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USING SUSTAINABLE DEVELOPMENT PRINCIPLES TO ASSESS THE EFFICIENCY OF TRANSPORT INTERCHANGES FUNCTIONING

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Abstract. *The expediency of using the sustainable development principles for assessing the efficiency of public transport interchange functioning is shown. The passenger waiting time, the probable number of accidents in the area of transport interchanges, the queuing delay, and the amount of total emissions as CO_2 equivalent were chosen as indicators that the efficiency criterion includes.*

Key words: *public transport interchange, efficiency criterion, sustainability, indicators, costs.*

ИСПОЛЬЗОВАНИЕ ПРИНЦИПОВ УСТОЙЧИВОГО РАЗВИТИЯ ДЛЯ ОЦЕНКИ ЭФФЕКТИВНОСТИ ФУНКЦИОНИРОВАНИЯ ТРАНСПОРТНО-ПЕРЕСАДОЧНЫХ УЗЛОВ

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Аннотация. *Рассмотрена проблематика выбора критерия эффективности функционирования ТПВ с позиции устойчивого развития. Представлена структура компонентов критерия эффективности, состоящая из индикаторов. Значение каждого индикатора приведено к единым единицам измерения.*

Ключевые слова: *транспортно-пересадочный узел, критерий эффективности, устойчивость, индикаторы, расходы.*

ВИКОРИСТАННЯ ПРИНЦИПІВ СТАЛОГО РОЗВИТКУ ДЛЯ ОЦІНКИ ЕФЕКТИВНОСТІ ФУНКЦІОНУВАННЯ ТРАНСПОРТНО-ПЕРЕСАДОЧНИХ ВУЗЛІВ

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Анотація. *Розглянуто проблематику вибору критерію ефективності функціонування ТПВ з позиції сталого розвитку. Подано структуру компонентів критерію ефективності, що складається з індикаторів. Значення кожного індикатора приведено до єдиних одиниць вимірювання.*

Ключові слова: *транспортно-пересадочний вузол, критерій ефективності, сталість, індикатори, витрати.*

Introduction

The urban public transport system is an essential part of life support of modern cities that causes the economic, social and environmental situation in them. The psychophysiological state of the population, which affects its business activity and labor productivity, as a consequence, social progress, depends on the quality of transport services. Therefore, the problem of efficiency improvement of public transport functioning is rather urgent for all without exception city administrations. The choice and formalization of the efficiency criterion is one of the main problems when modeling any object, it can vary depending on the specific scientific problem to be solved.

Today, the majority of existing criteria do not allow full assessing the current state of passenger transportation, the level of achieved efficiency and identifying the necessary measures to ensure sustainable mobility. Public transport interchanges may become a central element in the development of more sustainable passenger transportation: the development of integrated passenger transport systems on their basis allows increasing public transport attractiveness and, as a result, reducing the automobile dependence. Thus, the choice of the criterion for evaluating the transport interchanges efficiency in the perspective of sustainable development is a problem of vital importance.

Analysis of publications

The problem of passenger transportation efficiency is reflected in dissertations of Ukrainian scientists V.O. Vdovychenko [1], O.D. Gulchak [2], O.I. Lezhneva [3], P.V. Lubyanov [4], Miroshnik O.I. [5] and others. Each of abovementioned authors has formed the original performance criterion. The efficiency of passenger transport systems depends on the proper functioning of its components, for example public transport interchanges. Scientific papers [6, 7] deal with the transport interchanges efficiency investigation, in publications [7, 8] their functioning is considered in terms of the quality of service. Moreover, authors evaluate the transfer process at transport interchanges and the quality of synchronization [9–12].

Modern approaches and the theoretical and methodological base related to the transport interchanges efficiency evaluation are being formed and need scientific substantiation of the efficiency criterion in accordance with modern requirements.

The aim and research tasks

The aim of the research is to identify the possibility of using the sustainable development principles for the formation of the efficiency criteria of transport interchanges functioning. The object of the research is public transport interchanges functioning, and the subject is criteria and approaches for efficiency assessment in the area of public transportation. To achieve the research aim, a review of modern scientific papers was conducted.

Forming the efficiency criterion of transport interchanges from the sustainable development perspective

The complexity of choosing the efficiency criterion consists in the fact that interests of passenger transportation market participants (municipalities, public transport operators, and passengers) do not coincide and they are often antagonistic. Each market participant evaluates the efficiency on the basis of his own goals and objectives, therefore when assessing the efficiency in the area of public transport it is typical that there are criteria that are in contradiction. For example, the minimum transport operators' costs needed for the transportation process implementation and the minimum passengers' travel time. Municipalities assess the performance of urban public transport, taking into account the development strategies adopted by the government, and transport policies and requirements concerning transport services specified in them.

At the present stage, the priority is given to monitoring the impact of urban transport on the environment and the quality of life of the population. To systematize the potential efficiency criteria in the field of passenger transportation it is proposed to classify them as shown in Fig. 1.

It is possible to distinguish two groups of approaches to assess the efficiency in accordance with the number of optimization criteria, namely single-criterion approaches and multi-criteria approaches.

In a single-criterion approach for assessing the efficiency, the following parameters are common in papers: System Costs, Profitability of Companies, Time Spent per Trip, Regularity of Bus Services, Operating Speed, Transport Fatigue, etc. In a multi-criteria approach for efficiency assessing they use a number of indicators that can be quantitative and qualitative, general and specific, monetary and natural, etc.

In addition, there are various methods of evaluating the efficiency that are adapted to the transport sector analysis. Data Envelopment Analysis (DEA) deserves special attention.

In paper [13] the efficiency of European and Brazilian transport systems was measured using DEA. The authors consider urban transport systems as decision making units (DMUs). The total operational cost, the total number of equiva-

lent vehicles and the number of employees has been chosen as inputs, representing three main blocks: labour, capital and operational costs, including gas and other expenses. The total numbers of passengers transported has been chosen as the output.

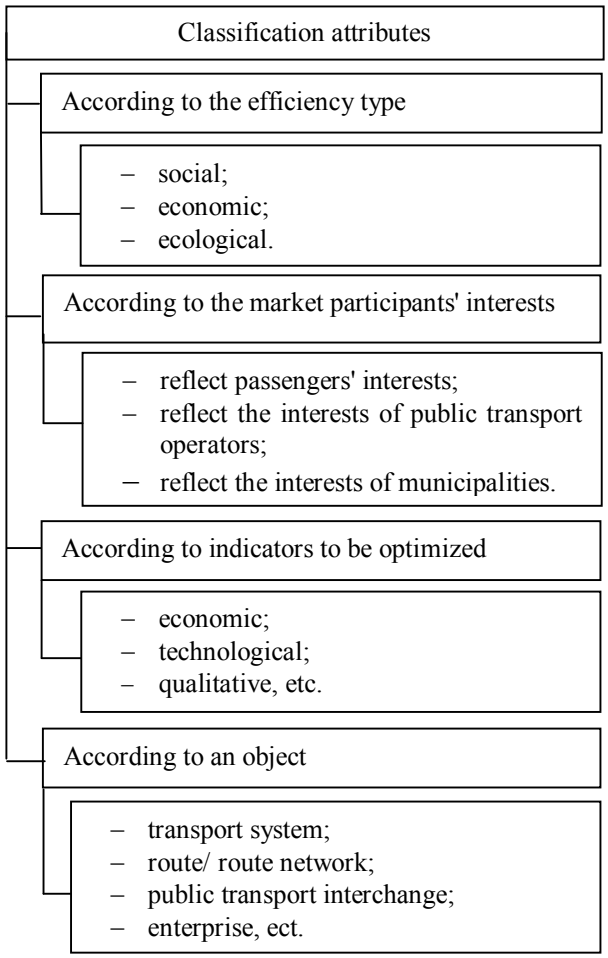

Fig. 1. Classification of possible efficiency criteria of passenger transportation

Scientific publications contain examples of DEA method application for assessing the efficiency of public transport interchanges.

The transfer efficiency of 10 transportation terminals has been determined by a Data Envelopment Analysis in study [9]. The following variables have been defined as inputs: the transfer area, the operating expense, the number of employees in the terminal, capacity of buses; the transfer safety and the average transfer time of all the transfer passengers are outputs. In papers, where the method DEA is used, indicators that reveal the impact of transport, transport interchanges, functioning on the environment have not been revealed.

A different vision on the efficiency criteria of transport interchanges functioning among scientists is demonstrated in specialized publications.

In paper [10] scientists have chosen the average transfer time, transfer comfort degree, safety, the degree of information services and other indicators and formed a group of five factors affecting the transfer efficiency. Evaluation of the transfer efficiency in urban transport interchanges is conducted, using the vector cosine law. The proposed set of indicators does not contain variables that characterize the resource costs for transfer organization at transport interchanges.

I. Huznenkov suggests using the efficiency criterion when choosing rational variants for location of transport interchanges, being the ratio of the number of public transport interchange users per time period to investments in their development.

$$\frac{Q}{I} \to \max \qquad (1)$$

where Q – the number of passengers using a transport interchange per a period of time, ppl/period; I – investment in the development of a transport interchange, UAH.

In the article it is explained that despite the absence of quality indicators in an explicit form they are considered in the model that will provide not only the commercial but also social effect, so the objectives of investor and the improvement of transport service quality will be ensured [6]. This criterion reflects the economic and social efficiency but does not assess the impact on the environment.

The author of the thesis research [7] has developed guidelines to assess the efficiency of transport interchanges and it is stressed that efficiency is to be evaluated by a group of indicators, which should take into account the interests of both the passengers and visitors, companies engaged in transportation and maintenance, and cities (suburbs) where a transport interchange is placed. The efficiency of public transport interchanges is measured, using the indicators of the public service quality provided. In the mentioned research, criteria and indicators of service quality of transport interchanges have been formed. However, they do not take into account the quality of transport modes interaction that affect the passenger waiting time being the main

indicator of the service quality from the passenger's point of view.

The quality of service for passengers at bus stations is studied in [8]. The quality is determined from the perspective of a company (the actual data) and users (survey data), services and executive processes are evaluated separately. In the proposed methodological approach summary indicators are defined, using different levels of generalization; the weight of service quality indicators is taken into account. The chosen indicators relate only to the design of transport interchange and services, and do not characterize the quality of transport services.

Although modern transport interchanges are multi-purpose centers, they perform a variety of functions and provide different services; the main task of public transport interchanges is to redistribute passenger flows and create conditions for the integration of public transport modes. So, the transport service is a major component, and the degree of synchronization is crucial when assessing the overall efficiency of any transport interchange.

Scientists raise the problem of the synchronization quality in the publication [14], in which the synchronization quality index is introduced for each possible transfer. A weight factor assessing the relative importance and values for the minimum, ideal, and maximum waiting times are given. The closer actual waiting time of a trip meet to its specified ideal waiting time the higher quality index is. A global SQI is obtained by summing the quality indexes.

In paper [11] scientists distinguish two main approaches to measure the schedule coordination quality, namely the passenger waiting time and the Synchronisation Quality Index (SQI). A Synchronisation Quality Ratio, which is calculated as the proportion of actual SQI in relation to the potential maximum, is proposed.

In publication [12] it is presented an optimization-based method to improve the transfer quality by approximation the passenger waiting time to «convenient» one while making minimal changes to the existing schedule.

The authors of publication [15] believe that their main contributions are a model to evaluate the transfer quality and an interactive optimization approach. In paper five classes of the waiting time are determined; weights representing the importance of the transfer are proposed to be calculated using an ABC-ranking system. The scientists have identified the overall solution quality as one of three main optimization goals for the timetable synchronization problem.

Based on the analysis of scientific papers on the efficiency of passenger transportation it is rightly to say that most authors confirm the correctness of the rejection of a one-sided approach to evaluating the efficiency only through economic indicators, the main of which is profitability. Firstly, it is impossible to confine oneself to some economic indicators due to the social importance of passenger transport. Secondly, in the present conditions it is important to take into account the environmental impact of the transportation systems elements functioning. Thirdly, some indicators are able to describe only certain aspects of the public transport interchanges functioning; using them it is impossible to provide an objective assessment.

In addition, when justifying the efficiency criterion of transport interchanges from the perspective of sustainable development it is necessary to study the existing experience in sustainability assessment of passenger transport systems. Since no single indicator can adequately describe such a complex term as sustainability of transport system and transportation, sets of indicators are used.

Scientists have developed several frameworks for their grouping. The following classification of such frameworks is proposed in thesis [16]:

– linkages-based frameworks;
– impacts-based frameworks (three-dimensional frameworks fall under this category);
– influence-oriented frameworks.

The most famous and common example of linkage-based frameworks is DPSIR, the name is the abbreviation of Driving force–Pressure–State–Impact–Response.

This framework was adopted by the European Environment Agency for representing the interactions between the society and the environment, (modification of the PSR model developed by OECD) [17]. Using this framework, experts try to describe the following linkages: human activities (transportation) put pressure on the environment (pollutant emissions) that leads

to changes in the environment and has an impact on the human health; appropriate responses for addressing them are identified.

Most often indicators are divided into three dimensions: economic, social and ecological [18]. The decomposition of this framework can be represented as follows: three dimensions contain categories, which consist of indicators. In some cases researchers expand this structure, adding institutional and other to the base ones. Researchers propose to use the institutional component to assess the state's activity in the promotion of sustainable transport systems development.

To ensure the sustainability of transport interchanges is defined as the main objective when increasing the efficiency of their functioning. At present in transport interchanges there exist the following economic, environmental and social problems the solution of which will achieve sustainability their functioning:
– the lack of synchronization causes additional passenger waiting time;
– due to the uncoordinated arrival of vehicles at stops occur their congestion;
– queuing delays nearby stops provoke the emission of pollutants.

The basis of the sustainable development principles is ensuring such variant of any system functioning that minimizes the negative impact on all components of the external environment.
Thus, the efficiency criterion of public transport functioning should be complex and take into account all possible economic, environmental and social costs and benefits.

Categories and indicators for each dimension to assess the public transport interchanges efficiency from the sustainable development perspective are presented in table 1.

Table 1 Components of the efficiency criterion from the sustainable development perspective

Dimension	Category	Indicator
Social	Time spent waiting on vehicle	Passenger waiting time
	Safety	The probable number of accidents in the area of a transport interchange
Economical	Transport expenses	Queuing delay before entering the stop
Ecological	Environmental pollution	Amount of total emission as CO_2 equivalent

The waiting time at transport interchanges being one of the most important indicators of transport services from the perspective of passengers and depending on the quality of schedule synchronization in transport interchanges is a component that allows displaying a criterion of social efficiency of transport interchanges.

The queuing delay before entering the stop has been chosen as an indicator for assessing the impact on the economic component. The amount of total emission as CO_2 equivalent has been chosen as an indicator for assessing the impact on the ecological environment. Since the measurement units of chosen indicators are different in order to calculate the integrated efficiency criterion we express their values in monetary terms:

$$S = t_w \cdot \mathrm{C}_{pass-hr} + n \cdot C_A; \quad (2)$$

$$E = t_d \cdot C_o; \quad (3)$$

$$ECO = Q_{\mathrm{CO}_2} \cdot C_{\mathrm{CO}_2}, \quad (4)$$

where E, S, ECO – accordingly valuation of the negative influence of economic, social and environmental components, UAH; t_w – passenger waiting time at transport interchanges, hr; $C_{pass-hr}$ – passenger time value, UAH/hr; n – the probable number of accidents in the area of a transport interchange; C_A – cost of an accident, UAH; t_d – queuing delay before entering the stop, hr; C_o – operating cost per vehicle hour, UAH/hr; Q_{CO_2} – amount of total emissions as CO_2 equivalent, that are emitted by vehicles staying in the queue, g; C_{CO_2} – carbon tax, UAH/g.

Thus, the efficiency criterion involves minimizing the economic, environmental and social costs:

$$EFF = E + S + ECO \rightarrow \min, \quad (5)$$

where EFF – valuation of the negative influence of public transport interchanges functioning, UAH.

Conclusions

An overview of the specialized scientific literature on methods and approaches to evaluate the efficiency of the transport sector allowed to systematize the possible efficiency criteria according to the proposed classification attributes. A special attention is given to works that have investigated the efficiency of public transport interchanges, the transfer efficiency and service quality of interchanges. It has been revealed that the chosen by scientists criteria mainly reflect the efficiency of the internal design of transport interchanges and services provided, but they do not evaluate transport services and the impact of transport interchanges functioning on the environment. Scientific resources contain examples of publications to assess the quality of the synchronization schedule, where the main criterion is the passengers waiting time, which is an important component of the integrated transport interchanges efficiency criterion.

According to the international tendencies, it has been determined that the sustainable development principles can be applied in assessing the transport interchanges functioning, by taking into account economic, environmental and social components of the efficiency criteria.

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