

## EVALUATION OF URBAN PASSENGER TRANSPORTATION OPERATIONAL EFFICIENCY IN TERMS OF SOCIO-TECHNICAL APPROACH

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Passenger transportation plays a key role in ensuring the vital activity of the present cities. The development of this mode of transportation determines the development of urban areas, the accessibility of institutions of production, educational and cultural and everyday life for the population. Urban transport has a systemic effect both on passengers being a staff of organizations in the material and non-material production, and on the overall efficiency of these enterprises. It is suggested to consider the urban passenger transportation as a socio-technical system, where the social results are the efficiency indices.

**Keywords:** sociotechnical approach, passenger, effect, psycho-emotional state.

**Problem statement.** Urban passenger transportation (UPT) is the most important branch of the urban economy. In the providing the vital processes and production, its importance is determined by the scale of the passenger transportation and significant impact on the efficiency of the urban economic system and social service. UPT is the part of social infrastructure related to the reproduction of labor and population activities along with health, education, retail trade, housing and communal services. UPT has a significant impact on the economic and social development of administrative and territorial units, and is able to act as a means of accelerating or slowing the development of cities, to provide or, conversely, to prevent the production of services, recreation and leisure of the population.

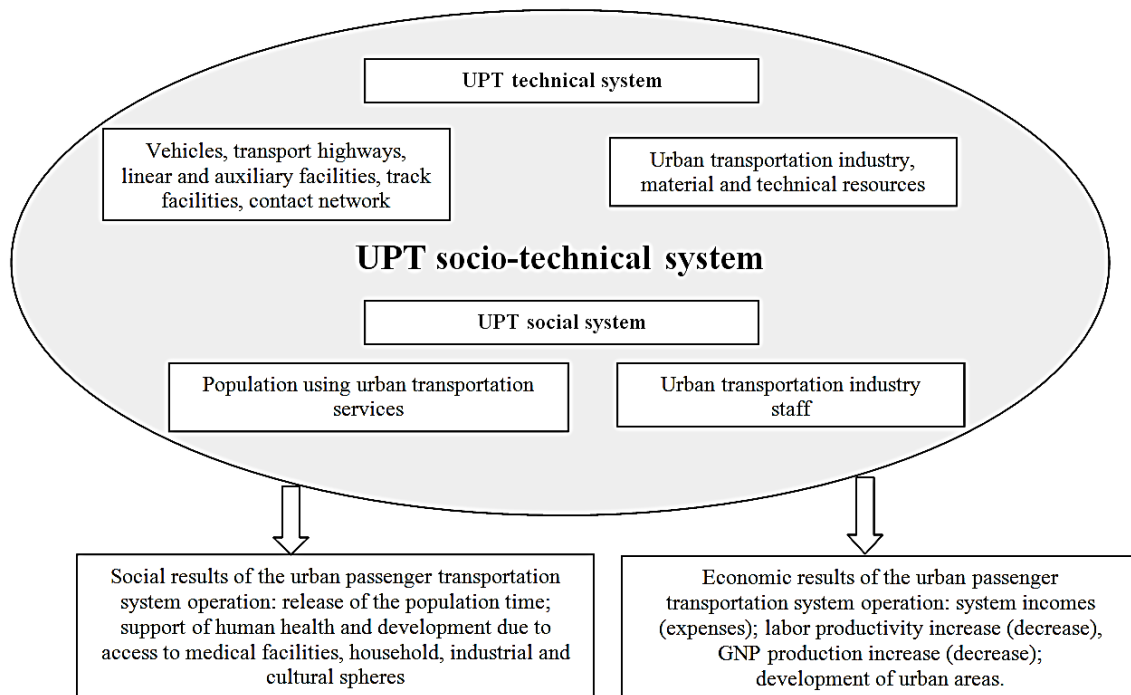
In the current issues [1, 2] the sociotechnical approach has been widely developed, in which any enterprise is considered as a socio-technical system, i.e. a set of staff, various mechanisms and the production environment. According to this concept [3], the main goal of the socio-technical system operation is to find the best balance between the

technologies used, the human resources and the organization needs, create an employee management system, and increase the productivity, product quality and profit. In this case, a human is considered as the main element of this system.

Taking into account the definition of socio-technical systems and the main goal of the socio-technical approach we believe that the UPT can also be represented as a socio-technical system shown in Figure 1. The result of the functioning of this system is social and economic consequences both for the population, enterprises and organizations, and the country as a whole.

Accordingly, the existing methods of management and evaluation of the functioning of such systems use an «income», «expenditure», «labor productivity, «motivation for work» etc. as criteria. Meanwhile, it is known that the urban transportation has systemic or «non-transport» effect on the personnel and the general efficiency of enterprises, where this personnel is the main productive force.

Thus, this assessment considers only partial effects of the functioning of urban transportation



**Fig. 1. Urban passenger transportation socio-technical system**

Source: developed by the authors

leaving out the social results. Consequently, the criteria for evaluating the transportation performance should include not only the above-stated ones, but more complex indicators that bring its systemic, and often hidden, impact on passengers as workers of various sectors.

#### Analysis of recent research and publications.

Currently, the study of the of urban transport effect on a human as the main element of this socio-technical system is conducted in two ways. The first way is described by an assessment of the impact on persons directly involved in providing the transportation process (for instance, passenger transport drivers and dispatch operators). The second way explores the impact of the transport functioning on society as a whole and, in particular, the transportation parameters – on the passengers. We believe this direction more important due to socio-economic significance and insufficient knowledge of the consequences mentioned earlier.

General approaches to the assessment of economic and social effects due to the functioning of passenger transport and its elements, and their impact on humans in current conditions are given in papers [7, 8], assessment of passenger fatigue due to the UPT use and its impact on the human productivity in the industrial sector – in the works [9-11], the effect of transport fatigue on the passenger's route choice – in the works [12, 13], the influence of the vehicle waiting time on the passenger's psychological state – in the studies [14, 15], the time cost estimation taking into account the passengers' opinion on the time value – in the studies [16-18], as well as the national income – in the paper [19].

**Unsolved aspects of the problem.** Taking into account a certain investigation of the above-mentioned problematic issues that, in our opinion, can be taken to the socio-technical aspect of the UPT functioning, special attention should also be paid to the influence of the transportation process on the passenger's psycho-emotional state as a trip result. From the above analysis of scientific sources we believe this issue did not find some suffi-

cient reflection. Meanwhile, the study of functional states of a human as an employee in the material or non-material production is one of the central problems for labor sciences [20].

In [21] it is also presented that the psycho-emotional state is a special form of mental states with the predominance of an emotional response that affects the human future activity. Emotional manifestations in responding to the reality are necessary for the individual, since they regulate his health and functional state. Deficiency as well as an excess of emotions reduces the activity of the central nervous system and can cause, first of all, a decrease in working capacity at the labor application.

Thus, the optimal emotional state of a human due to trip using the UPT is a condition for further work activity and its favorable implementation. If the fatigue can be objectively determined only with the help of special equipment, then the psycho-emotional state, which in the above studies was not distinguished at all, appears immediately after the individual or their group stayed in uncomfortable conditions (for example, in time of a trip) and can be a reason for reducing its efficiency, conflicts and general business climate deterioration in the team.

It is established [22] that violations of the human psycho-emotional state as an employee can increase the so-called «work adaptation period», i.e. gradual growth in working capacity depending on the functional status, age, work activity and other factors from 30 to 60 minutes. So, this result confirms the importance of studying the consequences from the UPT socio-technical system operation.

**Purpose of the article.** The purpose of the article is to determine the transportation process impact on the psycho-emotional state of passengers as one of the social results within the implementation of the socio-technical approach to the UPT operation.

**Main study statement.** The practical part of the study consisted of the forming, ascertaining and analytical stages. At the forming stage, an analysis of the methods to obtain the information necessary for the research tasks was made.

The ascertaining stage consisted of the initial processing of the survey results. The analytical stage included obtaining the dependencies to describe the psycho-emotional state of the passenger after the trip, drawing conclusions on the applicability of the approach proposed and determining the course of further research.

To assess the human psycho-emotional state, some instrumental and standardized test methods are used [23]. Advantage of the instrumental methods consists in the fact that they completely exclude the influence of the subjective opinion of the person being investigated and ensure the reliable data. The disadvantage is the need to use expensive equipment and to have a researcher's special education when obtaining and then correctly interpreting the data.

Дата проведення обстеження \_\_\_\_\_

Вид міського транспорту	Номер маршруту (назва лінії метрополітену)	Час очікування транспортного засобу, хв.	Час перебування в салоні транспортного засобу <i>i</i> -го виду транспорту, хв.	Ступінь наповнення під час поїздки, бал*, (1, 2, 3...)
Тролейбус				
Трамвай				
Метрополітен				
Автобус				

\*1 – в салоні є вільні місця для сидіння; 2 – все місця для сидіння зайняті; 3 – все місця для сидіння зайняті, але пасажир вільно стоять в салоні; 4 – місткість транспортного засобу використана повністю; 5 – транспортний засіб переповнений, частина пасажирів залишилася на зупинці.

1	самопочуття добре	3	2	1	0	1	2	3	самопочуття незадовільне
2	поганий настрій	3	2	1	0	1	2	3	добрий настрій
3	розсіяний	3	2	1	0	1	2	3	уважний

Fig. 2. Questionnaire part to determine the passenger's psycho-emotional state

Source: developed by the authors and [24]

Standardized test methods in the form of special tables allow a quickly determining a human's psycho-emotional state, are easy to use, however, they also generate a significant degree of subjectivity of the data obtained due to incorrect partial state differentiation that create a common psycho-emotional background.

Resulting from the review of standardized test methods, a technique on the basis of factor analysis using a modified stimulus material [24] was chosen. The person is presented with a list of 20 opposite states that must be assessed by a rating scale. The technique is designed to make decisions on a person's readiness to make an activity (first of all, working one) and the level of its effectiveness for people over 18 years without restrictions on educational, social, professional and other criteria. Thus, students, teachers at the KhNADU faculty of transportation systems, public officials and workers of manufacturing enterprises using the UPT for daily trips to the workplaces or study took part in the survey. The procedure was supplemented by entering into the questionnaire the trip parameters, which are relatively easy to measure and express to the passenger himself. Thus, for 5 working days each passenger had to register the parameters of the trip and assess the partial states after the trip, listed below.

The first column of the lower questionnaire table contains the number of the state, then – the rating scale and the number of points given for each answer. When moving «from right to left,» each state is put a score from 1 to 7. Taking into account the «in-between states», the test subject can score from 20 to 140 points. As a pilot survey result in the form of a random non-representative sample, 115 questionnaires were received, 112 of which were filled in accordance with the requirements. The questionnaire fragment is shown in Figure 2.

From the analysis of the special issues [25, 26], the results of the questionnaire survey and the answers of respondents as employees of material and non-material production, we adopted the following differentiation of the levels of the passenger's psycho-emotional state due to the UPT use: low (20-60 points), average (61-100 points) and high (101-140 points) levels, which, in our opinion, provides an easy interpretation and visibility of the results. The content characteristic of the psycho-emotional state levels is given below.

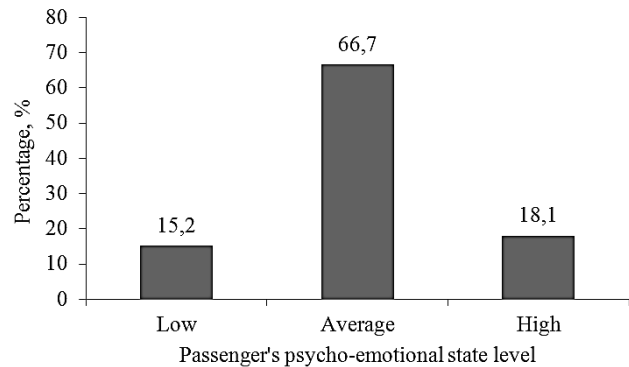
Low psycho-emotional level is characterized by passivity, involuntary participation in professional activities, often accompanied by an appearance of an external negative reaction to the actions that need to be performed; indifference to the activity quality; absence and unwillingness to gain experience in effectively solving practical problems.

The average psycho-emotional level is described by the following states: incomplete awareness of the relationship between theoretical knowledge and practical application; separate fragments of knowledge are allocated for solving the problems of professional activity; situational demonstration of initiative in the implementation of activities; partial indifference to the quality of activity or the labor result; situational effectiveness in practical activities.

At the high psycho-emotional level the active and conscious participation in labor activity is observed; intention for an effective tasks solution based on internal positive motivation; desire to finish the job at the best; effective solution of professional tasks in real-life conditions; accumulation of the real labor activity experience owing to professional functions.

Analysis of the data obtained during the ascertaining stage of the study is shown in Figures 3 and 4.

Figure 3 shows the distribution of passenger's states according to the survey results.



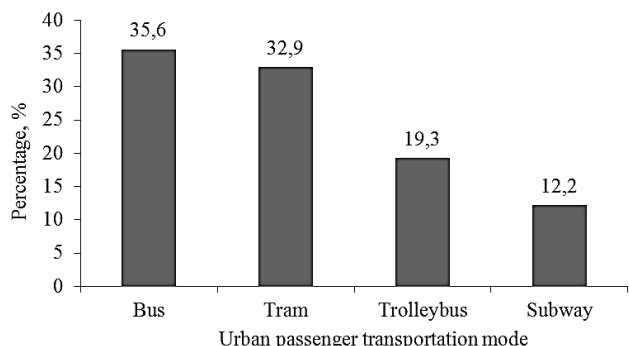
**Fig. 3. Influence of trip conditions in the UPT various modes on the passenger's psycho-emotional state**

Source: developed by the authors

Thus, under the results of the initial statistical material, it can be concluded that as a result of trips using Kharkiv mass transit, the majority of passengers have an average level of psycho-emotional state, the characteristics of which were given above. Mainly, these are passengers who spend from 20 to 30 minutes traveling in conditions of full passenger capacity rate.

Passengers of the low psycho-emotional level spend about 40 minutes traveling in an overcrowded vehicle, while the high level of psycho-emotional state is observed among passengers traveling up to 20 minutes with a low passenger capacity rate.

The impact degree of travel conditions in various types of Kharkiv mass transit on the passenger's psycho-emotional state is shown in Figure 4.



**Fig. 4. Travel conditions impact on the passenger's psycho-emotional state**

Source: developed by the authors

The most negative effect on the passenger's psycho-emotional state produces the use of bus and tram transportation, which is explained by

Table 1

## Correlation ratio of the psycho-emotional state and the trip parameters

Resultant parameter	Trip parameter		
	Vehicle waiting time, minutes, $X_1$	Time of stay in the $i$ -th transportation mode, minutes, $X_2$	Capacity rate within the trip, point, $X_3$
Passenger's psycho-emotional state, point, $Y$	-0,58	-0,66	-0,61

Source: developed by the authors

high rolling stock deterioration, traffic interval violation and, as a consequence, unbalanced capacity rate and low ergonomic trip.

The least negative impact on the passengers is rendered by the subway that is due to precise traffic schedule, the trip guarantee and the most favorable environment in which this trip is done (no exposure to temperatures, precipitation, etc.).

From the results of the ascertaining stage of the practical research, at the analytical stage the hypothesis about some dependence of the passenger's psycho-emotional state on the parameters of the trip was put forward, which resulted in a step-by-step correlation analysis of the psycho-emotional state scores and these parameters. This procedure allows substantiating the correlation ratio between the status and characteristics of the trip. The results of the analysis are shown in Table 1.

As can be seen from Table 1, the results of the analysis confirm the hypothesis on the influence of the parameters and demonstrate their sufficient correlation [27] with the passenger's functional state, i.e. an increase in the duration of a trip parameter effect leads to a deterioration in the passenger's state.

The next task of the analytical stage was to describe the relationship between the passenger functional state and the trip parameters. Taking into account the impact of many factors on the resulting value and the absence of known analytical dependences, regression analysis was chosen for this purpose [28].

From the practice of regression analysis it is known that the selection of the model most adequately presenting the process under investigation is made using a variety of linear and nonlinear dependences [29]. However, it should be noted that in current studies on psychophysiology, experimental psychology, labor physiology to describe such human conditions as a fatigue, irritation, etc. the logarithmic Weber-Fechner and the Stevens power law [25, 26] can be used.

Thus, in order to choose the most appropriate model that would describe the influence of the trip parameters on the psycho-emotional state using statistical material we investigated both dependencies.

After reducing the recommended dependencies to the linear form for regression analysis in the Microsoft Office Excel [29, 30] and performing inverse transformations, logarithmic and power-law models were obtained as follows

$$Y = 229,143 - 14,378 \cdot \ln X_1 - 41,607 \cdot \ln X_2 - 16,133 \cdot \ln \tilde{O}_3, \quad (1)$$

$$Y = 878,31 \cdot X_1^{-0,206} \cdot X_2^{-0,581} \cdot \tilde{O}_3^{-0,219}, \quad (2)$$

where  $Y$  – psycho-emotional state parameter, points;

$X_1$  – vehicle waiting time, minutes;

$X_2$  – time of stay in the  $i$ -th transportation mode, minutes;

$X_3$  – average capacity rate within the trip, points.

The regression model statistics is given in Table 2.

Table 2

## Regression model statistics

Parameter	Regression dependence	
	Logarithmic	Power-law
Multiple regression coefficient, $R$	0,77	0,878
Determination coefficient, $R^2$	0,59	0,771
Factor importance:		
- $X_0$ ;	0,461	0,024
- $X_1$ ;	0,771	0,036
- $X_2$ ;	0,671	0,006
- $X_3$ .	0,659	0,006
$F$ -test value:		
- calculated;	0,271	6,25
- tabulated.	215,7	2,28
Average approximation error, $A$ , %	30,12	8,75

Source: developed by the authors

As can be seen from Table 2, the logarithmic model is unsuitable for describing a passenger's state, while the power-law dependence demonstrates the acceptable basic statistical characteristics – multiple regression coefficient, determination coefficient, importance of factors, information capacity and adequacy. The adopted power-law model is valid under the following constraints (actual parameters of the transportation process)

$$\begin{cases} 1 \leq X_1 \leq 17; \\ 11 \leq X_2 \leq 40; \\ 1 \leq X_3 \leq 5. \end{cases} \quad (3)$$

Thus, resulting from the model statistics we believe that the above dependence can be used to forecast a psycho-emotional state after the trip with the UPT usage.

**Conclusions and recommendations.** In the context of the socio-technical approach, the UPT evaluation should be made using indicators that take into account its systemic impact on passengers as workers. One of such «social» indicators along with transport fatigue, waiting time, etc. can be the value of the psycho-emotional state of the passenger that plays a significant role in the successful labor activity at the main workplace and is of the close correlation with the transportation process quality through the trip parameters.

The research results can be used as a component of the social effect when planning or improving the quality of public transport services and developing the passenger transportation systems in the modern cities.

The next stage of the study is to increase the number of observations for improving the pro-

posed model characteristics and to find the value of societal costs due to the unsatisfactory functional state of passengers for expressing the social effect in monetary terms.

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## **ОЦІНКА ЕФЕКТИВНОСТІ ФУНКЦІОНУВАННЯ МІСЬКОГО ПАСАЖИРСЬКОГО ТРАНСПОРТУ НА ОСНОВІ СОЦІОТЕХНІЧНОГО ПІДХОДУ**

### **Анотація**

Пасажи́рський транспорт відіграє ключову роль в забезпеченні життєдіяльності сучасних міст. Ступінь розвитку цього виду транспорту визначає розвиток міських територій, доступність установ виробничої, освітньої та культурно-побутової сфери для населення. Міський транспорт завдає системного ефекту як на пасажирів, які є персоналом організацій сфер матеріального і нематеріального виробництва, так і на загальну ефективність роботи цих підприємств. Запропоновано розглядати міський пасажирський транспорт як систему, показниками ефективності функціонування якої можуть служити соціальні результати.

**Ключові слова:** соціотехнічний підхід, пасажир, ефект, психоемоційний стан.

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## **ОЦЕНКА ЭФФЕКТИВНОСТИ ФУНКЦИОНИРОВАНИЯ ГОРОДСКОГО ПАСАЖИРСКОГО ТРАНСПОРТА НА ОСНОВЕ СОЦИОТЕХНИЧЕСКОГО ПОДХОДА**

### **Аннотация**

Пассажи́рский транспорт играет ключевую роль в обеспечении жизнедеятельности современных городов. Степень развития этого вида транспорта определяет развитие городских территорий, доступность учреждений производственной, образовательной и культурно-бытовой сферы для населения. Городской транспорт оказывает системный эффект как на пассажиров, являющихся персоналом организаций сфер материального и нематериального производства, так и на общую эффективность работы этих предприятий. Предложено рассматривать городской пассажирский транспорт как социотехническую систему, показателями эффективности функционирования которой могут служить социальные результаты.

**Ключевые слова:** социотехнический подход, пассажир, эффект, психоэмоциональное состояние.