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ROTARU IGOR

INCREASING THE EFFICIENCY OF THE PUBLIC TRANSPORT SYSTEM IN CHISINAU MUNICIPALITY

271.01. ENGINEERING AND PRODUCTION MANAGEMENT (on branches of industrial production)

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PhD Supervisor:

CEBAN Victor, PhD., assoc. prof.

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The thesis was developed within the Department of Transport, Faculty of Mechanical, Industrial Engineering and Transport.
Technical University of Moldova

Author: ROTARU Igor

PhD Supervisor: CEBAN Victor, PhD., assoc. prof., UTM

Public defense committe:

1 BUGAIAN Larisa, Dr. hab., prof., Technical University of Moldova.
2 CEBAN Victor, PhD., assoc. prof., Technical University of Moldova.
3 GOIAN Vladimir, PhD., assoc. prof., Technical University of Moldova.
4 BOROIU Alexandru, PhD., prof., National University of Science and Technology Politehnica Bucharest, Pitesti University Center.
5 SACHELARIE Adrian-Constantin, PhD., prof., "Gheorghe Asachi" Technical University of Iasi.

The public defense of the thesis will take place on 24.04.2026 at 14.00 o'clock, within UTM, FIMIT, 9/8 Student Street, study block no. 6, aud. 6-114, MD 2045, Chisinau, Republic of Moldova.
The doctoral thesis and the abstract can be consulted at the library of the Technical University of Moldova and on the ANACEC website (www.anacec.md).

Author:
ROTARU Igor ____________

PhD Supervisor:
CEBAN Victor, PhD., assoc. prof. ____________

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Main research highlights

Urban public transport is a fundamental component of sustainable development and the efficient functioning of modern cities. In the context of the Republic of Moldova, and especially of the Chisinau municipality, road transport remains the main means of transportation for the population, but outdated infrastructure, lack of modal integration and poor traffic management limit the performance of the system. At the same time, the pressure generated by urban growth and increased population mobility imposes the need for a strategic approach, oriented towards efficiency, sustainability and safety.

To meet these challenges, it is essential to modernize infrastructure, digitize planning and operation processes, and promote a coherent urban mobility policy that integrates public transport with other modes of travel.

Thus, the research aims to evaluate the current state of the urban public transport system, to identify dysfunctions and factors that limit its performance, but also to substantiate directions for the modernization and integration of transport services, in accordance with the principles of sustainable urban mobility and good European practices.

Topic relevance: The relevance of research into the functioning of the public transport system in the municipality of Chisinau is sustained by the continuous growth of the city's population, the intensification of urban mobility and the need to develop a sustainable and efficient transport system that can meet these requirements.

From the above it follows that increasing the efficiency of the transport system is an important scientific and practical task, the solution of which will significantly improve the quality of public transport in the municipality of Chisinau.

Research goal: Identifying scientifically substantiated engineering and managerial methods aimed at increasing the efficiency of the public transport system in the municipality of Chisinau and contributing to increasing the population's satisfaction with mobility services.

Research objectives:

1. Analysis of the principles and mechanisms of operation of the public transport system in Chisinau, to identify strengths, weaknesses, and key factors.
2. Development of a modern methodology for assessing the quality of urban transport services, based on passenger satisfaction by processing complex data sets.

3. Conducting a study of passenger flows on routes in Chisinau, in order to determine operating indicators and develop fundamental measures to make the public transport system more efficient.

4. Development of practical solutions to make public transport more efficient, through technical and organizational measures, reducing costs, improving quality, and promoting sustainability.

Research hypothesis: the efficient functioning of an urban public transport system can only be ensured through an optimal correlation between technical, organizational and operational parameters, so as to respond adaptively to the dynamic requirements of urban mobility, increase passenger satisfaction and contribute to reducing the negative impact on urban infrastructure and the environment. It is assumed that only by applying modern analysis methods and by implementing innovative technological and organizational solutions, it is possible to significantly increase the performance and sustainability of a municipality's public transport.

Scientific novelty and originality

The paper brings an integrated approach to the urban public transport system in the municipality of Chisinau, combining structural-functional analysis, user perception assessment and practical solutions for efficiency.

1. To assess passenger satisfaction with the quality of public transport services, the multivariate statistical method Principal Component Analysis (PCA) was used for the first time.

2. As part of the thesis, studies of transport demand and passenger flow were conducted, where original results were obtained, which are of scientific interest and will allow us to develop reasoned solutions to increase the efficiency of the public transport system in the municipality of Chisinau.

Original elements include:

Customized evaluation methodology, based on surveys and performance indicators, for a realistic analysis of passenger requirements and satisfaction.

Adaptation of the tabular passenger counting method to substantiate decisions on sizing and improving the transport network.

Correlation between technical (capacity, frequency) and operational (reliability, comfort) parameters for optimizing efficiency in a dynamic urban context.

Optimization recommendations focused on efficiency, sustainability and alignment with European sustainable mobility policies, which do not require significant material costs.

Theoretical significance: the paper presents a significant contribution to the theoretical foundation of the study of public transport systems in large cities, by developing an integrated methodological framework that combines qualitative, quantitative and technical-economic indicators. This approach allows for a more complex and realistic understanding of the functioning of public transport in an urban context.

Based on the results of the sociological survey, the evaluation of passenger satisfaction was theoretically approached, which allowed clarifying the role of infrastructural, organizational and operational factors in the perception of the quality of transport services.

By integrating user perception into the system performance evaluation based on the PCA method, the thesis enriches the theory of urban mobility, offering a user-oriented perspective and supporting the need to correlate technical-organizational decisions with the real needs of the population.

For the first time, for the conditions of the city of Chisinau, the concept of reducing the null route of buses was substantiated by creating a technological ground, which can serve as a basis for the further development of the theory of optimizing operational processes in the public transport system.

The proposed model of systemic analysis of a public transport network can be applied and adapted in other urban contexts (cities of similar size, with similar urban and demographic characteristics), which highlights its theoretical value and potential for generalization in the field of public transport planning.

Implementation of the scientific results

Following the results obtained during the research, the Directorate General for Urban Mobility of the Chisinau Municipal Council implemented a series of changes related to the road network, new routes, adjusting traffic schedules, creating lanes dedicated to public transport, etc.

THESIS CONTENT

1. Analysis of the activity of the municipal public transport system

This chapter describes the principles of operation of the urban public transport system and the importance of public transport in the urban and socio-economic context of the city in ensuring the mobility of residents, their accessibility to essential services, such as work, studies or other facilities. It was noted that at the current stage of city development, one of the main tasks is to create a safe, economical, reliable and environmentally friendly public passenger transport system [1, 2].

The principles and mechanisms of operation of the public transport system of municipalities with a population between 0.5 and 1 million inhabitants, such as Chisinau, are presented. The principles of organization and operation of public transport system in similar cities in the USA, Great Britain and some European countries that face the same problems as Chisinau are analyzed, and solutions that could be implemented are proposed. [2–7].

The national legislative framework that guarantees the efficiency, safety and quality of services provided by public transport in the Republic of Moldova was analyzed.

The structure of Chisinau municipality was analyzed by the number of localities, area and number of inhabitants, population dynamics for the last six years, population density in the city and suburbs. [8].

An analysis of the structure of public transport operators was carried out, which consists of eight private operators managing 22 minibus routes and two municipal operators (Î.M. RTE and Î.M. PUA) managing 31 trolleybus routes and 24 bus routes.

A detailed analysis of the structure and dynamics of the rolling stock of the STP in Chisinau was carried out, having as main benchmarks the total number of transport units, the average age of the vehicles and their transport capacity. The study aimed to highlight the evolution trends of the fleet in relation to the demand for urban mobility, the degree of technological renewal and the operational efficiency of the means of transport used. The analysis allowed the identification of the existing imbalances between the available transport capacity and the real needs of the population, as well as the degree of physical and moral wear and tear of the rolling stock and the influence on the environment.

The efficiency indicators of the public transport system are presented by the number of passengers transported and their route for the last 6 years.

The normative requirements were analyzed and the characteristics of the road infrastructure of the municipality of Chisinau were presented by road categories and types of pavement.

A SWOT analysis of the current public transport system in the municipality of Chisinau was developed and presented, with the objective of identifying strengths and weaknesses, as well as opportunities and threats that influence its development and efficient functioning.

An analysis of the fare policy applied in the public transport system in Chisinau, the principles of formation and the mechanisms of fare subsidy was carried out. The study was complemented by a comparative analysis of fare practices in other cities of the European Union, with the aim of identifying efficient and sustainable models that can be adapted to the local context. [9–12].

An analysis was carried out to evaluate the efficiency of the operation of the public transport system in the municipality of Chisinau according to criteria such as: accessibility [13]; quality of services [14]; the impact of the transport system on the environment; safety and security.

2. Methodology of research into the functioning of the municipal public transport system

This chapter presents the technical-operational indicators of the urban public transport system, as well as the methodology for determining them based on experimental data, highlighting the role of urban road network indicators in the efficiency of public transport operation.

Passenger flow research methodology. The most common methods of passenger flow research in public transport system are analyzed with a description of the advantages and disadvantages of each method [15,16].

Research on socio-economic needs in public transport services is presented, dedicated to analyzing the social and economic role of the public transport system, with the aim of identifying the degree of correspondence between the transport offer and the real needs of the community. [2, 17]. Research is focused on assessing the population's mobility demand, determined according to the socio-demographic structure of the population, the spatial distribution of urban activities and the particularities of daily mobility [18], as well as on analyzing the economic indicators that characterize the functioning of the public transport system in terms of efficiency and financial sustainability.

In passenger flow research, the tabular method is applied, which consists of systematically recording the number of passengers boarding and disembarking at each station, for each trip. The method allows determining transport flows, identifying correspondences between network sectors, assessing the degree of vehicle capacity utilization and calculating performance indicators necessary for the analysis and optimization of the public transport network.

This entire chapter is dedicated to the evaluation of the quality of services offered by the urban public transport system, with the objective of assessing the degree of user satisfaction and identifying the factors that influence their perception of transport services. The quality of services is analyzed both by classical methods [19, 20] and by modern multifactorial analysis methods (Principal Component Analysis PCA) [21].

We propose to apply the principal component analysis (PCA) method as a statistical tool for complex assessment of the quality of urban public transport services [4, 22]. The method allows to reduce the dimensionality of the set of analyzed indicators and identify the main factors that influence the overall satisfaction of users. The theoretical framework of the PCA method, the basic principles and the advantages of its use in the analysis of public transport systems, characterized by a large number of intercorrelated variables, are presented.

The steps necessary for applying the method are described, which include: standardizing the initial data to eliminate the influence of different measurement units and ensuring the comparability of the analyzed variables; calculating the covariance matrix; calculating the eigenvalues and eigenvectors of the covariance matrix; selecting the principal components based on the analysis of explained variance.

Projection of data on a new coordinate space. Interpretation of results - the results obtained through PCA are analyzed and interpreted, highlighting the dominant components and mixes of factors that influence the quality of urban public transport services.

3. Study of the public transport system in Chisinau municipality

The evaluation of the efficiency of the public transport system in Chisinau is carried out in two stages:

- conducting a passenger survey to determine satisfaction with the services provided by the public transport system;
- determining the technical and operational indicators of the public transport system with highlighting those that have a greater influence on the efficiency of the system.

For the survey to be representative, the following conditions must be met:

- the sample is of sufficient size to generate relevant and accurate results;
- the sample structure reflects the diversity of the population according to criteria such as: gender, age and data collection area (including central and peripheral areas for coverage of suburban routes).

To ensure representativeness, the sampling method at contact points - face-to-face interviews at public transport stations - was applied. The survey was conducted in 16 locations, on both directions of traffic, with each location being interviewed for two working days.

Survey period: November 28 – December 2, 2022, data collection was carried out daily in three time slots: 06:30 – 10:00 (morning, peak hours); 10:00 – 16:00 (noon); 16:00 – 19:00 (evening, peak hours), with an equal number of surveys. A total of 2084 surveys were completed.

The margin of error for a sample of 2084 people from a finite population adjusted for the number of inhabitants is approximately 2.46 %.

The survey results show that out of the total of 2084 people, 45.2 % are women and 54.8 % are men. The participants were divided into 7 age categories, starting from the age of 12, the vast majority 83.4% of respondents represent the active population aged between 18 – 57.

Of the total number of respondents, 69.1 % are city residents, and 30.9 % are suburban residents and guests of the capital. Depending on the mode of transport used, the distribution of respondents is as follows: 65.6 % use trolleybuses, 20.3 % use city buses, 10.2 % use suburban buses, and 3.9 % use minibuses.

The survey results show that 48.1 % take advantage of school or general subscriptions, about 40.3 % of travelers prefer to pay cash for each trip, 7.9 % are exempt from payment.

The data obtained indicate that the majority of passengers, namely 67.7 %, use public transport with a frequency of 5 – 7 days a week.

The factor analysis in figure 3.1 shows that four of the main criteria for choosing public transport are directly or indirectly related to travel time, accounting for 55.0 % of the total importance. The next most relevant factor is comfort – the possibility of sitting down 35.2%, and the cost of the trip has a significantly lower role, at only 9.8 %.

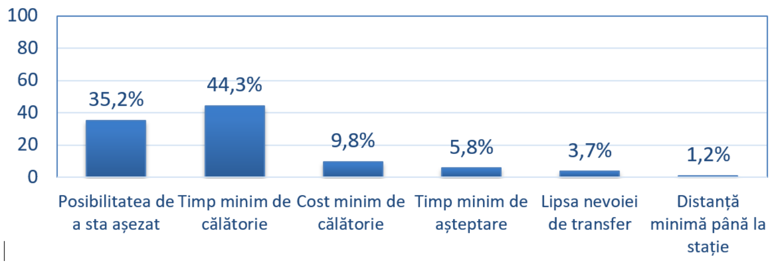


Figure 3.1 Distribution of respondents according to public transport choice criteria

Regarding obtaining information about public transport routes and schedules - about 55.4 % obtain information at public transport stations, 23.3 % - do not use the information, 14.8 % - obtain information online from their mobile phone, which shows us a weak development of placing information online [7].

The results of the survey on various aspects are presented below.

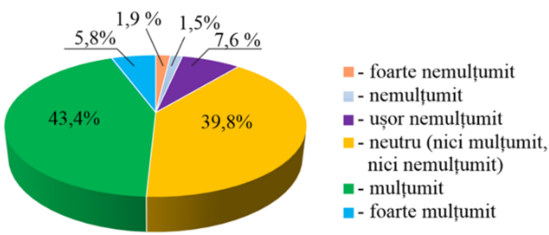


Figure 3.2 Level of satisfaction with the provision of information about public transport timetables overall.

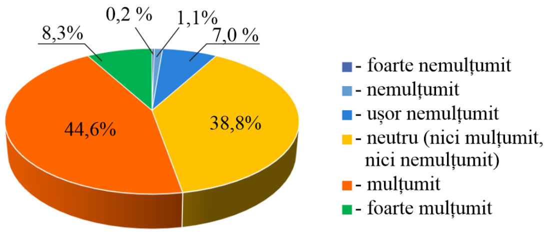


Figure 3.3 Level of satisfaction with public transport stations (lighting, cleanliness, weather protection, presence of seats, condition of the sidewalk, crowding)

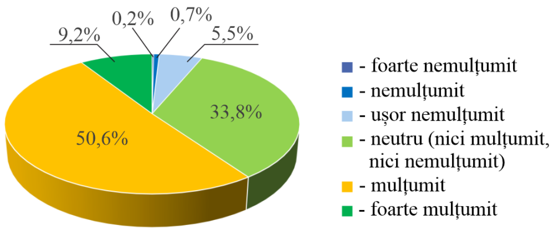


Figure 3.4 Level of satisfaction with the means of transport (crowdedness, cleanliness, comfort, temperature in the cabin in winter/summer, lighting, ease of boarding and disembarking)

The following results include only the satisfaction of respondents who use these means of transport, namely on the following aspects:

- the ability to reach any area of the city, at any time;
- distance to the nearest public transport station;
- walking time to and from the public transport station;
- the number of available routes.

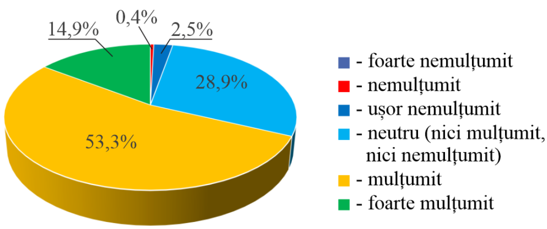


Figure 3.5 Level of satisfaction with the trolleybus route network (1792 respondents)

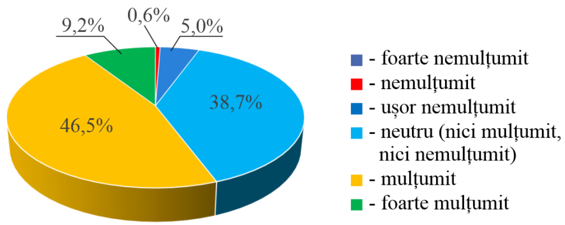


Figure 3.6 Level of satisfaction with the urban bus route network (1330 respondents)

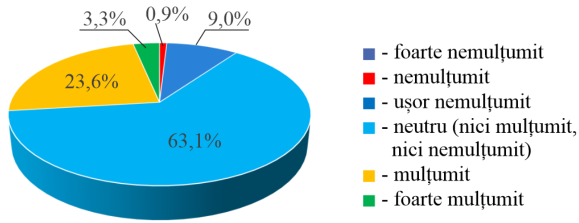


Figure 3.7 Respondents' level of satisfaction with the suburban bus route network (877 respondents)

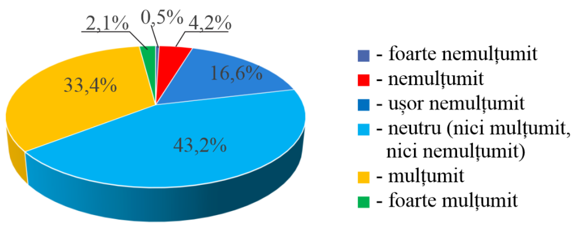


Figure 3.8 Respondents' level of satisfaction with the minibus route network (874 respondents)

3.1. Processing passenger survey data using the "Principal Component Analysis" (PCA) method

For processing relatively large data and reducing the dimensionality of a complex data set, without significant loss of essential information, it is proposed to use the multivariate statistical method "Principal Component Analysis" (PCA), which allows the identification of latent factors that influence user perception and the determination of relationships between qualitative variables. PCA offers the possibility of transforming sets of correlated variables into a smaller number of uncorrelated variables (principal components), each representing a fundamental dimension of service quality.

Applying the method involves completing the following steps:

a) standardization of data to eliminate the influence of different units of measurement and allow comparability between variables. These transformations were performed using a program developed in the Python programming language [23];

b) calculating the covariance matrix to highlight the links between variables. For this I used the *pandas* library in Python;

c) calculating the eigenvalues and eigenvectors for the covariance matrix uses the *numpy* library in Python;

d) selection of relevant principal components, based on the criterion of explained variance. As a result of the calculations, the 5 most important principal components presented in table 3.1 were identified along with the corresponding variance share.

Table 3.1 The first 5 eigenvalues of the covariance matrix and their importance in explaining data variance

No.	The value of the eigenvalue	The explained variant, %	Cumulative explained variance, %
1	10,27404491	21,85	21,85
2	3,589577401	7,63	29,48
3	2,973504444	6,32	35,80
4	2,286543124	4,86	40,66
5	2,150963809	4,57	45,24

The explained variant provides information about the weight of each principal component (associated with each eigenvalue) in the data set. Thus, the results can be interpreted as follows:

- *eigenvalue* - represents the amount of variation captured by the corresponding principal component (a direction in feature space). A larger eigenvalue indicates that the corresponding principal component captures a larger portion of the variation in the data.

- *explained variance* (%) - tells us the proportion of the total variance in the data set that is explained by each principal component. For example, the first principal component captures 21.85 % of the total variance, and the second component captures 7.63 %.

According to the data, we obtain the following interpretations of the data:

- *dimensionality reduction*. The principal components with the greatest variance explained are the most significant. To reduce dimensionality, it is possible to keep only the components that explain most of the variation. For example, the first 5 components explain over 45 % of the variation, so by reducing the dimensionality to 5 components, we retain a significant amount of information at the same time.

- *cumulative variance*. It helps us select a reasonable number of principal components that explain the total variance well enough. If we need 60 % of the variance explained, we can keep only the components that are necessary to reach this threshold. In this case, the first 10 features are responsible for at least 61.69 % of the variance, and the first 6 features explain a little more than 49 % of the variance.

The factors that determine the behavior of the main components can also be analyzed, as shown in table 3.2.

Table 3.2 Important features in the first three main components

No.	PC1 Top features	PC1	PC2 Top features	PC2	PC3 Top features	PC3
1	F18	0,2248	F41	0,3383	F31	0,2590
2	F26	0,2232	F39	0,3253	F9	0,2590
3	F25	0,1939	F42	0,3161	F11	0,2523
4	F11	0,1904	F40	0,3082	F8	0,2395
5	F15	0,1902	F38	0,2778	F28	0,2375

The features of F1 … F47 are presented below:

F1 = Gender of the respondent.

F2 = Age of the respondent.

F3 = Lives in Chisinau or in the suburbs.

F4 = What type of public transport does he use.

F5 = How often does he use public transport.

F6 = Availability of correct public transport timetables at stations.

F7 = Easy to read and understand timetables of public transport routes at stations.

F8 = Public information available on electronic monitors in public transport.

F9 = Mobile applications available.

F10 = Effective compliance with the established public transport timetable.

F11 = Satisfaction with the provision of information about the public transport timetable as a whole (availability of timetables, public information on panels, applications).

F12 = Satisfaction with stations regarding lighting.

F13 = Satisfaction with stations regarding cleanliness.

F14 = Satisfaction with stations regarding shelter provision.

F15 = Satisfaction with stations regarding the provision of seating.

F16 = Satisfaction with stations regarding the condition of the sidewalk in the area.
F17 = Satisfaction with stations regarding the crowding of passengers.
F18 = Overall satisfaction with transport stations.
F19 = During the journey – occupancy of the cabin.
F20 = During the journey – smooth ride.
F21 = During the journey – comfort in the car cabin.
F22 = During the journey – temperature inside the cabin in winter.
F23 = During the journey – temperature inside the cabin in summer.
F24 = During the journey – quality and level of lighting in the cabin.
F25 = Getting in and out of public transport (using physical force).
F26 = Overall satisfaction during the journey.
F27 = Trolleybus route network - can be reached anywhere and anytime.
F28 = Trolleybus route network - distance to the nearest station.
F29 = Trolleybus route network - time to reach the station.
F30 = Trolleybus route network - number of available routes.
F31 = Trolleybus route network - overall satisfaction.
F32 = Urban bus route network - can be reached anywhere and anytime.
F33 = Urban bus route network - distance to the nearest station.
F34 = Urban bus route network - time to reach the station.
F35 = Urban bus route network - number of available routes.
F36 = Urban bus route network - overall satisfaction.
F37 = Minibus route network - can be reached anywhere and anytime.
F38 = Minibus route network - distance to the nearest stop.
F39 = Minibus route network - time to reach the stop.
F40 = Minibus route network - number of available routes.
F41 = Minibus route network - overall satisfaction.
F42 = Suburban bus route network - can be reached anywhere and anytime.
F43 = Suburban bus route network - distance to the nearest stop.
F44 = Suburban bus route network - time to reach the stop.
F45 = Suburban bus route network - number of available routes.
F46 = Suburban bus route network - overall satisfaction.
F47 = Overall satisfaction with public transport in Chisinau.

The most important features for the first three principal components (PC1, PC2, and PC3) were identified. For each component, the features with the highest values that contribute the most to that principal component.

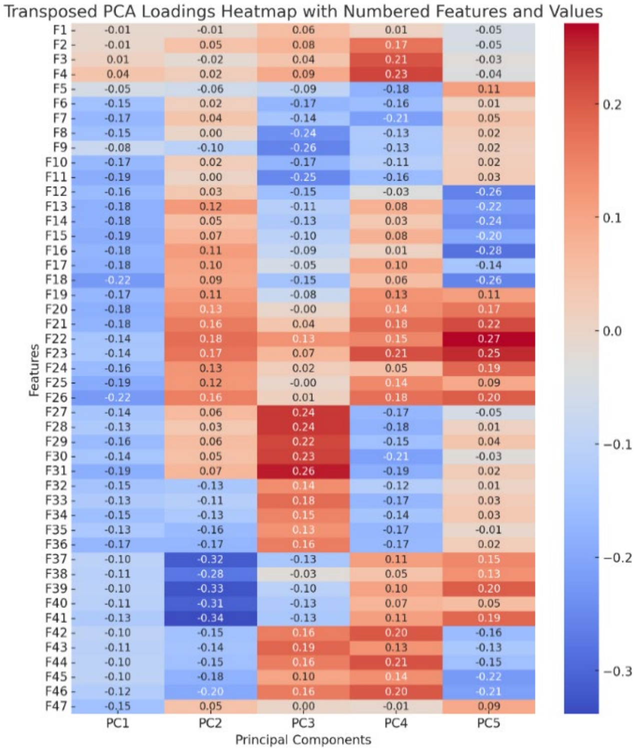


Figure 3.9 Heatmap of loadings for the top 5 principal components

We can also obtain a heatmap for the first 5 principal components (figure 3.9). The color intensity indicates the contribution (positive or negative) of each feature to the respective principal component. This visualization helps to envisage the features that strongly influence each component.

Principal component analysis shows that the satisfaction of public transport users in Chisinau does not depend on a single dominant factor, but on combinations of variables that act together. PCA allowed the reduction of the 47 indicators to five relevant principal components, highlighting the mixes of factors with a real impact on the perception of services.

The results provide a solid analytical basis for prioritizing measures that can effectively improve the quality of public transport.

3.2. Passenger flow study results

Based on the gravity model [26, 27] and statistical data on the population of Chisinau municipality together with information on the road network provided by Directorate General for Urban Mobility, the "Origin – Destination" matrix for the municipality was developed, in order to estimate transport demand (figure 3.10).

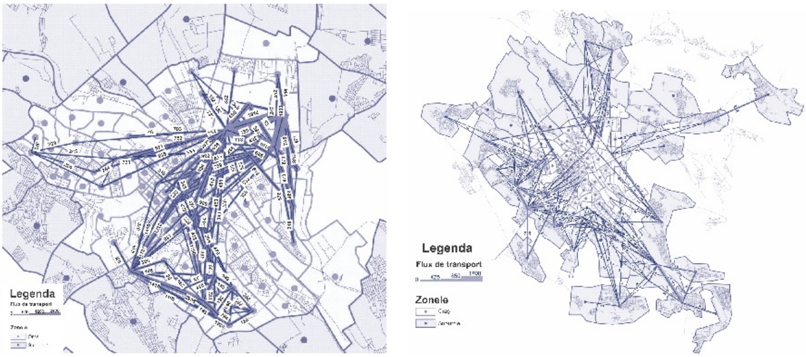


Figura 3.10 Network transport demand graph for urban and suburban areas

Determining the technical and operational indicators of the routes.

During the period 05.12.2022 - 09.12.2022, by applying the tabular method, which involves placing observers in the means of transport, data were collected and recorded on the number of passengers boarding and disembarking at each station, the route time and the capacity of the means of transport used, in order to form the passenger correspondence matrix and calculate the technical and operational indicators of the means of transport on the route.

To ensure the accuracy of the research, data collection was carried out daily in three time intervals: 06:30–10:00 (morning, peak hours); 10:00–16:00 (noon); 16:00–19:00 (evening, peak hours), analyzing the 31 trolleybus routes, 24 bus routes and 22 minibus routes.

These results are presented graphically in the form of passenger traffic cartograms applied to the public transport network (figure 3.11).

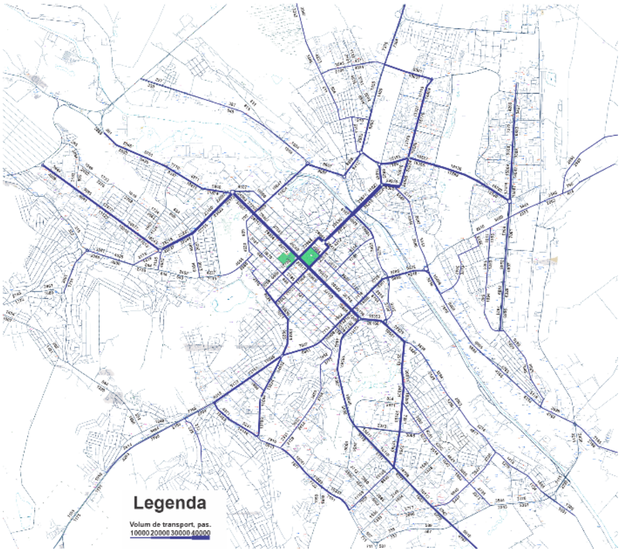


Figure 3.11 Interstation transportation volume according to the calculation performed

Based on the results of the calculation, the total length of the analyzed public transport network is 2125.1 km, distributed by transport types as follows: trolleybus network – 32 %, urban bus network – 8 %, suburban bus network – 30 %, and minibus network – 30 %.

According to the calculation results, the density coefficient of the public transport network $K_d=3.72\ km/km^2$, and the branching coefficient of the network $K_R=1.9\ km/km$, values that fall within the ranges characteristic of medium-sized cities [28].

The collinearity coefficient of the existing route network for the city of Chisinau is $K_{col} = 1.38\ km/km$, for the municipality – $K_{col} = 1.5\ km/km$.

As a result of the analysis of the transport volume, it can be noted that the maximum transport volume falls on trolleybus routes – about 72 %, followed by suburban bus routes – 11 %, urban buses – 9 % and minibuses – 8 %. The transport volume confirms the demand (figure 3.12).

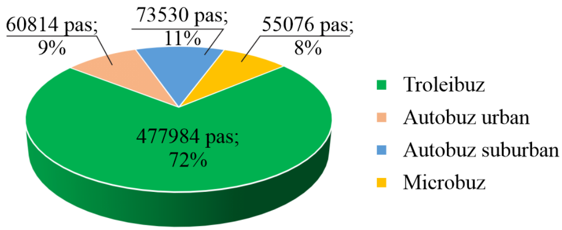


Figure 3.12 Distribution of daily transportation volume depending on the type of means of transport, pass.

Table 3. Technical and operational indicators of urban public transport system routes

No.	Route type	l_R	V_{com}, km/h,	Q_{pas}, pas.	P, pas·km	γ_d	$\eta_{n.lr.}$
5	Urban	37.74	16.7	16896	83506	0.366	1.93
19	Urban	27.92	15.9	9793	42544	0.303	1.72
23	Urban	37.46	17.4	23073	90626	0.266	1.61
26	Urban	32.57	17.1	10727	44726	0.276	1.79
65	Urban	29.3	20.3	325	1881	0.200	1.95
2	Suburban	32.17	20.7	4920	39033	0.218	1.51
4	Suburban	34.40	23.9	2702	20330	0.144	1.80
9	Suburban	27.20	15.7	10422	46645	0.341	1.83
10	Suburban	22.55	19.1	1413	9267	0.237	1.63
11	Suburban	22.64	16.0	4021	20891	0.308	1.90
16	Suburban	34.08	18.6	3430	14276	0.145	1.75
18	Suburban	39.04	20.0	7653	48786	0.229	1.75
24	Suburban	25.83	19.4	1392	6529	0.118	1.70
28	Suburban	31.97	19.0	5165	22167	0.240	1.99
31	Suburban	58.29	22.0	3496	32732	0.256	2.33
33	Suburban	51.85	22.0	3130	32855	0.282	1.82
37	Suburban	24.24	20.0	3851	16522	0.245	2.03
38	Suburban	32.15	18.5	1771	13922	0.213	1.82
39	Suburban	28.00	18.0	3109	12862	0.159	1.82
44	Suburban	43.00	20.5	2278	17895	0.255	1.71
46	Suburban	30.96	18.8	5979	31199	0.277	1.71
47	Suburban	33.18	20.0	5689	31755	0.267	1.63
48	Suburban	39.63	20.4	957	7785	0.321	1.84
49	Suburban	31.62	22.0	2139	7582	0.083	2.16
1	Troleibuz	22.01	15.6	21856	73961	0.228	1.98
2	Trolleybus	13.06	15.0	19045	48927	0.173	2.29
3	Trolleybus	21.81	16.2	12784	41446	0.243	1.60
4	Trolleybus	28.85	15.0	27956	66451	0.249	1.91
5	Trolleybus	19.16	15.5	17401	58119	0.286	1.76
7	Trolleybus	15.53	16.5	11308	35405	0.225	1.99
8	Trolleybus	23.45	15.7	34236	134479	0.307	1.86
9	Trolleybus	17.85	15.6	7290	34963	0.225	1.59

No.	Route type	l_R	V_{com}, km/h,	Q_{pas}, pas.	P, pas·km	γ_d	$\eta_{n.lr.}$
10	Trolleybus	19.87	15.4	44217	132518	0.285	1.81
12	Trolleybus	18.5	16.0	25406	77895	0.33	1.69
13	Trolleybus	31.07	15.7	29997	96470	0.252	1.69
16	Trolleybus	26.38	15.6	5793	17709	0.201	2.07
17	Trolleybus	23.86	16.1	17860	46365	0.228	1.86
20	Trolleybus	17.44	14.9	5213	10541	0.136	1.88
21	Trolleybus	28.71	17.0	31256	168282	0.351	1.71
22	Trolleybus	30.53	16.0	60859	249522	0.36	1.80
23	Trolleybus	24.37	16.7	11424	42463	0.232	1.77
24	Trolleybus	25.8	15.8	22967	73219	0.268	1.75
25	Trolleybus	12.29	15.5	11153	23544	0.161	1.56
26	Trolleybus	16.13	16.9	1941	7030	0.188	1.77
27	Trolleybus	15.25	16.5	2375	9191	0.174	1.48
28	Trolleybus	26.39	14.5	6086	16481	0.205	1.68
29	Trolleybus	14.06	16.6	5100	12765	0.16	1.58
30	Trolleybus	28.91	17.0	8268	19256	0.294	1.70
32	Trolleybus	21.39	17.1	3001	9747	0.138	1.75
33	Trolleybus	12.12	15.1	747	1502	0.068	1.53
34	Trolleybus	29.67	17.7	6935	52914	0.391	1.57
35	Trolleybus	19.33	14.3	5812	12996	0.078	3.13
36	Trolleybus	28.44	15.4	4622	15535	0.224	1.72
37	Trolleybus	21.97	16.5	2828	10571	0.2	2.06
38	Trolleybus	33.72	15.4	12248	33792	0.263	1.88
101	Minibus	12.85	19.30	3048	7411	0.433	1.709
103	Minibus	42.73	19.70	5645	20098	0.402	1.859
106	Minibus	21.65	21.80	631	4146	0.304	1.599
112	Minibus	34.54	20.50	1332	9277	0.436	1.665
113	Minibus	18.76	19.70	1699	10250	0.467	1.843
120	Minibus	25.83	20.40	4013	21157	0.479	1.608
121	Minibus	24.02	20.20	530	2226	0.155	1.413
124	Minibus	25.56	19.80	1940	7076	0.338	2.235
130	Minibus	75.61	22.40	2465	49948	0.367	1.983
134	Minibus	14.90	22.10	1925	9931	0.529	1.428
138	Minibus	28.39	20.10	1266	8072	0.405	1.561
151	Minibus	19.37	22.20	585	4152	0.264	1.481
157	Minibus	39.41	23.20	2768	33284	0.782	1.693
159	Minibus	21.08	22.40	921	8816	0.383	1.355
162	Minibus	20.81	20.10	2217	8923	0.498	1.599
169	Minibus	28.30	19.80	2874	14732	0.482	1.786
173	Minibus	27.21	20.50	2642	8787	0.299	1.748
174	Minibus	31.86	20.40	4539	28350	0.454	1.689
178	Minibus	7.19	22.20	1292	2122	0.529	1.832
184	Minibus	27.35	20.00	4735	14508	0.421	1.552
186	Minibus	50.75	20.30	2912	14678	0.412	1.558
191	Minibus	31.09	21.30	5097	21187	0.631	1.720

4. Developing an efficient public transport system in Chisinau

The analysis of the suburban bus network, which consists of 19 routes, finds that approximately 90% of them (17 routes) have their route ends in the city center, or large common sections with other city center routes, affecting the efficiency of the public transport network.

Figure 4.1 Suburban transport routes from the “Circul” station area with a terminus in the city center on V. Alecsandri street

In order to develop measures to increase the efficiency of the public transport system in Chisinau, it is proposed to modify six routes that have a large overlap of itineraries and a common route head on V. Alecsandri Street and move towards the northern suburb of the city.

The analysis of these routes highlights a significant overlap between certain routes, generated by the need to ensure transport demand in suburban areas with low population density, where long distances do not allow for effective avoidance of these overlaps.

Table 4.1 Technical operating indicators of the analyzed routes

Route No.	l_R, km	n_c		A_R, un.	I_{min}, min	t_R, min	V_{com}, km/h	Q_{zi}, pass	γ_d
		tour	return						
2	32,17	52	52	7	15	93	20,7	4920	0,218
10	22,55	17	17	2	36	71	19,1	1413	0,237
28	31,97	27	27	4	22	101	19,0	5165	0,24
37	24,24	26	26	3	25	73	20,0	3851	0,245
47	33,18	33	34	4	26	100	20,0	5689	0,267
48	39,63	6	6	1	82	116	20,4	957	0,321

For example, Route 2 (Chisinau city – Cricova city), which provides transport to Cricova city with a population of 10,392 inhabitants, the daily round-trip passenger volume diagram is presented below (figure 4.2), and graphs of passenger flows during morning peak hours (figure 4.2a.) and evening (figure 4.2b) are also presented.

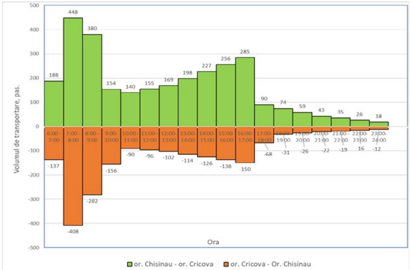
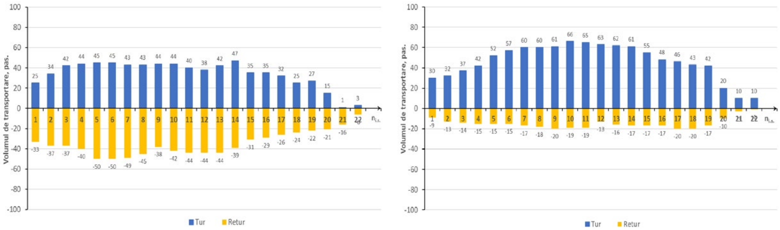


Figure 4.2 Hourly passenger volumes on route 2 Chisinau city – Cricova city



a) *b)*

Figure 4.3 Passenger flow graph on route 2 in the round trip direction during morning and evening peak hours

Figure 4.1 Proposed changes for suburban routes 10, 37, 47, 48 in the "Circul" station area

Following the analysis of the suburban subsystem (chapter 4.2), it is proposed to adjust the traffic schedules for all routes in accordance with the real transport demand, as well as to modify the itineraries of routes 10, 37, 47, 48 by excluding the route segment between the "Circul" stations – V. Alecsandri Street – "Circul". At the same time, for route 47, it is recommended to replace 2 buses with a capacity of 130 passengers, being used primarily during peak hours. These changes will contribute to increasing the efficiency of the network and reducing overlaps with urban routes.

Table 4.2 Technical operating indicators obtained following route changes

Route No.	l_R, km	n_c		A_R, un.	I_{min}, min	t_R, min	V_{com}, km/h	Q_{zi}, pass	γ_d
		tour	retour						
2	32,17	52	52	7	15	93	20,7	5722	0,247
10	19,8	17	17	2	29	57	20,8	1243	0,225
28	31,97	27	27	4	17	101	19,0	5601	0,261
37	21,4	26	26	3	20	59	20,7	3389	0,210
47	30,4	31	32	4	22	86	21,2	5050	0,257
48	36,8	6+2*	6+2*	1	102	102	21,7	1034	0,227

* – during peak hours a bus from route 47 will be used.

Proposals for creating infrastructure for the analyzed suburban public transport system. Creation of a technological field.

It is proposed to arrange a technological land with the end of the route at the "Circul" station, for parking buses both during breaks between trips, at night and on days off.

This technological land is provided for all buses currently operating the routes passing through "Circul" station, (including the 21 buses on the routes examined above). In summary, the land is designed for 50 buses, including articulated ones.

According to technological calculations, based on the reference dimensions of buses and their characteristics [27], and the design standards of automotive enterprises, the total area of the technological land will be approximately 5000 m^2. It is proposed to locate the technological land on Pietrăriei 2 street (figure 4.5).

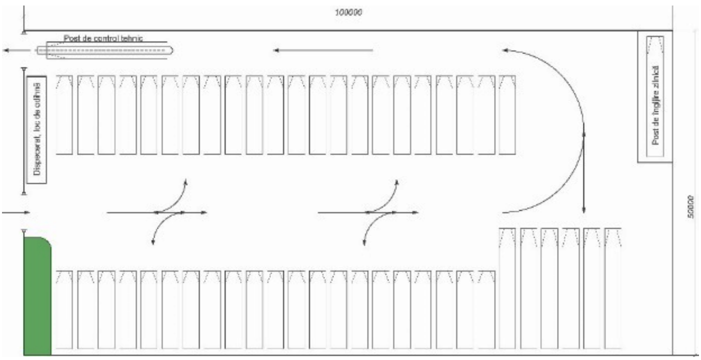


Figure 4.5 Technological land project in the area of the "Circul" station

The creation of a technological land will allow to reduce the null (technological) distance of buses by approximately 6.13 %.

According to the results of the calculations performed in the thesis, optimizing the operation of the analyzed routes will reduce the annual distance traveled by the 21 buses by approximately 165 thousand km. This reduction in distance is directly reflected in a significant reduction in fuel consumption, estimated at approximately 66 tons annually, which indicates an increase in operational efficiency and a decrease in the economic and energy impact of operating the public transport system [28].

The implementation of the technological terrain will lead to annual savings as a result of the reduction in fuel, oil and lubricant consumption, the costs of purchasing tires, as well as the costs of performing technical inspections (TI) and current repairs (CR) of buses, the total value of the savings being estimated at approximately 1.86 million lei annually. At the same time, the creation of this technological terrain, together with the necessary infrastructure, requires initial investments estimated at approximately 6.4 million lei [29].

The creation of such technological lands can bring benefits to both transport operators and passengers [30], while also having positive effects on the environment by reducing gas emissions [31–33], according to the Transport Emissions Protocol (TEP), only direct emissions (Tank-to-Wheel, TTW) of CO2 calculated for buses on the analyzed routes will be reduced by 176.8 tons, NO_x (nitrogen oxides) by 66.0 kg, PM (solid particles) by 1.65 kg, CO (carbon monoxide) by 247.5 kg, HC (hydrocarbons) by 21.5 kg [34–36].

GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. The study of the transport system of the municipality of Chisinau showed that it can be characterized as follows:

- ensures the mobility of residents within 35 localities, including 6 cities and 29 villages with a total population of over 882 thousand inhabitants;
- it has a road network of 900 streets with a total length of 1116.9 km;
- the route network consists of 31 trolleybus routes, 24 bus routes and 22 minibus routes with a total length of 2125.1 km;
- population mobility is ensured by two municipal enterprises (ÎM RTE and ÎM PUA) and eight private transport operators;
- the rolling stock of the public transport system consists of 468 trolleybuses, 215 buses and 202 minibuses;
- the annual passenger transport volume is about 258.2 million passengers.

2. The study of the activity of municipal public transport systems allows us to conclude that increasing the efficiency of their activity requires the joint observance of the following conditions [37]:

- solving transport problems must take into account in a balanced way the interests of all those involved: the inhabitants of the municipality, economic agents, public transport operators and local administrations [37];
- solutions may be acceptable if they meet accessibility, safety, economy and ecology requirements;
- it is necessary to optimize the economic, technical and operational parameters of the transport system.

3. The survey analysis highlights dissatisfaction with: the suburban bus route network (satisfied only 26.9 %); the minibus route network (satisfied only 35.4 %); the provision of information about public transport timetables (satisfied only 49.1 %); public transport stations (satisfied only 52.8 %); the urban bus route network (satisfied only 55.6 %), [38].

The Principal Component Analysis (PCA) statistical method was used to process the survey results, which highlighted the fact that the perception of quality is influenced by an extensive set of factors, largely independent of each other [23].

The survey conducted highlights that most passengers in the municipality of Chisinau emphasize the travel time factor when choosing their mode of mobility.

4. Following passenger flow research, it was found that the public transport system in Chisinau, with a daily transport volume of approximately 667.4 thousand passengers, is facing a challenge specific to large cities: passenger flows on the main transport routes are already reaching the limit of the operational capacity of the current public transport system based on trolleybuses and buses (“Circul” station – 41023, Stefan cel Mare blvd. - 37007 pas., etc.). These transport volumes confirm

the topicality of promoting high-capacity transport and/or revising the road network in the city center.

Therefore, increasing the efficiency of the existing public transport system becomes both a scientific and practical priority, of an urgent nature.

5. As a result of the research, the values of the technical and operational indicators of the means of transport on the routes of the transport system in the municipality of Chisinau were determined, where the following was found:

- a significant variation in the coefficient of non-uniformity of passenger flow on the routes of: trolleybus up to 3.128; bus up to 2.333; minibus up to 2.235;

- the dynamic coefficient of capacity utilization of means of transport, which is one of the main indicators of performance and quality, is for: trolleybuses from 0.068 to 0.391; buses from 0.083 to 0.366; minibuses from 0.155 to 0.782. With recommended average daily values of 0.2 – 0.4, low values indicate low efficiency of operation of means of transport on the route, and high values lead to a decrease in the quality of services.

- the average commercial speed on the routes of: trolleybuses - 15.90 km/h, buses - 19.25 km/h, minibuses - 20.84 km/h. These values are well below the recommended limits and negatively influence the quality of services.

6. Ways have been developed to increase the efficiency of urban public transport system by:

- optimization of four suburban routes that will contribute to reducing urban transport in a sector of the city center with 10 units and 82 daily trips, increasing average commercial speeds from 19.9 km/h to 21.1 km/h, reducing route times on average by 14 min;

- the implementation of a specialized infrastructure unit (technological field) is estimated to reduce the annual mileage of 21 buses on 6 routes by 165 thousand km. This operational optimization is expected to generate an annual saving of approximately 66 tons of fuel, while also reducing operating costs and polluting emissions by 176.8 tons of CO_2 and other harmful gases.

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LIST OF AUTHOR'S PUBLICATIONS ON THE SUBJECT OF THE THESIS

1. Specialized books

1.1 CORPOCEAN, Anatolie; **Igor ROTARU** și Vasile PLĂMĂDEALĂ. *Ecologizarea sistemului om - automobil – mediu*. Manual. Chișinău: Tehnica UTM, 2016. 350 p. ISBN 978-9975-45-445-2. Available: http://repository.utm.md/handle/5014/16557

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ADNOTARE

Rotaru Igor: *„Sporirea eficienței sistemului de transport public din municipiul Chișinău"*, teză de doctor în științe inginerești, Chișinău, 2026.

Structura tezei: introducere, 4 capitole, concluzii și recomandări, bibliografie cu 153 titluri, 3 anexe, textul de bază conține 140 pagini, inclusiv 63 figuri și 27 tabele.

Cuvinte-cheie: calitatea serviciilor, cerere de transport, flux de pasageri, parc tehnologic.

Scopul lucrării: identificarea metodelor inginerești și manageriale, argumentate științific, menite să sporească eficiența sistemului de transport public din mun. Chișinău și să contribuie la creșterea gradului de satisfacție a populației față de serviciile de mobilitate urbană.

Obiectivele cercetării: analiza principiilor și mecanismelor de funcționare a sistemului de transport public din mun. Chișinău pentru identificarea punctelor forte, deficiențelor și factorilor-cheie; dezvoltarea unei metodologii moderne pentru evaluarea calității serviciilor de transport public urban bazată pe satisfacția pasagerilor prin prelucrarea seturilor de date complexe; realizarea studiului fluxurilor de pasageri pe rutele din municipiul Chișinău în vederea determinării indicatorilor de exploatare și elaborării măsurilor fundamentale de eficientizare a sistemului de transport public; elaborarea soluțiilor practice de eficientizare a transportului public prin măsuri tehnico-organizatorice, reducerea costurilor, îmbunătățirea calității și promovarea sustenabilității.

Noutatea și originalitatea științifică: lucrarea aduce o abordare integrată a sistemului de transport public din mun. Chișinău, combinând analiza structural-funcțională, evaluarea percepției utilizatorilor și soluțiile practice pentru eficientizare.

Rezultatele principale: cercetările au evidențiat disfuncționalități ale sistemului de transport public manifestate prin volume de transport necorelate cu indicatorii tehnici și de exploatare, distribuția neuniformă a fluxurilor de pasageri, utilizarea redusă a capacității vehiculelor și vitezei comerciale scăzute pe anumite rute. Totodată, s-a constatat că pe unele segmente de rute volumul de transportare a ajuns la limita capacității sistemului de transport public actual (staţia Circul – 41023 pas., pe bd. Ștefan cel Mare - 37007 pas.). Sondajul pasagerilor a arătat că principalul factor în alegerea transportului public este timpul minim de călătorie (peste 55% dintre respondenți), iar percepția calității serviciilor determinată prin metoda PCA depinde de un ansamblu larg de factori, în mare parte independenți între ei. S-a efectuat optimizarea a patru rute suburbane care va contribui la reducerea transportului urban în centrul orașului cu 10 unități și 82 curse zilnic, mărirea vitezei comerciale până la 21,1 km/h. S-a propus crearea unui parc tehnologic care va permite creșterea eficienței operaționale și micșorarea impactului negativ asupra mediului.

Semnificația teoretică: lucrarea aduce o contribuție importantă la fundamentarea teoretică a studiului transportului public urban prin dezvoltarea unui cadru metodologic integrat ce îmbină indicatorii calitativi, cantitativi și tehnico-economici. A fost elaborată o abordare teoretică pentru evaluarea satisfacției pasagerilor prin integrarea metodei PCA (Principal Component Analysis), care îmbogățește teoria mobilității urbane și subliniază necesitatea alinierii deciziilor tehnico-organizatorice la cerințele reale ale populației. Pentru prima dată în Chișinău a fost fundamentat conceptul reducerii parcursului nul prin crearea unui teren tehnologic, consolidând teoria optimizării proceselor operaționale.

Valoarea aplicativă: furnizarea de date actuale privind fluxurile de pasageri și opinia pasagerilor, demonstrarea necesității modernizării transportului public urban prin vehicule ecologice de capacitate medie și mare corelate cu cererea reală. Implementarea măsurilor propuse, inclusiv crearea terenurilor tehnologice și optimizarea rețelei, conduce la reducerea costurilor și a emisiilor, creșterea eficienței, confortului și atractivității transportului public, contribuind la mobilitatea urbană sustenabilă.

Implementarea rezultatelor științifice: de către DGMU a Consiliului Municipal Chișinău în sistemul de transport public din mun. Chișinău.

ANNOTATION

ROTARU Igor: „*Increasing the efficiency of the public transport system in Chisinau Municipality*" PhD thesis in engineering sciences, Chisinau, 2026.

Thesis structure: consists of introduction, four chapters, conclusions and recommendations, bibliography with 153 titles, 3 annexes, the main text contains 140 pages, including 63 figures and 27 tables.

Keywords: service quality, transport demand, passenger flow, technological park.

Purpose of the work: Identifying scientifically substantiated engineering and managerial methods aimed at increasing the efficiency of the public transport system in the municipality of Chisinau and contributing to increasing the population's satisfaction with mobility services.

Research objectives: analysis of the principles and mechanisms of operation of the public transport system in Chisinau, to identify strengths, weaknesses, and key factors; development of a modern methodology for assessing the quality of urban transport services, based on passenger satisfaction by processing complex data sets; conducting a study of passenger flows on routes in Chisinau, in order to determine operating indicators and develop fundamental measures to make the public transport system more efficient; development of practical solutions to make public transport more efficient, through technical and organizational measures, reducing costs, improving quality, and promoting sustainability.

Scientific novelty and originality: The paper brings an integrated approach to the public transport system in the municipality of Chisinau, combining structural-functional analysis, user perception assessment and practical solutions for efficiency.

Main results: The research highlighted dysfunctions of the public transport system, manifested by transport volumes not correlated with technical and operational indicators, uneven distribution of passenger flows, low vehicle capacity utilization and low commercial speeds on certain routes. At the same time, it was found that on some route segments the transport volume has reached the capacity limit of the current public transport system (station Circul – 41023 pas., blvd. Stefan cel Mare – 37007 pas.). The passenger survey showed that the main factor in choosing public transport is the minimum travel time (over 55% of respondents), and the perception of service quality determined by the PCA method depends on a wide range of factors, largely independent of each other. Optimization of four suburban routes was carried out, which will contribute to reducing urban transport in the city center by 10 units and 82 daily trips, increasing commercial speeds up to 21.1 km/h. It was proposed to create a technological park that allows for increasing operational efficiency and reducing the negative impact on the environment.

Theoretical significance: the paper makes an important contribution to the theoretical foundation of the study of urban public transport, by developing an integrated methodological framework that combines qualitative, quantitative and technical-economic indicators. A theoretical approach was developed for assessing passenger satisfaction, by integrating the PCA (Principal Component Analysis) method, which enriches the theory of urban mobility and emphasizes the need to align technical-organizational decisions with the real requirements of the population. For the first time in Chisinau, the concept of reducing the null path by creating a technological terrain was substantiated, consolidating the theory of optimizing operational processes.

Applicative value: by providing current data on passenger flows and passenger opinion, demonstrating the need to modernize urban public transport through medium and large capacity environmentally friendly vehicles, correlated with real demand. The implementation of the proposed measures, including the creation of technological lands and network optimization, leads to cost and emission reductions, increased efficiency, comfort and attractiveness of public transport, contributing to sustainable urban mobility.

The implementation of the scientific results was carried out by the GDUM of the Chisinau Municipal Council in the public transport system of the municipality of Chisinau.

ROTARU IGOR

INCREASING THE EFFICIENCY OF THE PUBLIC TRANSPORT SYSTEM IN CHISINAU MUNICIPALITY

271.01. ENGINEERING AND PRODUCTION MANAGEMENT
(on branches of industrial production)

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