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CREATING A QUALIMETRIC CRITERION FOR THE GENERALIZED LEVEL OF VEHICLE

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Запропоновано комплексний кваліметричний критерій для визначення узагальненого рівня транспортного засобу, який був отриманий за допомогою методу аналізу розмірностей. Визначено, що складові цього критерію є суперечливими, тому при виборі технології перевезень вантажів враховується важливість тієї чи іншої складової критерію у кожний конкретний момент часу при прийнятті рішень. Процедуру комплексної оцінки транспортного засобу реалізовано у вигляді номограм, які комплексно оцінюють показники транспортних засобів для різних варіантів перевезень

Ключові слова: кваліметричний критерій узагальненого рівня транспортного засобу, метод аналізу розмірностей, бімодальні перевезення

Предложен комплексный квалиметрический критерий для определения обобщенного уровня транспортного средства, который был получен с помощью метода анализа размерностей. Определено, что составляющие этого критерия являются противоречивыми, поэтому при выборе технологии перевозок грузов учитывается важность той или иной составляющей критерия в каждый конкретный момент времени при принятии решений. Процедура комплексной оценки транспортного средства реализована в виде номограмм, которые комплексно оценивают показатели транспортных средств для различных вариантов перевозок

Ключевые слова: квалиметрический критерий обобщенного уровня транспортного средства, метод анализа размерностей, бимодальные перевозки

1. Introduction

As world practice demonstrates, two-thirds of freight transportations by international traffic have been carried out over recent years by mixed combinations according to the "door-to-door" principle [1]. In this case, railway transport played a crucial role in the mixed freight transportation. Under modern conditions, relevant is the task of beneficial interaction between railway and automobile transport with the use of positive aspects of both of them.

According to the draft law of Ukraine "On the mixed (combined) transportation", "The state purpose-oriented program for reforming railway transport in 2010–2019", approved by the decree of Cabinet of Ministers of Ukraine as of December, 16, 2009, No. 1390, "Complex program for the modernization of railway rolling stock in Ukraine in 2008–2020", which was implemented by the Ministry of Transport and Communications of Ukraine as of October, 14, 2008, No. 1259, "Strategies of development of railway transport of Ukraine through 2020", approved by Cabinet of Ministers of Ukraine as of December, 16, 2009 No. 1555-p, as well as according to the Directives of the European Parliament and Council of railway transportations, the tasks concerning cargo transportation improvement and the rolling stock modernization were set. Under these conditions, it is necessary to substantiate the interaction between the rail and automobile types of transport and to define a criterion for assessing transportation effectiveness. Implementation of the studies conducted will provide for a choice of the optimum transportation variant at different volumes of cargo transportation and for different distances.

2. Literature review and problem statement

A great number of scientists have been engaged in studying the problems of modernizing mixed, combined, and intermodal transportation and interaction of the various types of transport; they have considered a wide range of issues, but the formation of the integrated criterion for determining a generalized level of a vehicle has not been given sufficient attention.

Thus, articles [2, 3] are devoted to the elimination of obstacles towards wide introduction of combined transport in the European countries, aimed at improving the competitiveness of railway transportation, simplifying paperwork when crossing borders, but do not describe the procedure as for selecting the optimum variant of cargo delivery.

One of the main problems in mixed transportation [4, 5] is the provision of efficient interaction of all transport streams of related types of transport, in case this condition is not satisfied, demurrage increases because of waiting for vehicles, therefore the need for the effective use of combined transport arises.

Article [6] pays much attention to the reduction of time needed for performance of technological operations in intermodal cargo transportation, but such indicators as specific costs for vehicle maintenance and its reliability are not taken into account.

In paper [7], the emphasis is on the reduction of costs for transporting the intermodal cargos, it presents comparison of cargo delivery costs for automobile and railway transport, depending on transportation distance, but authors do not describe the procedure for choosing the type of transportation.

Articles [8–10] consider cargo delivery in containers using bimodal technology of goods delivery, which allows reducing the cost value of transportation and transport costs, they give a comparison of cargo transportation costs for automobile and railway transport, but it is necessary to take into account a larger number of indicators for adequate interaction of all transport sections.

Thus, an analysis of the significant volume of research, devoted to the problems of interaction between different types of transport and organization of bimodal cargo transportations, demonstrates that the problems of choosing the type of transportation and of the formation of integrated criterion for determining the generalized level of a vehicle were not studied enough.

3. The aim and tasks of the study

The aim of present work is to determine a criterion for the generalized level of a vehicle. Determining the directions to increase effectiveness of interaction between automobile and railway transport can be assessed using qualimetric methods. Hence, there is a need for creating an integrated criterion for the generalized level of a vehicle.

To achieve the set aim, the following tasks were to be solved:

– analysis of existing technologies of combined cargo transportations in Ukraine and in the world;

– substantiation of strategy for choosing the type of transport depending on the volume and distance of transportation;

– determination of criterion for assessing transportation effectiveness for choosing the best option.

4. Selecting a criterion for assessing a vehicle using qualimetric methods

Currently, when choosing the type of cargo transportation, much attention is paid to such indicators as transportation costs, transportation reliability, delivery promptness, cargo safety and many other factors that affect the choice of the type of transportation. In modern terms of competition between the types of transport, the one of a better quality is preferred [11].

For an objective assessment of the quality of services of different types of transport, it is common to use the methods of theoretical qualimetry, a scientific area that combines quantitative methods of quality evaluation, used for the substantiation of decisions, made in managing product quality and standardization [12, 13].

At the same time, the varieties of vehicles do not make it possible to fully evaluate their properties. In different types of transport, the range of using technical characteristics is different. Therefore, there is a need to use the integrated indicator of vehicles quality.

Qualimetry equation for assessing the indicator of the technical level of a vehicle is determined using the "tran" [14], which in a general form will be equal to

$$Z=f(Q, h, V, g, v, L, Vmax), \qquad (1)$$

where Q is the load-carrying capacity of a vehicle, t; h is the characteristic of a route complexity, m; V is the technical speed of a vehicle, km/h; g is the total weight of a vehicle under loaded conditions, t; v is the volume of a vehicle, m^3; L is the cargo transportation distance, km; Vmax is the maximum speed of a vehicle, km/h.

Operating form of this equation may be determined using the method of dimensionality analysis [15, 16]. Any function of independent variable arguments may be displayed as a product of these arguments, taken with different exponents of a power, i. e.

$$Z = C^{/} Q^{\alpha} h^{\beta} V^{\chi} g^{\delta} \nu^{\varepsilon} L^{\kappa} V_{max}^{\lambda}. \quad (2)$$

After performing procedures of searching for exponents of power in general view, formula of dimensionality of both parts of the equation at the main measurement units M, L_x, L_y, L_z, T, we accept Q=M, L=L_x, L_y, L_z, T=T. Then the equation will take the form

$$\frac{M\left(L_x^{1/2}L_z^{1/2}\right)^3}{T^2} = M^{\alpha} \cdot L_y^{\beta} \cdot \left(\frac{L_x^{1/2}L_z^{1/2}}{T}\right)^{\chi} \times$$
$$\times M^{\delta} \cdot \left(L_x L_y L_z\right)^{\varepsilon} \cdot \left(L_x^{1/2}L_z^{1/2}\right)^{\kappa} \cdot \left(\frac{L_x^{1/2}L_z^{1/2}}{T}\right)^{\lambda}. \quad (3)$$

Comparing the coefficients at appropriate quality parameters, we find: $\alpha=1-\delta$, $\beta=-\varepsilon=-1/2+\kappa/2$, $\chi=2-\lambda$, $\delta=\delta$, $\varepsilon=1/2-\kappa/2$, $\kappa=\kappa$, $\lambda=\lambda$.

Then the previous expression takes the form

$$Z = C^{/} \cdot QV^2 \cdot \left(\frac{\nu}{h}\right)^{1/2} \cdot \left(\frac{g}{Q}\right)^{\delta} \cdot \left(L\frac{h^{1/2}}{\nu^{1/2}}\right)^{\kappa} \cdot \left(\frac{V_{max}}{V}\right)^{2}. \quad (4)$$

Based on engineering analysis, we may accept that $\delta=-1$, that is, quality of a vehicle will be proportional to the magnitude of coefficient of commercial payoff $\frac{Q}{g}$, which does not contradict the practice. The indicator takes the value of $\kappa=2$ for the purpose of simplifying parameters as a part of the equation, we accept value $\lambda=2$ as an indicator of kinetic energy storage.

So, finally taking $\delta=1$, $\kappa=2$, $\lambda=2$, we obtain

$$Z = C^{/} \cdot QV^2 L \cdot \frac{Q}{g} \cdot L\left(\sqrt{\frac{h}{\nu}}\right) \cdot \left(\frac{V_{max}}{V}\right)^2 =$$
$$= C^{/} \cdot QV^2 L \cdot k_1 \cdot k_2 \cdot k_3. \quad (5)$$

Usually, they accept the value of constant $C^{/}=1$, which simplifies calculations without disrupting qualimetry of vehicles.

Analyzing the obtained result, it is possible to state that the multiplier in the form $A=Q \cdot V^2 \cdot L$ is the quantitative magnitude of useful effect of the transport operation,

$$k_1 = \frac{Q}{g}$$

characterizes the weight perfection of this vehicle, that is, cargo payoff to the weight of a vehicle,

$$k_2 = L\left(\sqrt{\frac{h}{\nu}}\right)$$

characterizes road advantages of a vehicle,

$$k_3 = \left(\frac{V_{max}}{V}\right)^2$$

considers storage of kinetic energy.

In the given form of this indicator, such important indicators as specific costs for maintenance of specific vehicle, time cost for performing technological operations, value of competitive level are not taken into account. Taking into consideration these indicators, qualimetric criterion of the generalized level of vehicle takes the form

$$Z = \frac{A}{\phi \cdot (1-\tau)} \cdot \prod_{i=1}^{m} k_i = \frac{Q \cdot V^2 \cdot L}{\phi \cdot (1-\tau)} \cdot \prod_{i=1}^{m} k_i =$$
$$= \frac{Q \cdot V^2 \cdot L}{\phi \cdot (1-\tau)} \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot k_5 \to \max, \quad (6)$$

at

$$\begin{cases} C_{lc} > 0, C_l > 0, Q > 0, \\ \Delta T > 0, T > 0, L > 0, \\ 0 < V \le V_{max}, \tau < 1, \\ 5 < \phi < 30, \end{cases}$$

where Q is the load-carrying capacity of a vehicle, t; V is the technical speed of a vehicle, km/h; Vmax is the maximum speed of a vehicle, km/h; L is the distance of cargo transportation, km; φ is the ratio of costs for maintaining a vehicle within its life cycle and the cost of a vehicle,

$$\phi = \frac{C_{lc}}{C_l};$$

where C_{lc} is the costs for maintaining a vehicle within its life cycle, UAH.; Cl is the cost of a vehicle, UAH.; τ is the coefficient of reduction of costs for breaks in motion,

$$\tau = \frac{\Delta T}{T};$$

where ΔT is total time of breaks in motion break in, h; T is the total time in motion, h.; m is the number of coefficients; k_i are the coefficients of certain properties, $k_i=k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot k_5$; k_1 is the coefficient of commercial payoff; k_2 is the coefficient of road advantages of vehicle; k_3 is the coefficient of storage of dynamic properties of vehicle; k_4 is the coefficient of competitiveness level of vehicle; k_5 is the coefficient of reliability of vehicle; g is the total weight of vehicle under loaded condition, t; h is the characteristic of route complexity, m; v is the volume of vehicle, m^3.

Specific tasks in the determination of quality criterion are the substantiation of optimum load-carrying capacity of vehicle and transportation distance. Based on the results of article [17], it is possible to determine optimum transportation costs in the framework of change in tariff regulations and prices for each type of transport. Fig. 1 presents graphic dependences P=f(Q, L), which supplement previous analysis [17] in the form of a three-dimensional model.

The following dependences demonstrate that automobile transport could compete with bimodal transport only at short distances and at much smaller transportation volumes. Railway transportations, on the contrary, are inefficient at short distances and are not so effective as bimodal transportation in the medium-distance range, while they are almost the same for long-distance transportation.

Based on results of paper [18], a specification of optimal transportation distance for different types of transport was determined. For transport corridor No. 3 and No. 5, bimodal transportation is optimal; for transport corridor No. 9, railway transportation is preferable at the transported cargo weight 40 tons; at the transported cargo weight 70 tons, railway or bimodal transportation is optimal, the values of which are accepted as boundary for cargo transportation by automobile and railway transport, respectively.

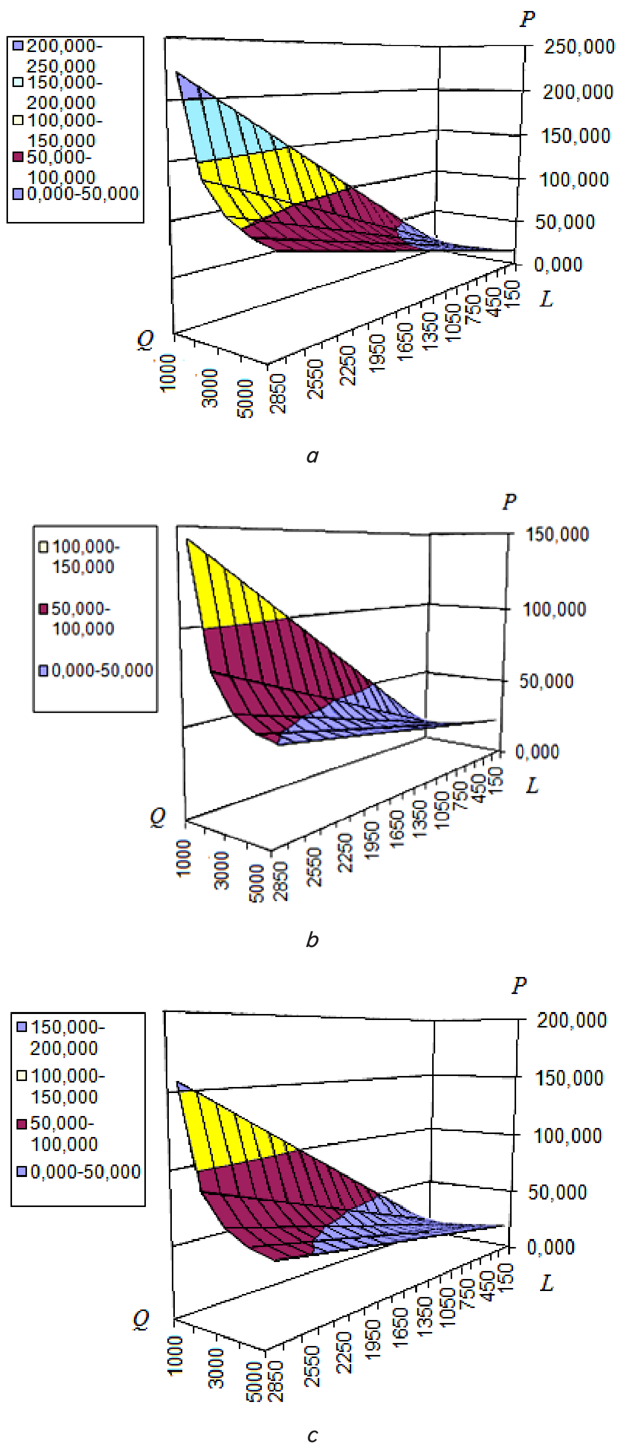

Fig. 1. Total transportation costs: *a* – motor vehicles; *b* – bimodal vehicles; c – railway vehicles

5. Results of determining a criterion for assessing a vehicle by qualimetric methods

Integrated qualimetric criterion of generalized level of vehicle Z (6) is a nonlinear function, which is multiplicative. In this case, the solution may be found by taking logarithms of both parts of the equation, then we obtain

$$\ln Z=\ln Q+2\ln V+\ln L-\ln\varphi-\\-\ln(1-\tau)+\ln k_1+\ln k_2+\ln k_3+\ln k_4+\ln k_5. \quad (7)$$

Due to the fact that the function is monotonically increasing, the equation is true

$$\max\ln Z=\max Z. \quad (8)$$

In a general form, the solution is reduced to the problem on linear programming, in particular, including simplex-method, if restrictions have linear dependence, or problems on dynamic programming, if restrictions have non-linear dependence. Then we write down

$$Z=e^{Q+2V+L-\varphi-(1-\tau)+k_1+k_2+k_3+k_4+k_5}. \quad (9)$$

However, since the analytical way of solving is multifactor and complex, as well as for better clarity, it is proposed to solve the problem graphically as nomographs.

Thus, based on conducted analysis, it was demonstrated that effectiveness of transportation is affected by the choice of vehicle with regard to the range of optimum values of load-carrying capacity of this vehicle and the distance range of transportation based on determining the optimal value for the integrated qualimetric criterion.

To calculate the criterion and compare different variants of using vehicles for transportation, two nomographs were plotted Z=f(A, φ, τ, ki), which comprehensively estimate considered indicators that are presented in Fig. 2.

As an example, values Z in the railway transportation were defined on the nomograph, at Q=3000 t, V=50 km/h, L=2000 km, φ=20, τ=0.5, k1=0.3, k2=1.5, k3=$2\cdot10^6$, k4=1, k5 =0.9. Value k4 is accepted according to [19, 20], k5 is accepted according to [21].

Thus, for the specified variant of railway transportation Z=$1215\cdot10^{12}$ tran, for bimodal Z=$6075\cdot10^{12}$ tran, and for automobile transport Z=$506.25\cdot10^{12}$ tran.

Integrated qualimetric criterion of the generalized level of vehicle $\bar{Z}$ can be defined for the combination of types of transport as

$$\bar{Z}=\max\left\{\sum_{i=1}^{N}\frac{Z_i}{N}\right\}, N=\overline{1,N}, \quad (10)$$

where N is the number of types of transport.

When choosing a technology for cargo transportation, it is necessary to take into account the importance of each component of the qualimetric criterion in any time period when making decisions, the choice of type of transport is shown in Fig. 3.

That is, the optimal quantity, coverage range and load-carrying capacity are assessed based on the characteristics of vehicles; and given the level of reduction of unproductive time consumption, costs for maintenance of a vehicle within its life cycle, and the level of competitiveness, a complex qualimetric level of this vehicle is determined.

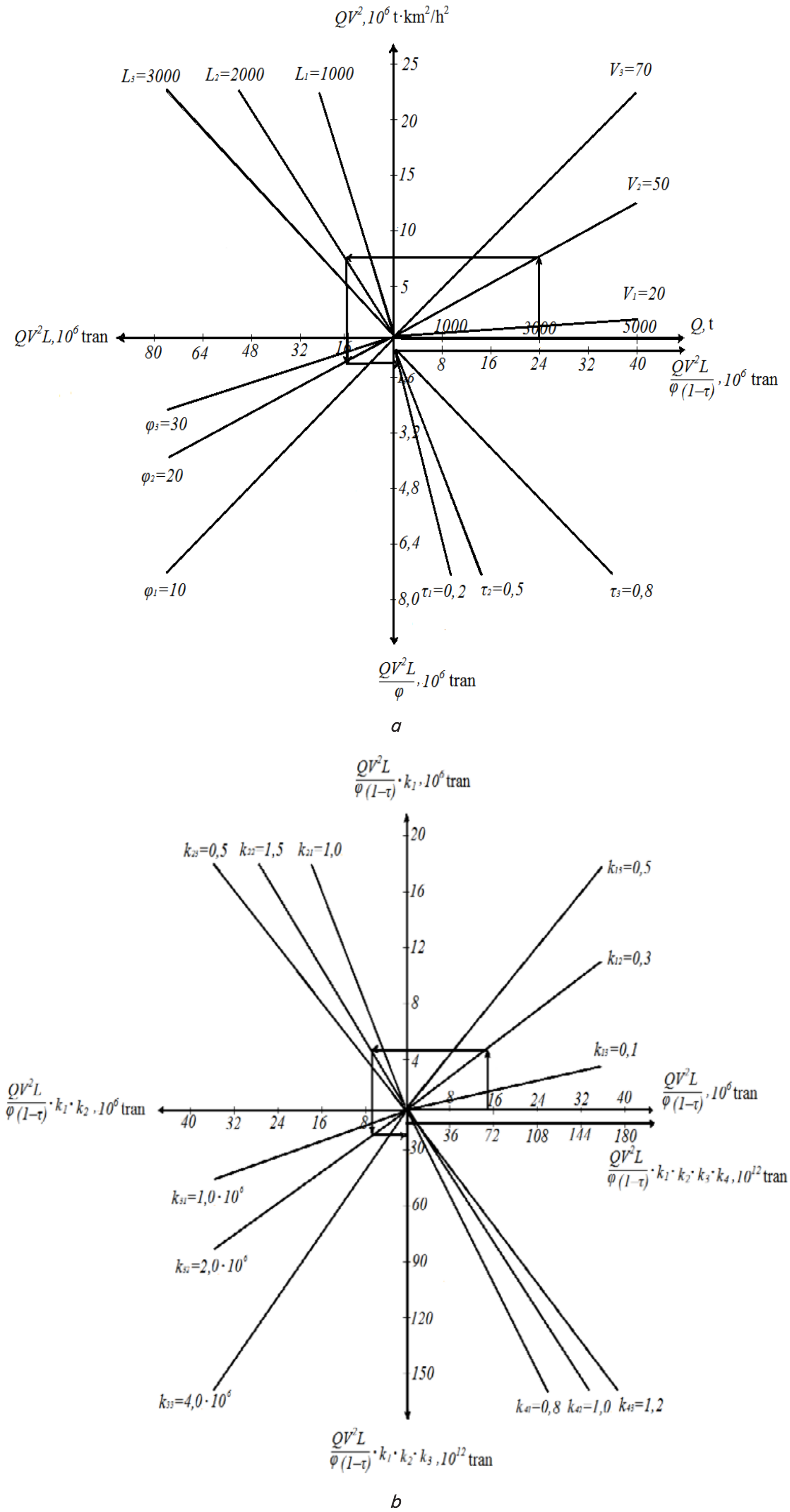

Fig. 2. Nomographs of determining a criterion of the generalized level of vehicle: *a* — defining the parameters of tran; *b* — refining the parameters of tran

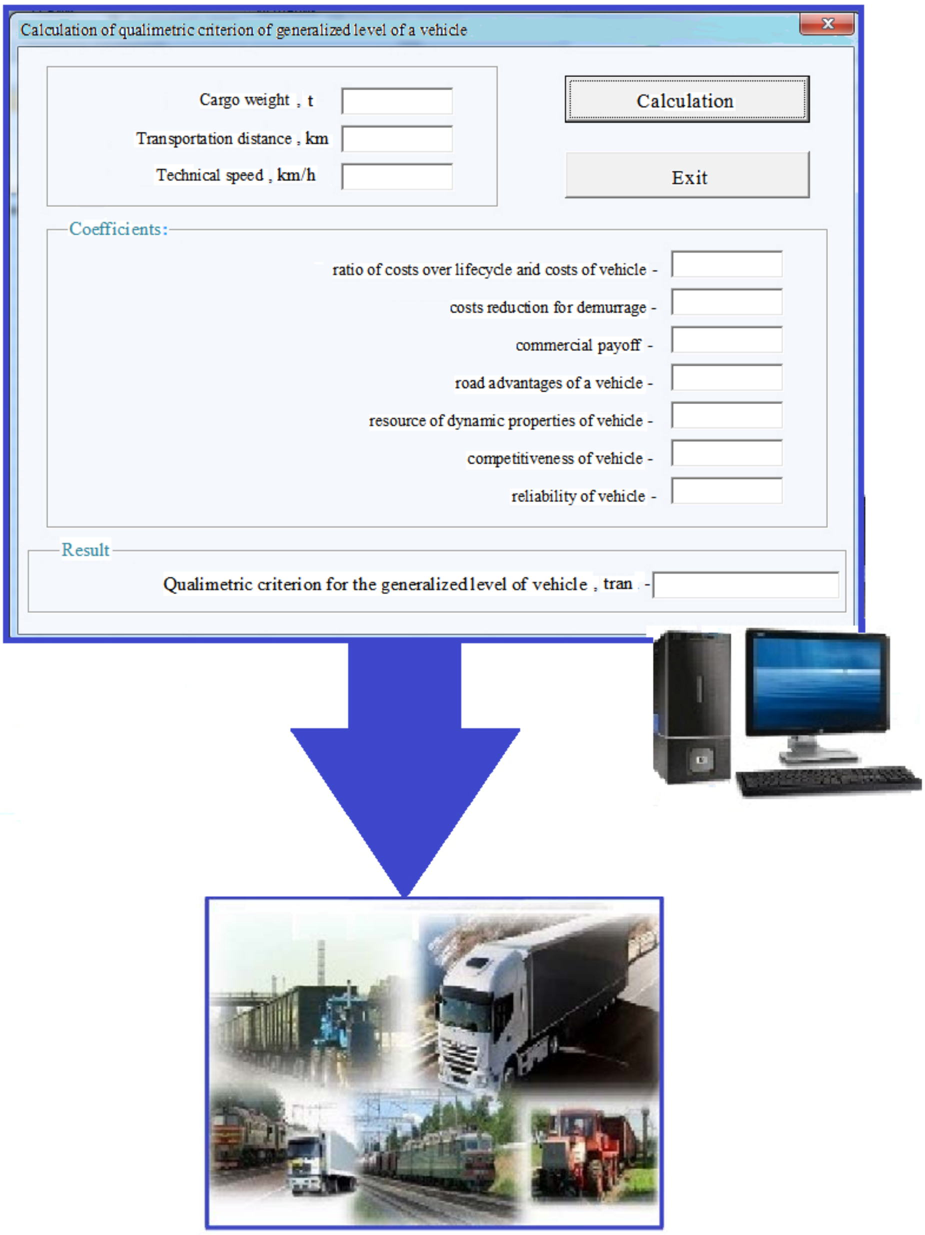

Fig. 3. Implementation of the choice of transportation type using the integrated qualimetric criterion of the generalized level of vehicle

6. Discussion of results of research into determining an integrated qualimetric criterion for the generalized level of vehicle

Obtained results of research into determining an integrated qualimetric criterion for the generalized level of a vehicle allow making a decision on the choice of technology of cargo transportation at a specific moment of time, given the importance of components of this criterion (Fig. 2, 3).

The proposed qualimetric criterion has a major advantage over the existing ones [2–10], it is of systemic nature, takes into account complexity of indicators of a vehicle's level, which exert influence on effectiveness of transportation.

However, limited format of present article does not make it possible to pay sufficient attention to the problems of competitiveness and to the model of reducing the time for supporting operations.

The proposed qualimetric criterion may be used both to increase the efficiency of interaction between road and railway transport and for other types of transport because of its integrated nature and due to the fact that graphic dependences have better possibilities for visualization.

The next stage of scientific research in this direction may include improvement of such mathematical dependences that will take into account additional characteristics of transport, a possibility of non-overloading technologies, for example, at different track width.

7. Conclusions

Based on the assessment of vehicle level, it was demonstrated that the impact of vehicle on the transportation efficiency has an integrated character, depending on many parameters, which made it possible to establish the following:

1. Components of the integrated qualimetric criterion for determining the generalized level of a vehicle are controversial, so when choosing technologies for freight transportations, it is necessary to take into account the importance of one or another component of the criterion at a specific moment of time when making a decision.

2. To refine the qualimetric indicator, it is necessary to determine the coverage range of vehicles at different volumes of cargo transportation and different distance of transportation.

3. A procedure of integrated assessment of a vehicle was implemented in the form of nomographs $Z=f(A, \varphi, \tau, ki)$, which comprehensively evaluate characteristics of vehicles for various transportation options. For the railway transportation, we obtained $Z=1215\cdot10^{12}$ tran; for the bimodal transportation, $Z=6075\cdot10^{12}$ tran; and for the automobile transportation, $Z=506.25\cdot10^{12}$ tran, which demonstrates the prospects for cargo transportation by bimodal transport.

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