Capital investments in the context of sustainable development of railways

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Abstract. Ukraine, due to its geographical position and developed transport infrastructure, has significant potential as a transit country, primarily in the supply chain of trade between Asia and Europe. According to the estimates of the British Institute for Transport Rendell Ukraine, the transit coefficient of Ukraine is 3,75 (with a maximum of 5); This is the best indicator among the countries of Europe (for comparison, in Poland, which occupies the second place, this indicator is 2,92).
Nowadays, Ukraine uses its transit potential extremely insufficiently and inefficiently; over the past 10 years, the volume of transit traffic through the territory of Ukraine has declined by more than 2,5 times, primarily due to the fall in transit traffic by rail. One of the reasons for this situation is, of course, the general political and economic situation in the country. However, there are a number of other negative factors that prevent Ukraine from fully and effectively using its transit potential. These problems lie both in the purely technical plane (deterioration of transport infrastructure and rolling stock, lack of capacity of the main transport routes, underdevelopment of logistics terminals in the country and at land borders, difference in width with the European railway system) and the legislato-thick (high level of port dues, bureaucratization and regulation of customs procedures, lack of flexible tariff policy for carriers, etc.).

1 Introduction

Analyzing the problems of transport complex of Ukraine one can certainly denote that at present there is a practical absence of methods for optimal distribution of capital investments directed at the development of fixed assets of transport system, in particular the railway transport. Significant wear-out of rolling stock and infrastructure objects, the absence of new generation means of transport, the low speed of movement as well as insufficient level of service lead to the reduction of efficiency of the country's transport complex functioning and appear a serious obstacle to its integration into the European and world transport system.

The solution of problems of the country's transport complex lies in the complex and systemic approach that should contribute to [1]:

- creation of favorable conditions for the attraction of additional freight traffic for the transport system of the country;
- increase of competitiveness of railway transport both on internal and external markets of transport services;
- increase of the level of economic and social welfare of the industry staff;
- support of environmental conservation.

The Ministry of Infrastructure of Ukraine together with the representatives of the EU have developed a document - "The transport strategy of Ukraine for the period up to 2020", in which the main directions of the development of transport sector of Ukraine are defined as follows [2]:

- upgrading of the transport system and the increase of its functioning efficiency;
- meeting the needs of national economy and population in transportation, improvement of quality and affordability of transport services;
- provision of timely cargo delivery;
- improvement of the system of administration of transport industry;
- increasing the capacity of transport network;
- increasing the level of safety on transport;
- acceleration of rate of integration of national transport system into the European and world transport system.

The fulfillment of key issues of this strategy is impossible without the construction of modern and efficient system of management of the country's transport system. At present the most promising paradigm of management of complex systems, which railway transport can be surely referred to, is the concept of sustainable development [3].

The concept of sustainable development is aimed at replacing the concept of economic growth. In the second half of the 20th century productivity and profit were seen as an indicator of successful economic performance of the country. Thus the state of environment and social

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problems were relegated. Recently more and more experts have expressed doubts as to whether the principles of economic growth are fundamental to maintaining the pace of development of mankind. Therefore nowadays leading countries transition to the concept of sustainable development, according to which a number of economic, social, cultural, ecological and other factors are comprehensively taken into consideration.

Ukraine, due to its geographical position and developed transport infrastructure, has a significant potential as a transit country, primarily in the logical chain of trade exchange between Asia and Europe. It is estimated by the British Randall Institute for Transport Issues that the transit ratio of Ukraine is 3.75 (while 5 is maximal); this is the best figure among European countries (for comparison, Poland, ranking second, has the ratio of 2.92) [4]. In addition, the basis of transport system of Ukraine is formed by the railway transport which provides for more than 60% of total freight traffic and more than 35% of passenger traffic. Moreover, the railway industry is one the biggest taxpayers in the country and more than 240000 job opportunities provided by the industry determine its high social importance [5]. Major advantages of railway transport in the current circumstances are its cost-effectiveness and environmental friendliness. This means of transport is characterized by an extensive use of electricity for mass transportation which presents a critical factor for competitiveness of railway transport in the context of reducing its negative impact on the environment [6].

The territory of Ukraine is crossed by three international pan-European railway transport corridors (ITC) number 3, 5 and 9, international corridors number 5 and 8 of the Organization for Cooperation between Railways, and the international transport corridor TRACECA. The overall length of the network of international railway transport corridors going through the territory of Ukraine is 3162 km. ITC network mainly consists of double-track electrified sections equipped with an automatic blocking system and having high throughput and carrying capacity [7].

However, for the full utilization of ITC and its integration into common European transport network, the systemic upgrading of the respective infrastructure needs to be carried out. This involves the task of the most rational distribution of investment resources that can be allocated to modernize ITC in order to obtain the maximum effect. Accordingly, the research in the area of efficiency increase of the railway functioning from the point of view of sustainable development is nowadays a relevant scientific and practical undertaking.

2 Bibliography analysis

The concept of sustainable development consists in the achievement of meeting the vital needs of the present generation of people without depriving future generations of such possibility because of exhaustion of natural resources and environment degradation [3, 8].

In the context of this definition and main directions of transport sector development it can be said that sustainable development of railways must incorporate such rational distribution of investments that would eventually provide for the balanced solution of the issues of social and economic development, the reduction of negative impact on the environment and would also address the existing and future needs of different branches of the economy for transport services.

Analyzing theoretical advances in the field of efficiency increase of functioning of railways and their units one can note that most works [9-12] use complex economic indicators as the criterion of efficiency. However, there are also methods and approaches considering the processes of efficiency increase of railway unit functioning on the basis of technological indicators [13, 14] or quality indicators [15]. A number of works use for this purpose indicators that take into account the ecological dimension of technological processes as well [6, 16, 17]. At the same time the analysis of works mentioned above shows that in fact they lack mathematical models and methods for qualitative and quantitative assessing of activities addressing complex and systemic approach on the basis of the concept of sustainable development.

At the same time, the strategy of development of one of the biggest transport companies of Great Britain NetworkRail is oriented towards increasing the safety and reliability as well as improving the price/quality ratio for the clients; and the principles of sustainable development lie at the heart of this strategy [18].

In [19] it is pointed out that the construction and functioning of complex systems are based on the realization of the principle of systemic approach which is demonstrated, first of all, by integration and an unambiguous definition of parameters of interaction of all elements of the system. Consequently, considering the tasks of efficiency increase of railway functioning, it is necessary to take into account not only the many factors determining the main parameters of technological processes and the characteristics of their arrangement, but also factors connected with ecological and social aspects of transport organization, and the quality of provided services. Therefore addressing such challenges requires a complex approach stipulated in the concept of sustainable development.

3 Purpose and tasks of the study

The purpose of the study is to obtain the dependency of functions of elasticity of capital investments along the main directions of sustainable development on the parameters of demand for the railway transport services. In doing so, the most effective instrument to use for obtaining the dependencies is simulation. Analyzing the obtained dependencies one gets the solution of the problem of the most rational distribution of investment resources that can be allocated for the upgrading of the railway network or its separate section, e.g. an international transport corridor.

To reach the objective the following tasks have been solved by the authors:

- to make the mathematical model of the task: to form the target function and limitations;
- to draw up a plan of experimental studies that makes it possible to estimate the nature of dependencies of indicators of elasticity of capital investments along the directions of sustainable development on the parameters of demand for the transport services;
- to create an economic and mathematical model of forward-looking development of backbone transport networks;
- to analyze the results of the experiment which form the basis for determining functional dependencies of indicators of elasticity of capital investments along the directions of sustainable development on the parameters of demand for the transport services.

4 Research methodology

4.1 Formalization of the task

According to recommendations [3, 8] the main directions of sustainable development of a system, in particular one of transport, are improvement of technical and technological parameters, preservation of environment, social programmes and guarantees, ensuring the quality of provided services. It is suggested to estimate the sustainable development of railways on the basis of integral criterion of efficiency offered in the work [20]:

$$E_и = E_{тех} + E_{эк} + E_{соц} + E_к \rightarrow max \qquad (1)$$

where $E_{тех}$ - indicator characterizing the operating efficiency of railway units towards improving the technical and technological parameters (e.g. from the point of view of resource conservation);

$E_{эк}$ – ecological component reflecting change of emission of harmful substances by railway units during realization of a set of actions expressed in monetary equivalent;

$E_{соц}$ – social component of the process of railway functioning that can be assessed by the amount of contributions to social programmes, salary increase, staff education, etc.;

$E_к$ – indicator of quality of customer service that can be assessed by the change of wagon turnover value expressed in monetary equivalent.

If the sum of investments in the execution of actions connected with the areas of sustainable development Сур, is unchanged during a definite period t, then the target function of task (1) of ensuring the most effective option of sustainable development of a railway or its separate section can be presented as

$$F_ц = \frac{E_и}{C_{ур}} = \delta_{тех} \cdot \varepsilon_{тех} + \delta_{эк} \cdot \varepsilon_{эк} + \delta_{соц} \cdot \varepsilon_{соц} + \delta_к \cdot \varepsilon_к \rightarrow \max \qquad (2)$$

where $\delta_{тех}$, $\delta_{эк}$, $\delta_{соц}$, $\delta_к$ - the share of money in the total amount along directions of development of resource-saving technologies, reduction of harmful impact on the environment, ensuring the social component of functioning and quality increase of client service respectively;

$\varepsilon_{тех}$, $\varepsilon_{эк}$, $\varepsilon_{соц}$, $\varepsilon_к$ - functions of elasticity of capital investments along directions of development of resource-saving technologies, reduction of harmful impact on the environment, ensuring the social component of functioning and quality increase of client service respectively.

Optimization of target function (2) with regard to variables $\delta_{тех}$, $\delta_{эк}$, $\delta_{соц}$, $\delta_к$ must be implemented with the following limitations

$$\begin{cases} \delta_{тех} + \delta_{эк} + \delta_{соц} + \delta_к = 1 \quad \text{or} \quad \sum \delta_i = 1 \\ \delta_i \le \delta_i^{\min} \end{cases} \qquad (3)$$

where $\delta_i^{\min}$ - set lower limit of the share of general investments made to ensure the *i*-th direction of sustainable development.

The function of elasticity of expenditure of resources ε_i, on the *i*-th direction of sustainable development is defined as the ratio of effect E_i, obtained from the realization of actions, to the value of resources, used in doing so, P_i:

$$\varepsilon_i = \frac{E_i}{P_i} \qquad (4)$$

It should be noted that for the social component, the sum of allocated funds serves directly as the effect, therefore $\varepsilon_{соц}$=1.

At the same time, in order to determine the numerical value of efficiency indicator, a prior explanation of numerical values of a number of relevant technical and operational, and technical and economic parameters is required. Moreover, these indicators must characterize an option of functioning of a railway ground (in this case of an international transport corridor) which is rational from the perspective of sustainable development. A rational option of functioning for a ground is determined on the basis of known features of demand for transport services, taking into account the features of the current transport network. [21].

4.2 Formulation of an economic and mathematical model of a railway ground

To determine the numerical values of separate indicators of a railway ground (e.g. ITC), including the characteristics of demand for transport services (the intensity of transportation process) for further calculation of efficiency indicators E_i, is a difficult task on account of a non-determined character of the railway transportation process. In this regard the authors have designed an economic and mathematical model of a railway ground (ITC) based on the methods of graph theory and non-linear optimization.

A transport corridor is presented as a directed graph *G* (*V*, *L*) [22], where *V* is a multitude of vertices, each of which corresponds to a certain junction (a station, a border crossing, a point of cargo flow emergence or

release) of the corridor; L is the multitude of edges each of which corresponds to a railway section between the junctions of the corridor.

Main parameters of the model are: X – one-year volume of transportation along the transport corridor; d – the level of technical facilities of the corridor; i – a random element of the transport corridor; p – the sort of cargo transported along the corridor; K_i - the cost of upgrading of a transport corridor element; E – annual operational expenses on cargo transportation and maintenance servicing of transport devices in corridors; t – a period (stage) of capital investments (years, months) within the specified reference period T. Then X_{tid} - vector characterizing the amount of work at the stage t of network element i with it being equipped to the technical level d; K_{tid} - the cost of reconstruction (construction) at the stage t of element i to the level d; E_{tid} - operational expenses at the stage t on element i equipped to the level d. Thus every combination *{tid}* characterizes a certain option of development of the transport corridor: at the stage t the technical condition of element i is being changed to the level d, which corresponds to a certain set (vector) of technical limitations b_{tid} (e.g. throughput or carrying capacity).

It is accepted that for every point of departure and arrival of goods (passengers) $v_g \in V$ the amount of arrival (departure) of every specific cargo p_k at every stage of upgrading t is determined by the function $Q(vg, pk, t)$.

It is necessary that among the multitude M of possible options of upgrading *{tid}* such subset M^* is identified, that with specified standard ratio of capital investment efficiency F during the reference period T the following condition is fulfilled:

$$\sum_{M^*} \frac{K_{tid} + E_{tid}}{\left(1+F\right)^t} \to \min \tag{5}$$

In (1) capital K_{tid} and operational E_{tid} expenses are added together for all elements *{tid}* of subset M^*; in addition to this the values of elements X_{tid} and *{tid}*, minimizing the target function (5), must satisfy the following conditions (limitations):

1. The specified amounts of arrival and departure of all kinds of cargo p_k for all points v_g of the transport network must be carried out at every stage of upgrading t:

$$\sum_{l} X_{tpvl} = Q\left(v_g, p_k, t\right) \tag{6}$$

Here the summation in (6) is carried out for all edges l along which cargo p_k can be transported and which connect the junction v_g under consideration with adjacent junctions; in this case X_{tpvl} is accordingly the amount of cargo p_k, transported at the stage t from the junction v_g along the edge l.

2. Amounts of transportation work on all elements i, upgraded at the stage t to the level of technical equipment d, must meet corresponding technical limitations b_{tid}:

$$f\left(X_{tid}\right) \le b_{tid} \tag{7}$$

If only maximum amount of cargo flow for element i of transport corridor (throughput or carrying capacity) is meant by limitations b_{tid}, then limitation (7) takes the form of:

$$\sum_{p} X_{tpj} \le b_{tid} \tag{8}$$

Additional limiting conditions can be introduced into the model, e.g. concerning the amount of capital investments at every stage of investment project, the terms of transportation, the priority of upgrading of transport corridor elements, etc.

The solution of task (5) generally requires finding extreme value of non-convex functionality in the space of rather large dimensionality having many linear and non-linear limitations, which needs a considerable amount of computational work to be accomplished. One of the possible ways of solving this task is using methods of vector optimization, as a result of which a subset of Pareto-efficient solutions is obtained. It is appropriate to verify the obtained solutions using methods of simulation which is an effective instrument of evaluation of various options of investment level distribution in the process of upgrading the infrastructure in transport corridors [21, 23, 24].

4.3 Development of a plan of experiment

The developed model of ground functioning was used as a framework for carrying out experimental research in the field of efficiency increase of its operation due to achieving sustainable development. The developed programme model highlights the intensities of freight train traffic over a transport network and the number of cars in trains as the main numerical parameters allowing the description of a probabilistic demand for railway services. In the course of experimental research for the purpose of defining functional dependency of elasticity indicators of resource expenditure along the directions of sustainable development on the characteristics of demand for services, a mathematical expectation of train traffic intensity μ_ζ and a mathematical expectation of the number of cars μ_ψ in one freight train are considered. Therefore, the purpose of simulation exercise is to determine the following functional dependencies:

$$\begin{cases} \varepsilon_{\text{тех}} = f(\mu_\zeta, \mu_\psi), \\ \varepsilon_{\text{эк}} = f(\mu_\zeta, \mu_\psi), \\ \varepsilon_{\text{к}} = f(\mu_\zeta, \mu_\psi). \end{cases} \tag{9}$$

To carry out a full factor experiment a plan of experimental research has been drawn up that makes it possible to estimate the non-linear nature of dependencies (9). The number of test series N_s in the full factor plan of the experiment is defined as the number of all possible combinations of levels of variation of incoming factors [25]:

$$N_s = \prod_{i=1}^{N_f} l_i \qquad (10)$$

where N_f - the number of incoming factors;
l_i - the number of levels of variation of the i-th factor.
According to (10), the number of test series in the experiment by the definition of the combination of functional dependencies (9) amounts to 12.

The numerical results of modelling are a set of four variables – functions of resource expenditure elasticity $\varepsilon_{\text{тех}}$, $\varepsilon_{\text{эк}}$, $\varepsilon_{\text{к}}$ and a feedback function $F_{\text{ц}}$ (2).

To determine the sufficient number of tests in series using the developed model for one of ITCs of Ukraine a trial experiment with 100 tests in every series has been conducted. The analysis of trial experiment outcome reveals that to achieve correct results of modelling in experiment series it is sufficient to carry out 52 tests.

4.4 Analysis of simulation experiment results

The analysis of samples obtained as a result of simulation experiments revealed that in all series random values of functions of capital investment elasticity in directions of reduction of harmful impact on the environment $\varepsilon_{\text{эк}}$ and quality increase of client service $\varepsilon_{\text{к}}$ have normal distribution; on the other hand, the function of elasticity of capital investments in development of resource-saving technologies $\varepsilon_{\text{тех}}$ has gamma-distribution in all test series.

Figures 1-3 illustrate distribution histograms of random values of elasticity functions $\varepsilon_{\text{тех}}$, $\varepsilon_{\text{эк}}$ and $\varepsilon_{\text{к}}$ in the first test series.

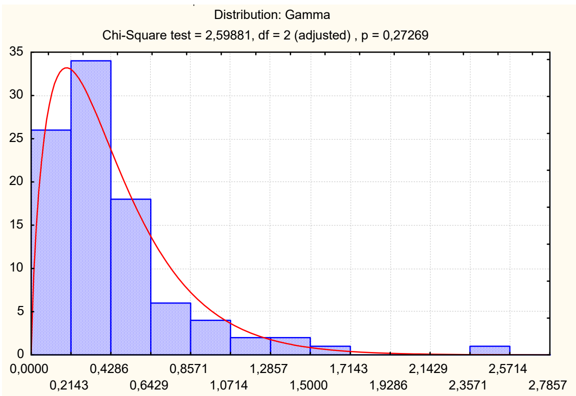

Fig. 1 Distribution histogram of elasticity indicator of capital investments in development of resource-saving technologies.

The value of feedback function $F_{\text{ц}}$ is determined on the basis of elasticity functions according to (2). In this case the value of resource shares δ_i in directions of sustainable development which are defined by the results of solving the task of linear programming (2) (e.g. by simplex method) act as normalizing values.

The correctness of experiment results, i.e. their reproducibility was confirmed using Cochran's test.

To process the results of experimental research the methodology of regression analysis [26] of samples obtained in consequence of the experiment is used. So about 40 possible regression models characterizing the kind of elasticity functions (9) were examined. Among the obtained regression models for the function of elasticity of capital investments in development of resource-saving technologies $\varepsilon_{\text{тех}}$, the power-law model is characterized by the highest adequacy (the lowest deviation of experimental values from values obtained with the help of the model). At the same time the models of present sum are the most adequate for functions of capital investment elasticity in directions of reduction of harmful impact on the environment $\varepsilon_{\text{эк}}$ and quality increase of client service $\varepsilon_{\text{к}}$.

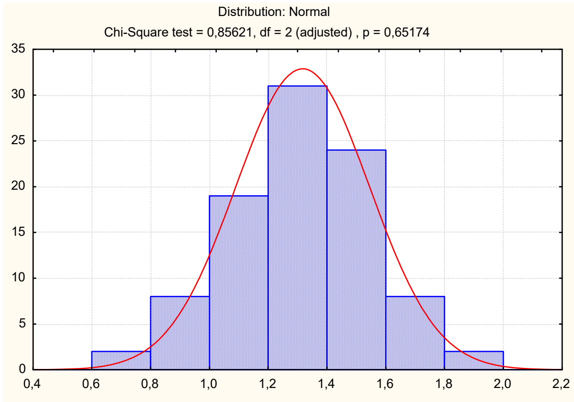

Fig. 2 Distribution histogram of elasticity indicator of capital investments directed at reduction of harmful impact on the environment.

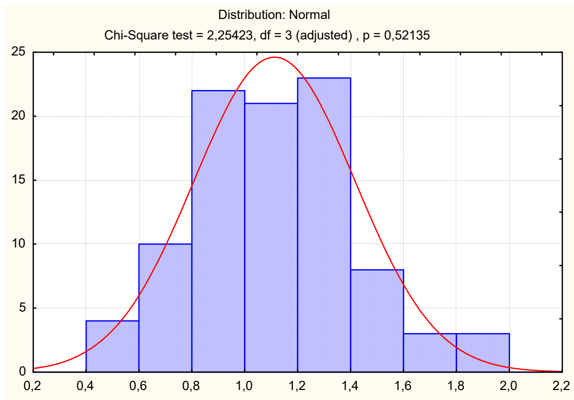

Fig. 3 Distribution histogram of elasticity indicator of capital investments directed at quality increase of client service.

Thus the functions of elasticity of capital investments along the directions of sustainable development of a railway ground depending on the parameters of demand for the transport services (9) is defined as the following set:

$$\begin{cases} \varepsilon_{\text{рес}} = \mu_{\zeta}^{0,477} \cdot \mu_{\psi}^{0,043}, \\ \varepsilon_{\text{эк}} = 0,370 \cdot \mu_{\zeta} + 0,206 \cdot \ln \mu_{\psi}, \\ \varepsilon_{\text{соц}} = 1, \\ \varepsilon_{\text{к}} = 0,054 \cdot \mu_{\zeta} + 0,268 \cdot \ln \mu_{\psi}. \end{cases} \qquad (11)$$

4.5 Research results

The obtained dependencies (11) in practice make it possible to take decisions concerning the choice of the

most promising directions of resource expenditure (investments) on the basis of data about the parameters of demand for transportation (the intensity of wagon flow – parameters μ_ζ and μ_ψ) on a railway ground (e.g. within ITC). It is revealed that the highest value of resource expenditure share δ_i corresponds to the direction for which the value of elasticity function ε_i is maximal in relation to the values of elasticity functions for other directions. The values of elasticity functions ε_i lie in intersecting intervals. Therefore it is obvious that for the set of sustainable development directions of the highest priority there exists variability which is determined by the parameters of demand for a transport service within a railway ground (ITC).

As an example, figure 4 illustrates graphs of elasticity function values (11) depending on the train traffic intensity μ_ζ (with the fixed train composition μ_ψ =40 cars).

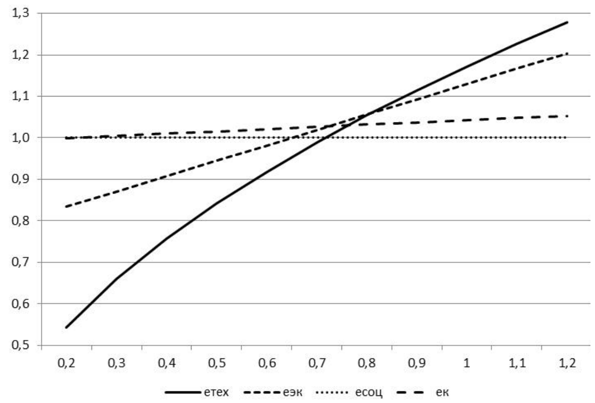

Fig. 4 Graphs of elasticity function values (11) depending on the train traffic intensity μ_ζ (with the fixed train composition μ_ψ =40 cars).

Analyzing the dependencies illustrated by figure 4 it can be identified that in the reviewed range of parameter μ_ζ for values $\mu_\zeta < 0{,}21$ the maximum value belongs to function $\varepsilon_{соц}$, in range $0{,}21 < \mu_\zeta < 0{,}72$ - function $\varepsilon_к$, in range $0{,}72 < \mu_\zeta < 0{,}81$ - function $\varepsilon_{эк}$ and function $\varepsilon_{тех}$ has the maximum value if $\mu_\zeta > 0{,}81$. Consequently, for the indicated example table 1 presents the most prioritized directions of sustainable development of a railway ground (international transport corridor) depending on the intensity of transportation process.

In table 1 the following reference codes are used: *T*- the improvement of technical and technological parameters, *E* – the reduction of harmful impact on the environment, *S* – the development of social programmes, *Q* – the increase of service quality.

Table 1. The most prioritized directions of resource expenditure for ensuring sustainable development for a railway ground (ITC)

μ_ζ	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
Direction	*S*	*Q*	*Q*	*Q*	*Q*	*Q*	*E*	*T*	*T*	*T*	*T*

5 Scientific novelty and practical relevance

The authors have offered a methodology of planning and estimation of actions, aimed at improvement of technical and technological parameters of railway transport system, first of all in international transport corridors, which is based on the concept of sustainable development of complex systems. The task of effective resource distribution in directions of sustainable development is formulated as an optimization task of non-linear programming, where variables represent functions of elasticity of resource expenditure on separate directions. To solve the task an economic and mathematical model of railway ground is designed which is used to carry out a series of tests for defining the nature of elasticity functions for one of the international transport corridors of Ukraine. The obtained dependencies make it possible to identify the most prioritized directions of resource distribution depending on the parameters of demand for transport services.

6 Conclusions

Within the context of integration of the railway transport of Ukraine into the European transport system, the issues of bringing up technical facilities and operation technology of Ukrainian railways to the requirements and standards of the EU are becoming particularly relevant. The EU requirements and standards stipulate not only technical and technological aspects of transportation process, but also ensuring ecological safety as well as quality increase of provided services. In connection with the above there arises a task of effective distribution of capital investments directed at improving transportation process on railway grounds, first of all in international transport corridors. The concept of sustainable development of complex systems makes it possible to take into account the multitude of directions of their operation in a comprehensive and systemic way. The authors offer approaches and mathematical models that are based on the principles of sustainable development of systems. These approaches and models enable to obtain efficiency evaluation and prioritize activities aimed at improving transportation process on railway grounds. Thus the obtained dependencies form the basis for the solution of the task of optimization of finance resources distribution in directions of sustainable development of railway grounds.

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