald test checked the restrictions on the parameters of the statistical model, which were estimated based on sample data. Thus, all the identified factors significantly affect the time spent by the people on travel.

The calculated values of the logistic regression coefficients do not quantitatively determine the existing relationships between the variables, only the sign next to the parameter indicates the direction of the odds: plus – the odds are greater, minus – the odds are smaller relative to the control level [27, 30]. The information provided by the estimated parameters of the logistic regression model is supplemented by the odds ratio (Table 6), calculated according to equation (4).

Table 6

Odds ratios for individual predictors

Predictors x_i	Odds ratio OR_{AxB}	Upper limit of variance β 95.00 %	Lower limit of variance β 5.00 %	$P(x)_a$
Number of movements	0.543	0.516	0.571	0.000
Number of trips	1.074	0.949	0.981	0.000
Traffic jams	1.584	1.285	1.943	0.000
Distribution by territory	0.545	0.435	0.677	0.000
Connection speed	0.582	0.498	0.623	0.000
Period 1	2.344	1.759	3.149	0.000
Period 2	3.189	2.161	4.665	0.000
Period 3	2.626	1.779	3.562	0.000
Period 4	2.911	1.899	3.956	0.000

The odds ratio calculated for the number of trips is 0.54, which means that each predicted increase in this number leads to a decrease in the chances of exceeding the travel time standard by 0.54 times. At the same time, the effect of the number of trips that passengers make, taking into account transfers within one trip, is opposite. An increase in this number by one leads to an increase in the probability of exceeding the travel time standard by 1.07 times. Streamlining the traffic system in terms of traffic congestion for public transport can potentially reduce the probability of ensuring proper service to city residents in terms of travel time by 1.58 times. Among other variables, improving the conditions for providing transport services by their distribution across the city and increasing the speed of communication leads to a decrease in the probability of exceeding the travel time standard by 0.54 and 0.58 times, respectively. This indicates the possibility of a 1.12-fold increase in the quality of transport services for city residents. The odds ratios for the 1st, 2nd, 3rd, and 4th periods of residents' travel characterize the potential for increasing the level of transport service by 2.34, 3.19, 2.63, and 2.91 times, respectively.

The diagnostics of the constructed logistic model for adequacy and consistency with empirical data were checked using the Hosmer-Lemeshow criterion and ROC analysis. That is, the issue of the model's acceptability for further use was resolved. The calculated value of the Hosmer-Lemeshow test statistic is 8.892, and $p=0.3428$, which means that there is no reason to reject the hypothesis of equality of observed and predicted values. The results of ROC analysis are given in Table 7.

Table 7

The cut-off point of the studied logistic regression model

Observation No.	Cut-off point	Number of results				Sensitivity SE	Specificity SP	Yuden index, j
		TP	*TN*	*FP*	*FN*			
70	0.411	86	187	63	64	0.569	0.746	0.315

According to the results of ROC analysis for this logistic model, the sensitivity is 0.746, and the specificity is 0.746. It was determined that there are 273 well-classified cases (86 true positives and 187 true negatives), and 127 poorly classified cases (63 false positives and 64 false negatives).

According to analysis of the predictors, the city is recommended, based on the predictors x_1, x_2 (number of movements and number of trips), to open one new route and extend two bus routes to the areas of new buildings in the city. This could help increase the volume of service provision and reduce passenger transfers. To improve the predictor x_3 (traffic jams), the city should introduce a one-way traffic regime on two streets and provide a separate lane for public transport on one street. According to the predictor x_4 (territory distribution), it is proposed to change the routes of two bus routes in areas of the city with single-story buildings in order to better take into account passenger formation by the settlement of residents. According to the predictor x_5 (speed of communication), it is recommended to review the modes of movement of trolleybuses on three routes, change the location of two stops, and remove one stop. Regarding the predictors x_6–x_9, it is proposed to increase the number of buses used in the route taxi mode on two routes. Also, the city authorities should increase the level of control over the regularity of public transport, streamline the schedules of vehicles on three bus routes. This could help bring the actual duration of travel of city residents closer to the standard value.

In the case of implementing the proposed measures, a reduction in delay time by 17.5 % is predicted, which indicates the effectiveness of the devised assessment method.

Therefore, the built model and the assessment method based on it can be considered acceptable for practical use with these predictors, which may indicate the need to revise the strategy and program for managing the quality of transport services of the city.

6. Discussion of results based on testing the devised method for assessing the level of public transport service provision

The method devised for assessing the level of public transport service provision is based on a binary statistical model of logistic regression (2), (3). This allows for the implementation of a comprehensive approach to the characteristics of service activities of enterprises and the management of the quality of transport services for people.

At the first stage, the concept of influence of the characteristics of the "People – Transport – Road – Environment" system on transport services in cities was developed (Fig. 1, (1)). Based on our review of the literature, as well as information related to the transport services of cities, the predictors of transport activity were studied and characterized. Next, a statistical model based on the logistic function (3) was adapted, and its interpretation was carried out in terms of the odds ratio (4). It is proposed to verify the obtained logistic regression model using the Wald test (5), Table 1.

The next stage was to devise a method for diagnosing the logistics model for adequacy and consistency with empirical data (section 5.2). It is proposed to use the Hosmer-Lemeshow goodness of fit test and ROC analysis (Receiver Operator Characteristic) for the task defined at this stage (Table 2, (7) to (9)). Based on the results of the method diagnosis, it is recommended to calculate the percentage change in indicators (10). This will make it possible to determine the effect of implementing measures based on the results of applying the method in practice.

Unlike assessing the quality of transport services to people using existing methods [5, 8, 9, 13–15], the proposed method is not implemented fragmentarily but according to the main areas of service activity and its provision at the city level. In particular, in relation to the research problem [5], the issue of consistency of service quality indicators was resolved. Unlike the approach proposed in [8, 9], the results of our study can be applied to all characteristics of the transport system, including the state of the environment, the quality of roads, and the capacity of service companies. The devised method takes into account the impact of various characteristics on the level of quality of public transport services, which qualitatively distinguishes it from papers [13–15], which are based on modeling the impact of only one element of the transport system.

Thus, the method proposed in this study makes it possible to develop an effective program for managing the quality of transport services to people, systematized according to the parameters of the logistic regression model (3) and the odds ratio for individual predictors (4). At the same time, the program parameters are flexible since they can be assessed according to the criteria of agreement and ROC analysis (7) to (9). Such an interpretation of the study results makes it possible in practice to devise an action plan for carriers or a program of measures for the city regarding improving the quality of public transport.

At the third stage, a practice-oriented diagnosis of the constructed logistics model was carried out and its adequacy and consistency with empirical data were confirmed. The diagnosis was carried out on the basis of a sample of data on transport services for people in a city of regional significance with a population of about 262 thousand people. According to the results of a survey of consumers of transport services of this city, predictors were established that were included in the logistic regression model (Table 5). Statistical significance was established by the Wald test (5), which was performed with a significance level of $\alpha=0.05$ in the MS Excel environment (USA). Further application of the Hosmer-Lemeshow criterion and ROC analysis (Table 7) confirmed the adequacy of the method. In particular, the calculated value of the Hosmer-Lemeshow test statistic was 8.892, and according to the ROC analysis – 0.3428. This means that there is no reason to reject the hypothesis of equality of observed and predicted values. Based on the results of diagnosing the services of the city of regional significance, recommendations and measures were provided to improve the performance of public transport, and it was determined that there will be a reduction in delay time by 17.5 %.

The limitations of the devised method for assessing the quality of public transport services are that it is focused only on mass passenger transport. The disadvantages of this method include the fact that in the process of its implementation there may be a need to take into account the prospects for the development of the transport system in terms of the use of bicycles, scooters, motorcycles, and other individual vehicles.

Further development of this study is to expand the possibilities of taking into account the conditions for the provision of transport services by other types of passenger transport, in particular suburban, intercity, and international, depending on the specificity of the economic activities of various enterprises.

7. Conclusions

1. The statistical logistic regression model has been adapted, its function was specified, describing the dependence of the output variable of the quality of transport services for people on the set of input predictors of transport activity. The adaptation of the logistic model involved taking into account the influence of each individual characteristic of the element of the "People – Transport – Motorway – Environment" system depending on its features on the level of public transport services in the model. A list of the main characteristics (predictors) of the "People – Transport – Motorway – Environment" system that affect transport services in cities was determined. These are parameters and forecasting tools that determine the function – the level of quality of public transport services for city residents in the logistic model. To check the significance of these predictors in the logistic model, the Wald statistical test was used, which makes it possible with sufficient probability to reject the null hypothesis about the influence of a particular predictor on the modeling results.

2. A methodological approach to diagnosing the logistic model for adequacy and consistency with empirical data has been devised, which is based on the application of the Hosmer-Lemeshow agreement criterion and ROC analysis. In the future, based on the results of ROC analysis, it is recommended to determine the percentage change in indicators, which would make it possible to determine the effect of implementing measures based on the results of applying the method in practice.

3. A practice-oriented diagnosis of the proposed logistics model was carried out and its adequacy and consistency with empirical data were confirmed using the example of a city of regional significance with a population of about 262 thousand people. In particular, the influence of transport activity parameters on exceeding the standard time costs of the people for movement was characterized and described using a binary logistic model. The statistical significance of these parameters was confirmed using the Wald statistic test and the odds ratios were calculated for the established predictors. The adequacy of the method was confirmed using the Hosmer-Lemeshow criterion and ROC analysis. The corresponding values of the Hosmer-Lemeshow test statistics and ROC analysis were 8.892 and 0.3428, i.e., there is no reason to reject the hypothesis of equality of observed and predicted values using this method. Based on the results of diagnosing services of a city of regional significance, recommendations were provided, and appropriate measures were devised. The effectiveness of these proposals was assessed by the percentage change in the

time spent by city residents on travel, which for the analyzed city was 17.5 %. This confirms the acceptability of using a logistics model for evaluating the devised method, which allows transport business entities to measure the level of quality of services provided to people, counteract its deterioration, and identify areas for improvement.

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

The data will be provided upon reasonable request.

Use of artificial intelligence

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

References

1. Willberg, E., Tenkanen, H., Miller, H. J., Pereira, R. H. M., Toivonen, T. (2023). Measuring just accessibility within planetary boundaries. Transport Reviews, 44 (1), 140–166. https://doi.org/10.1080/01441647.2023.2240958
2. Melnychenko, O., Ignatenko, O., Tsybulskyi, V., Degtiarova, A., Kashuba, M., Derehuz, I. (2024). Development of a mechanism for information security risk management of transport service provision systems. Eastern-European Journal of Enterprise Technologies, 1 (3 (127)), 27–36. https://doi.org/10.15587/1729-4061.2024.298144
3. Kharchenko, A., Tsybulskyi, V., Chechuha, O., Zavorotnii, S., Shuliak, I. (2022). Building a model for managing the cost and duration of motor road projects. Eastern-European Journal of Enterprise Technologies, 3 (3 (117)), 13–22. https://doi.org/10.15587/1729-4061.2022.256213
4. Wang, Y., Cao, M., Liu, Y., Ye, R., Gao, X., Ma, L. (2022). Public transport equity in Shenyang: Using structural equation modelling. Research in Transportation Business & Management, 42, 100555. https://doi.org/10.1016/j.rtbm.2020.100555
5. Ojo, T. K. (2017). Quality of public transport service: an integrative review and research agenda. Transportation Letters, 11 (2), 104–116. https://doi.org/10.1080/19427867.2017.1283835
6. Moslem, S., Alkharabsheh, A., Ismael, K., Duleba, S. (2020). An Integrated Decision Support Model for Evaluating Public Transport Quality. Applied Sciences, 10 (12), 4158. https://doi.org/10.3390/app10124158
7. Santos, J. B. dos, Lima, J. P. (2021). Quality of public transportation based on the multi-criteria approach and from the perspective of user's satisfaction level: A case study in a Brazilian city. Case Studies on Transport Policy, 9 (3), 1233–1244. https://doi.org/10.1016/j.cstp.2021.05.015
8. Tarandushka, L., Shlionchak, I., Tarandushka, I. (2022). Assessment of the Quality Passenger Service by Public Transport in Cherkasy. Central Ukrainian Scientific Bulletin. Technical Sciences, 2 (5 (36)), 253–261. https://doi.org/10.32515/2664-262x.2022.5(36).2.253-261
9. Watthanaklang, D., Jomnonkwao, S., Champahom, T., Wisutwattanasak, P. (2024). Exploring accessibility and service quality perceptions on local public transportation in Thailand. Case Studies on Transport Policy, 15, 101144. https://doi.org/10.1016/j.cstp.2023.101144
10. Bin MD Saad, N. A. (2023). Deployment of Lean Six Sigma in Transportation Sector. International Journal of Empirical Research Methods, 1 (2), 74–80. https://doi.org/10.59762/ijerm205275791220231205140246
11. Dubernet, I., Axhausen, K. W. (2019). The German value of time and value of reliability study: the survey work. Transportation, 47 (3), 1477–1513. https://doi.org/10.1007/s11116-019-10052-4
12. Jamal, S., Newbold, K. B. (2020). Factors Associated with Travel Behavior of Millennials and Older Adults: A Scoping Review. Sustainability, 12 (19), 8236. https://doi.org/10.3390/su12198236
13. De Vos, J., Ermagun, A., Shaw, F. A. (2023). Wait time, travel time and waiting during travel: existing research and future directions. Transport Reviews, 43 (5), 805–810. https://doi.org/10.1080/01441647.2023.2220206
14. Rashidi, S., Ataeian, S., Ranjitkar, P. (2022). Estimating bus dwell time: A review of the literature. Transport Reviews, 43 (1), 32–61. https://doi.org/10.1080/01441647.2021.2023692
15. Merlin, L. A., Jehle, U. (2023). Global interest in walking accessibility: a scoping review. Transport Reviews, 43 (5), 1021–1054. https://doi.org/10.1080/01441647.2023.2189323
16. Miller, E. (2023). The current state of activity-based travel demand modelling and some possible next steps. Transport Reviews, 43 (4), 565–570. https://doi.org/10.1080/01441647.2023.2198458
17. Gkiotsalitis, K., Cats, O., Liu, T. (2022). A review of public transport transfer synchronisation at the real-time control phase. Transport Reviews, 43 (1), 88–107. https://doi.org/10.1080/01441647.2022.2035014
18. Hensher, D. A., Hietanen, S. (2022). Mobility as a feature (MaaF): rethinking the focus of the second generation of mobility as a service (MaaS). Transport Reviews, 43 (3), 325–329. https://doi.org/10.1080/01441647.2022.2159122
19. Maheshwari, R., Van Acker, V., De Vos, J., Witlox, F. (2023). A multi-perspective review of the impact of a workplace relocation on commuting behaviour, commuting satisfaction and subjective well-being. Transport Reviews, 43 (3), 385–406. https://doi.org/10.1080/01441647.2022.2119296

20. Wang, X., Wong, Y. D., Chen, T., Yuen, K. F. (2022). Consumer logistics in contemporary shopping: a synthesised review. Transport Reviews, 43 (3), 502–532. https://doi.org/10.1080/01441647.2022.2131010
21. Conceição, M. A., Monteiro, M. M., Kasraian, D., van den Berg, P., Haustein, S., Alves, I. et al. (2022). The effect of transport infrastructure, congestion and reliability on mental wellbeing: a systematic review of empirical studies. Transport Reviews, 43 (2), 264–302. https://doi.org/10.1080/01441647.2022.2100943
22. Zaidi, A., Al Luhayb, A. S. M. (2023). Two Statistical Approaches to Justify the Use of the Logistic Function in Binary Logistic Regression. Mathematical Problems in Engineering, 2023 (1). https://doi.org/10.1155/2023/5525675
23. Bangchang, K. N. (2024). Application of Bayesian variable selection in logistic regression model. AIMS Mathematics, 9 (5), 13336–13345. https://doi.org/10.3934/math.2024650
24. Kasiri, L. A., Guan Cheng, K. T., Sambasivan, M., Sidin, S. Md. (2017). Integration of standardization and customization: Impact on service quality, customer satisfaction, and loyalty. Journal of Retailing and Consumer Services, 35, 91–97. https://doi.org/10.1016/j.jretconser.2016.11.007
25. Kent, J. L., Crane, M., Waidyatillake, N., Stevenson, M., Pearson, L. (2023). Urban form and physical activity through transport: a review based on the d-variable framework. Transport Reviews, 43 (4), 726–754. https://doi.org/10.1080/01441647.2023.2165575
26. Kosmidis, I., Müller-Eie, D. (2023). The synergy of bicycles and public transport: a systematic literature review. Transport Reviews, 44 (1), 34–68. https://doi.org/10.1080/01441647.2023.2222911
27. Borucka, A. (2020). Logistic regression in modeling and assessment of transport services. Open Engineering, 10 (1), 26–34. https://doi.org/10.1515/eng-2020-0029
28. Logistic Regression Four Ways with Python (2022). University of Virginia. Available at: https://library.virginia.edu/data/articles/logistic-regression-four-ways-with-python
29. Tomaino, G., Walters, D. J. (2024). Presenting time-series data as absolute versus relative changes impacts judgments and choices. Journal of Consumer Psychology, 34 (3), 510–518. https://doi.org/10.1002/jcpy.1391
30. Pho, K.-H., McAleer, M. (2021). Specification and Estimation of a Logistic Function, with Applications in the Sciences and Social Sciences. Advances in Decision Sciences, 25 (2), 74–104. https://doi.org/10.47654/v25y2021i2p74-104