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DEVELOPMENT OF A MODEL OF THE WEIGHT OF MOTOR ROADS PARAMETERS AS PART OF THE INFORMATION AND MANAGEMENT SYSTEM OF MONETARY EVALUATION

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Розглянуто підходи до побудови багаторівневої ієрархічної системи показників оцінки якісного стану ділянки автомобільної дороги. Розроблено модель вагомостей параметрів та характеристик автомобільних доріг як дорожньо-транспортного активу у складі інформаційно-управлінської системи грошової оцінки. Проведення досліджень обумовлене необхідністю розробки уніфікованої кваліметричної моделі грошової оцінки ділянки автомобільної дороги. В результаті проаналізовано параметри та конструктивні елементи автомобільних доріг, що дозволило розглянути об'єкт оцінки – ділянку дороги з точки зору методології побудови складних багаторівневих ієрархічних систем. На основі запропонованого підходу побудовано повну кваліметричну модель для вартісної оцінки автомобільної дороги, яка ґрунтується на методі декомпозиції властивостей об'єкта та включає максимальну кількість можливих параметрів, характеристик, конструктивних елементів, показників транспортно-експлуатаційного стану.

Запропоновано механізм обґрунтування вагомостей параметрів та характеристик об'єкта оцінки – ділянки автомобільної дороги шляхом раціонального поєднання вартісного, експертного методів та методу еквівалентних співвідношень. Адекватність запропонованої моделі підтверджується аналізом стандартних похибок, які складають біля 5 %, що суттєво не впливає на достовірність результатів аналітичних розрахунків.

Результати проведених досліджень слугуватимуть подальшим розвитком інформаційно-управлінської системи грошової оцінки дорожньо-транспортного комплексу, метою функціонування якої є обґрунтування раціональних управлінських рішень щодо дорожніх активів в цілому та автомобільних доріг зокрема.

Розроблена модель вагомостей параметрів автомобільних доріг може бути використана підприємствами та організаціями дорожньої галузі та може бути підґрунтям для прийняття ефективних обґрунтованих управлінських рішень щодо дорожньо-транспортних активів

Ключові слова: вагомість параметрів, автомобільні дороги, рівень якісного стану, кваліметрія, ієрархічна модель, інформаційно-управлінська система

1. Introduction

Development of the transport infrastructure of any country has a key impact on the economy in general. In particular, the World Bank annually develops a program in the form of manuals and reports [1] with the involvement of private investors to designing, funding, implementation and management of infrastructure projects.

The programs of this kind are aimed at the development of efficient management of existing network of public roads of national importance considering the priority of improving consumer properties of international and national transport corridors, enhance traffic safety, speed, convenience and cost-effectiveness of passenger and freight transportation, as well as ensure proper operational maintenance of public roads of national importance. One of the main means of implementation of such programs is the development of the toolkit for technical analysis and monetary evaluation of existing road-transport assets. Such problem can be solved only by introduction of the information and management analytic system (IMAS) as a modern means for processing analytical data. Application of the IMAS in practice will enable, above all, the representatives of the executive authorities, local self-government, organizations of the road-transport sector to make timely effective and well-grounded solutions regarding the objects of the road-transport infrastructure in general and their separate elements in particular.

The tendencies concerning further involvement of private capital of both national and foreign investors on projects of the road-transport sector determine the need for revision of the traditional approaches to technical examination and monetary evaluation of the road-transport assets. The main problem of the evaluation of a motor road as a road-transport asset is complexity, multiple parameters, uncertainty of some characteristics, and the need to apply different methods, models, algorithms and combinations of methods and models for evaluation. In addition, it is necessary to substantiate the weight of each parameter and characteristics of a road, because assessment reliability and, therefore, the quality of the source information of IMAS depend on it.

At the current stage of development of the road-transport sector, we should highlight a series of problems associated with monitoring the state of road assets and carrying out their costs evaluation. They include the existence of a large number of sites under construction, destruction of elements of roads due to increased weight loads of vehicles and increased traffic intensity, lack or limitation of a long-term strategy for the development of motor roads at the state level.

The process of monetary evaluation of motor roads, unlike other objects in the road-transport infrastructure is uncertain and non-regulated. Given the relevance of the problem of such assessments, which is due, above all, to decentralization and the transfer of public roads from the sphere of control of one state authority to the sphere of control of the other, there arises the problem of development of a clearly regulated system of procedures and indicators, which would take into consideration the features of a motor road as the engineering facility and, at the same time, would be available for practical use. Therefore, the problem of development of the model of the weight of parameters of road-transport assets is rather relevant in the current context.

2. Literature review and problem statement

At the present stage of the development of scientific research in the road sector, there are several papers, in which the models for estimation of road assets during conditional privatization of roads within the framework of public–private partnership were proposed. However, it should be noted that the authors have not sufficiently worked over the toolkits of technical analysis and value assessment of roads and their elements, have not identified the importance of the influence of each parameter in general object.

The toolkit to approach the evaluation of the quality of state of an object is proposed in papers [4, 5]. In these studies, it is proposed to use qualimetry to determine the level of the quality states of real estate objects. However, the difficulty of using the proposed toolkit may include the specific features and multiple parameters of motor roads as objects of immovable property of road-transport organizations. Fundamentally, new methodological approaches to determining the weights of characteristics and parameters of objects are presented in [6, 7]. However, the specified methodological approaches can be used in this study only partially and only for the construction of methodology of determining the weights of parameters of road-transport assets. Objective difficulties of using such approaches are complexity of decomposition of characteristics and parameters of motor roads.

Paper [8] presents the arguments of the influence of the high-quality input information of the qualimetric model of the object quality evaluation on making effective managerial decisions in its regard. Approaches to qualimetric modeling of the indicators of the model of cost assessment are proposed in [9]. However, the problems of substantiation of weights of characteristics and parameters of the input information remain unresolved in these studies.

The conducted analysis of data in the scientific literature [2–9] makes it possible to assert that there is almost no research aimed at substantiation of weights of parameters of road-transport assets. These studies explored real estate objects in general, rather than such specific assets as a motor road. In the road-transport sector, the issue of determining the weights of parameters of objects of immovable property has not been solved so far, which determines the prospects of the selected direction of research.

3. The aim and objectives of the study

The aim of the study is to develop a model of weights of parameters of road-transport assets using the example of motor roads as a part of the information-management system of monetary evaluation. This will make it possible to perform substantial cost assessment of the sections of motor roads with the aim of making rational managerial decisions about road assets for further involvement of investors.

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

– to determine the fundamental approaches to the construction of a multi-level hierarchical system of indicators of a motor road assessment;

– to outline the conceptual approaches to the construction of the model of weights of parameters of road-transport assets;

– to construct a generalized qualimetric model of evaluation of the quality state of a motor road considering the model of weights of parameters and structural elements.

4. Materials and methods to study the parameters of road-transport assets and the methods of determining weights

4. 1. Fundamental approaches to the construction of a multi-level hierarchical system of indicators to assess a motor road section

A motor road is a complex set of engineering structures, the operational aim of which is to meet the needs of end consumers for continuous, safe, and comfortable motion. First of all, it is necessary to identify the features of a motor road, which determine uniqueness of this road asset:

– linear-extending structure;

– different normative service life of separate elements;

– existence of concentrated objects of significant cost (bridge crossings, transport interchanges, etc.);

– the opportunity to assess the actual state of separate elements only by numeric indicators that are determined by special equipment;

– existence of the large number of parameters that affect the cost, but do not change over time and depend only on the influence of a road on users.

That is why taking into consideration the features of a motor road, it is possible to highlight the directions of selecting the objective criteria for monetary evaluation, based on the actual state and the initial cost.

The main purpose of performing the monetary evaluation of a motor road is to provide with objective information those people who should, based on the analysis, make well-grounded rational managerial decisions regarding a road asset.

The proposed approach to monetary evaluation is based on the position of the asset quality assessment. The quality state of an object depends on properties, characteristics, and parameters. First, it is necessary to determine the list (nomenclature) of these qualities, the combination of which is sufficient and fully characterizes an object. At the next stage, it is necessary to evaluate the properties qualitatively and compare with the properties of similar objects or with reference (normative) values of properties themselves. Thus, it is possible to represent this process mathematically in the form of the following model:

$$K_K = f\langle R, B, A\rangle, \quad (1)$$

where K_K is the integrated indicator (level of the asset quality state), in the form of a coefficient; R is the category model of the assessment object (motor road); B is the assessment base (reference or normative values); A is the assessment algorithm (logical procedures, methods, techniques).

Thus, in the general form, the assessment of the level of quality state of a motor road for making managerial decisions consists of the following stages (Fig. 1).

Managerial decisions regarding motor roads are substantiated based on the information and management system of monetary evaluation according to the following structural-logical block diagram (Fig. 2).

The state of a motor road as an object of monetary evaluation can be represented as a hierarchical model of the totality of properties (Fig. 3) in accordance with the main approaches of the qualimetry methodology [10–12].

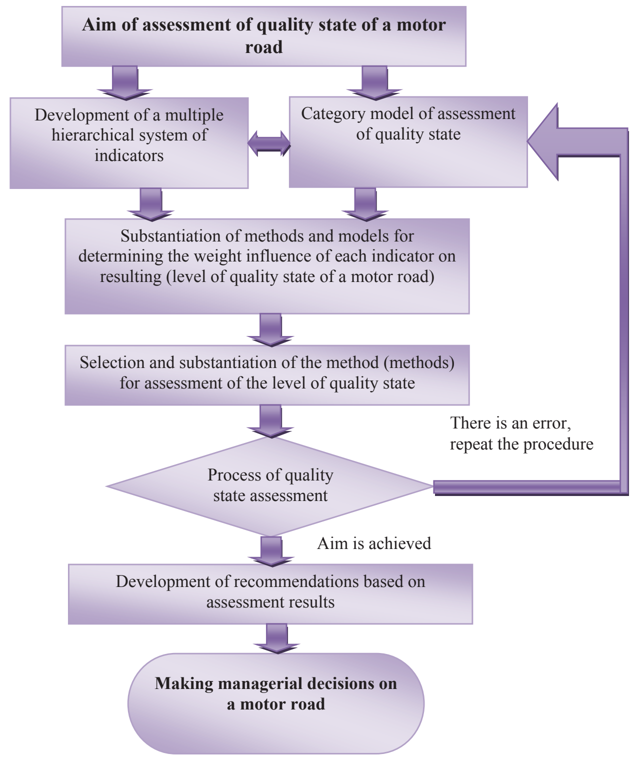

Fig. 1. Algorithm for assessment of the quality state of a motor road

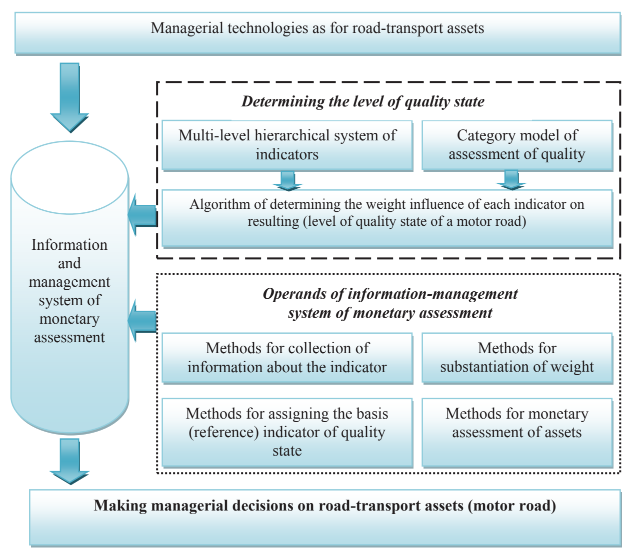

Fig. 2. Block diagram of substantiation of managerial decisions based on information and management system of monetary assessment

Such model is an artificial multilevel system of indicators that fully and reasonably describes quality features of a motor road as a property asset. The hierarchical model implies the rational decomposition of properties of a monetary evaluation object – a motor road. At this stage, it is advisable to use the methodology of AHP (Analytic Hierarchy Process) by Thomas Saaty [6, 7].

Application of decomposition based on the AHR approach as a result of mathematical modeling will enable determining a well-grounded integrated indicator (K_K) of the quality state of the road asset.

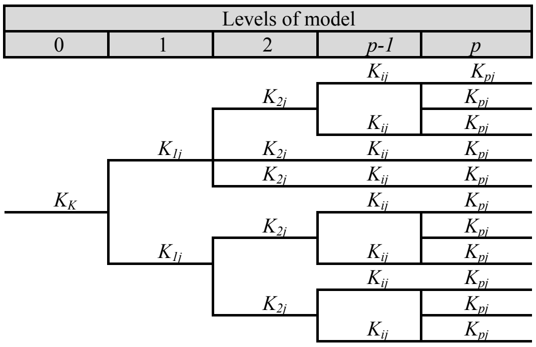

Fig. 3. General scheme of the qualimetric model of quality state of a motor road section

An integrated indicator (K_K) is located at the zero level and includes the sum of all differential indicators that are at the first (the highest) level and are formed from simple properties, which are located at the lowest (p-th) level. J-totality of differential indicators (K_{ij}) is formed at each i-th level.

The choice of the number of levels depends on the purpose of assessment of a motor road section, the significance (state or local) and the category of a road, the existence of those or other concentrated objects, etc. At an increase in the number of the levels of a qualimetric model (p), the information on the quality features of an object that make up its properties increase, and decomposition and hierarchy get more complicated. At the same time, selecting the large number of levels and, consequently, the indicators, leads to an increase in the number of measurements and calculations. Thus, a qualimetric model, if possible, should have a minimum number of levels, but enough to assess the quality with assigned precision and in accordance with the set goal.

When constructing models, it is necessary to introduce new relations so that they better correspond to assessment requirements at this level and reveal the properties of the previous level. The indicators of each level, in addition to the zero level, must be equivalent, that is, characterize an object equivalently. Each level of the model should have a minimal, but a sufficient number of links, determined by the completeness of description of properties.

4. 2. Conceptual approaches to the construction of a model of weights of parameters of road-transport assets

First of all, it is proposed to divide the indicators of evaluation of the road quality state into two main groups: physical and functional. Physical indicators change over time and can be characterized by a numeric value, or certain normative requirements that regulate the compliance or incompliance with the requirements of road users. Functional indicators do not change over time, but their compliance changes with the change of the users' structure and the significance of the assessed motor road section.

As a result of decomposition of the complex and average properties of the road asset into simple ones, the number of levels increases. The model is considered to be finished and complete, when the last p-th level is represented by simple, indivisible properties. This approach makes it possible to create different variants of indicators of the quality state.

Subsequently, it is proposed to divide two main groups of indicators (physical and functional) into subgroups.

The first group (functional) includes the characteristics of a road, affecting the convenience and safety of users, the transportation speed, but do not depend on the quality and durability of materials and the intensity of load influence on the road structure. Such indicators are usually laid as early as at the design stage, which is mainly due to the progressive development of the normative-technical base and lagging behind in the implementation of planned repairs. Thus, the first group of indicators includes:

– traffic intensity;
– parameters of the elements of the lay-out and longitudinal profile;
– parameters of transverse profile of an motor road;
– indicators of an motor road section on traffic safety;
– assessment of influence on the environment (hygienic indicators).

The second group (physical) includes the subgroups, depending on the components of the structural elements of a motor road in accordance with construction norms [13]:

– earth bed;
– road drainage facilities;
– road surface;
– road shoulders;
– transport structures;
– engineering road facilities;
– road service structures;
– road service facilities;
– traffic organization facilities.

Mathematically, the process of construction of the qualimetric model of the motor road state can be represented by formula:

$$K_K = f(K_{i1}, K_{i2}, \dots K_{ij}), \qquad (2)$$

where K_K is the level of quality state of asset in the form of coefficient: $K_K \in [0;1,0]$, $\{K_K \in Q\}$; K_{ij} is the value of the j-th indicator at the i-th level of the model; i is the level of the model, $\{i \in P\}$; j is the number of indicators within the i-the level of the model, $\{j \in L\}$; Q, P, L are the sets of rational numbers.

The level of quality state of the asset is the magnitude, dependent on the totality of indicators of the higher subgroup taking into consideration their weight, according to the qualimetric model [10, 14–16]:

$$K_K = \sum_{j=1}^{l} K_{1j} \times m'_{1j}, \qquad (3)$$

m'_{1j} is the coefficient of weight of the components of (complex) properties, which characterize the quality state of the assessment objects at the first (highest) level of the model; l is the number of the groups of indicators, $\{l \in N\}$.

Accordingly, at the lowest level of the model:

$$K_{pj} = \sum_{j=1}^{l'} P_{pj} \times m_{pj}, \qquad (4)$$

where P_{pj} is the single differential indicator of the quality state of a motor road at level p of the model; m_{pj} is the coefficient of the weight of simple properties, which characterize the quality state of the evaluation object at the lowest level of the model (p); l' is the number of indicators (properties) of the considered element of the road at level p of the model, $\{p \in N\}$.

Each level of the object properties can be quantitatively assessed by a single (differentiated) indicator of the quality state:

$$P_{pj}=\frac{P^{a}_{pj}}{P^{b}_{pj}} \text{ or } P_{pj}=\frac{P^{b}_{pj}}{P^{a}_{pj}}, \qquad (5)$$

where P^{a}_{pj} is the value of the j-th absolute indicator of the quality state at the lowest level of the model (p); P^{b}_{pj} is the value of the j-th basic (reference) indicator of the quality state at the lowest level of the model (p).

In this case, the single indicator is a dimensionless magnitude that determines the level of the quality state in the form of the coefficient or in percentage value.

However, the process of determining indicator K_{ij} in the model is complicated by the fact that it is necessary to determine clearly the weight of each indicator in a hierarchical system [7].

All existing methods for determining the weight can be conditionally divided into two groups: analytical and expert. The use of the latter implies determining the relationships between single indicators, involving experts. However, subjectivity is the main disadvantage of this group of methods. Among the analytical methods, the most common are: the cost method, the method of statistical treatment of estimates of the characteristics of such objects, and the method of equivalent relationships.

The cost method is the most common among the analytical methods, it is based on the assumption on that quality is proportional to cost and weight is identical to cost:

$$m_{ij}=f\left(C_j\right)\rightarrow m_{ij}=\frac{C_j}{\sum_j^{l'}C_j}, \qquad (6)$$

where m_{ij} is the weight coefficient of the j-the property at the i-the level; C_j is the cost value of the j-th property (of the motor road, component or a structural element of the motor road section); $\sum_j^{l'}C_j$ is the total cost value of the motor road section, component or element; l' is the number of indicators (properties) of the studied motor road section, component or element at the i-th level of the model.

To determine weight factors of some characteristics of a motor road, it is possible to use both directly cost method and its interpretation – the method of restoration cost value, or a combination of the two methods. When using simultaneously the classic cost method and the method of restoration cost value, it is necessary to perform the agreement of results in order to avoid errors. This can be done in two ways: to determine arithmetic mean magnitude or to use mathematical weighing. The method of subjective weighting the end results of determining weight factors from formula is the best:

$$m_{ij}=\sum_{j=1}^{q}m_j\times z_j, \qquad (7)$$

where m_{ij} is the weight factor of simple properties that characterize the quality state of the assessment object, determined by the j-th method; j is the number of the applied method, $\{j\in N\}$; q is the number of the applied methods; Z_j is the specific coefficient of the j-th method.

The process of agreement by the method of subjective weighing of end results of the weights obtained by different methods can be represented in the form of a hierarchical tree (Fig. 4).

The advantage of cost methods is a simplified approach to determining weight indicators. However, it should be noted that cost is a non-constant magnitude, which depends on many factors. Accordingly, at a change in cost over time, the weights of characteristics of objects may change. At significant fluctuations in cost, reliability of the obtained values of weights can decrease considerably. In addition, there are characteristics of road assets that are practically not possible to estimate by the cost method, specifically, intensity of traffic, designed parameters of a road, safety, environmental friendliness. For these characteristics, it is necessary to use other methods form the group of the analytical methods (for example, the method of equivalent relationships) or expert methods.

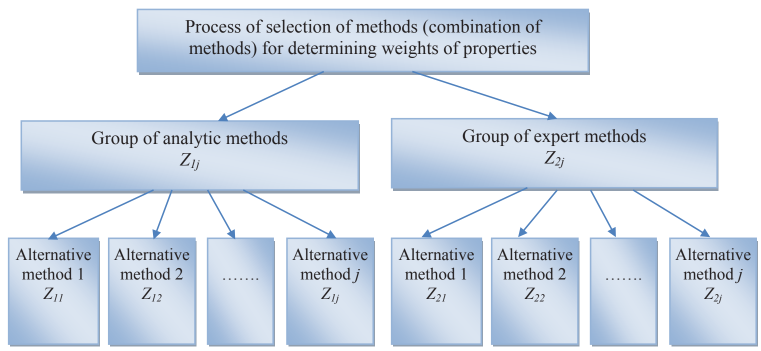

Fig. 4. Hierarchical tree of agreement between weights of indicators, obtained by different methods

4. 3. Development of the model of weights of parameters and construction of a qualimetric model for assessment of the quality state of a motor road

Taking into consideration the basic principles of qualimetry and using the methodology of the AHP (Analytic Hierarchy Process) by Thomas Saaty [6, 7], the analysis of the constituent elements of a motor road as an engineering structure was performed and the indicators of different levels that accurately and objectively characterize their state were determined empirically. The results of analysis made it possible to construct a general qualimetric model of the state of a motor road (Fig. 5).

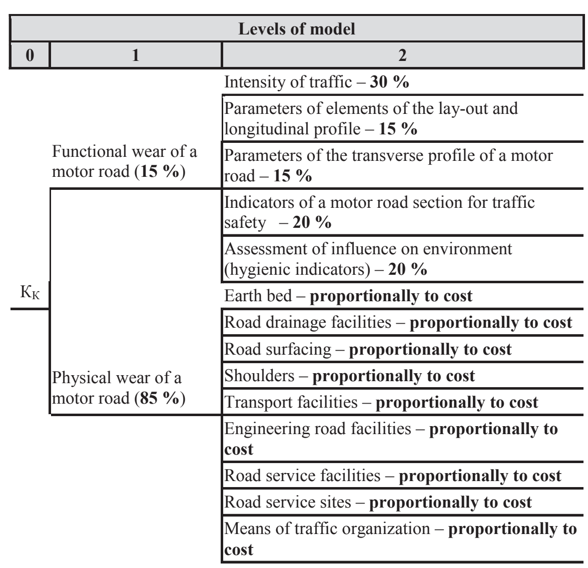

Fig. 5. Levels from 0 to 2 of a general qualimetric model of the motor road state

Let us perform decomposition of the second level of the indicator “the functional wear” of the qualimetric model of the motor road state and construct level 3 and 4 (Fig. 6).

To separate the properties of the totality of sections with incompliance of parameters with the established regulatory requirements on the total length of a motor road, we will use the formula:

$$At_{ij} = \frac{\sum_{i=1}^{n} l_i}{L}, \tag{8}$$

where At_{ij} is the j-th property, established for the i-th section; l_i is the length of the i-th section with incompliance of parameters with the established regulatory requirements; n is the number of the sections with incompliance of parameters with the established regulatory requirements $\{n \in N\}$; L is the total length of the assessed road.

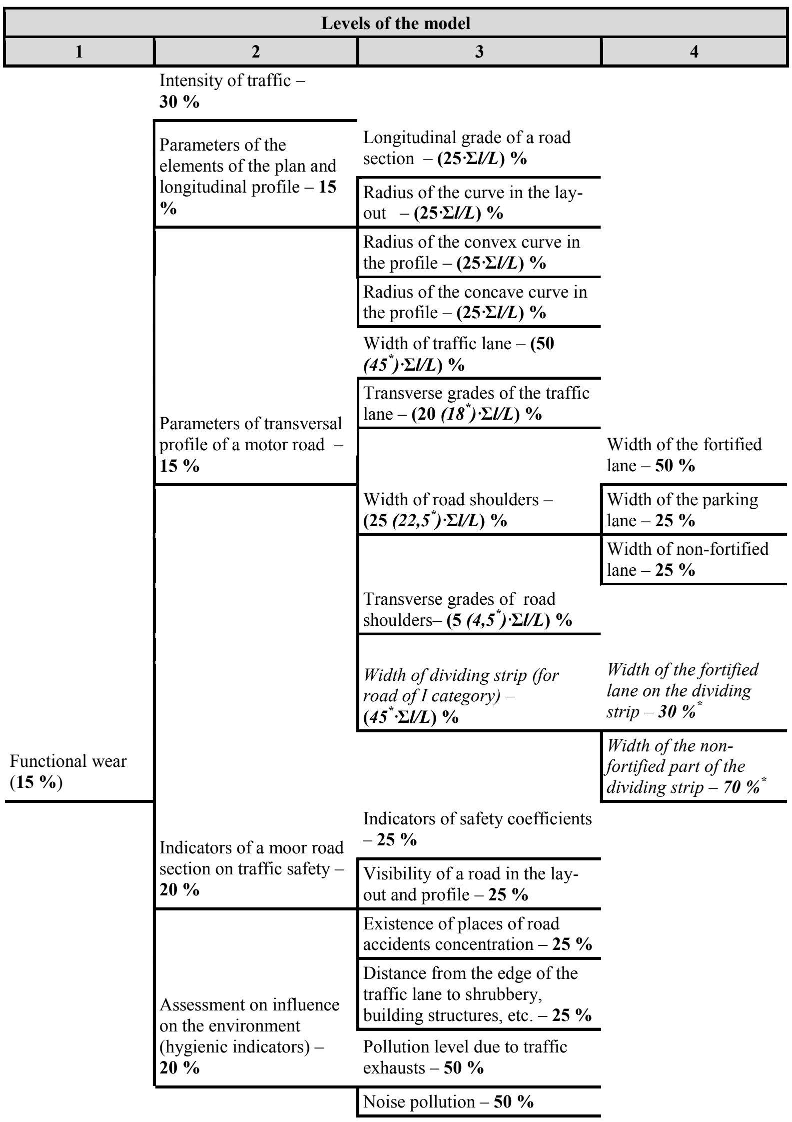

Fig. 6. Qualimetric model of the functional state of a motor road: * – data for the first technical category are indicated in brackets

Let us consider the indicators of functional wear of the third level. The intensity of traffic, assessment of the environmental impact and indicators of a road section on traffic safety depends on a certain totality of factors. These include: socio-economic development of the region, the state of a road section, the time of operation of a road section after the last current (capital) repairs, legislation concerning the requirements to vehicles, seasonality of road load, etc. Depending on the prospective traffic intensity, a technical category of a motor road is given, at the inconsistency of the actual traffic intensity on the road section of the corresponding technical category, it is necessary to carry out the reconstruction of this section. The criterion “indicators of a motor road section on traffic safety” at the second level includes a specific set of indicators. This list includes: indicators of safety coefficients, visibility of a road in the plan and the profile; existence of road accidents concentration and the distance from the edge of the traffic lane to green spaces, and building structures.

The first group of indicators is the most uncertain, the requirements for traffic safety are not regulated by current regulations in Ukraine, so the group will be studied separately. The rest of the indicators have regulatory requirements to their boundary costs, or are determined by the current regulatory documents, procedures (for example, existence of places of road accidents concentrations). Based on the above, it is proposed to evaluate the described second level indicators using the method of fixed cost relative to the boundary condition, according to [17]. That is, if the actual traffic intensity on the motor road section does not meet the requirements for the technical category of a road, the cost of this section is reduced by the corresponding percentage. It is proposed to apply the same approach to the indicators of noise pollution, the level of pollution due to traffic exhausts, the distance from the edge of the traffic lane to green spaces, buildings; existence of places of road accidents concentrations; visibility of the road in the lay-out and in the profile.

Indicators “parameters of the transverse profile of a motor road” and “parameters of the elements of the lay-out and longitudinal profile” are laid down as early as at the stage of the construction of a road section. However, their parameters can be compliant or incompliant with the actual traffic conditions, depending on the intensity. In fact, it is possible to apply to them most reasonably the method of fixed cost in relation to the boundary state, but with a specific comment. Since these parameters are linear in nature and their compliance with current requirements can be different on separate sections, weight should be considered in proportion to the length of certain sections with the incompliance with the parameters (Fig. 6, (8)). In addition, for the first technical category, significance of indicators will be additionally affected by the corresponding parameters of the dividing strip: the width of the non-fortified part of the dividing strip and the width of the fortified part on the dividing strip, which is taken into account at the fourth level of the model.

Indicators of physical wear are variable in time, mainly, due to their wear and aging of the road elements they are related to. To evaluate these parameters, it is advisable to apply the expert method, a method for fixed cost in relation to the boundary state and the test results.

It is necessary to note that it is proposed to determine the weight of indicators of physical wear at the second level of the qualimetric model by the cost method, that is, in proportion to their cost in the cost estimation of an object. Such an approach will be most objective, since concentrated artificial facilities frequently have much higher estimated cost than linear (road surfacing, marking, etc.), and their state is much harder to characterize by physical indicators.

We will perform decomposition of the second level of the indicator "physical wear" of the qualimetric model of the motor road state and construct levels 3, 4 and 5 (Fig. 7, 8).

We will consider separately the indicators of physical wear, starting with the third level of the qualimetric model (Fig. 7).

It is proposed to evaluate the state of the elements of the earth bed by the expert method. It should be taken into account that according to [18], the destruction of the surface of the earth road shoulders, dividing strips and grades of the earth bed are not allowed to be deeper than 4 cm. It was empirically determined that the weight of the indicator the "state of non-fortified part of the road shoulder is 30 %, of the indicator "grades" – 70 %. This ratio was adopted taking into consideration the average geometric dimensions and complexity of removal of defects. Accordingly, at the fourth level of the model, the indicator "grades" is characterized by two indicators: "state of grades" (70 %) and "grade steepness" (30 %).

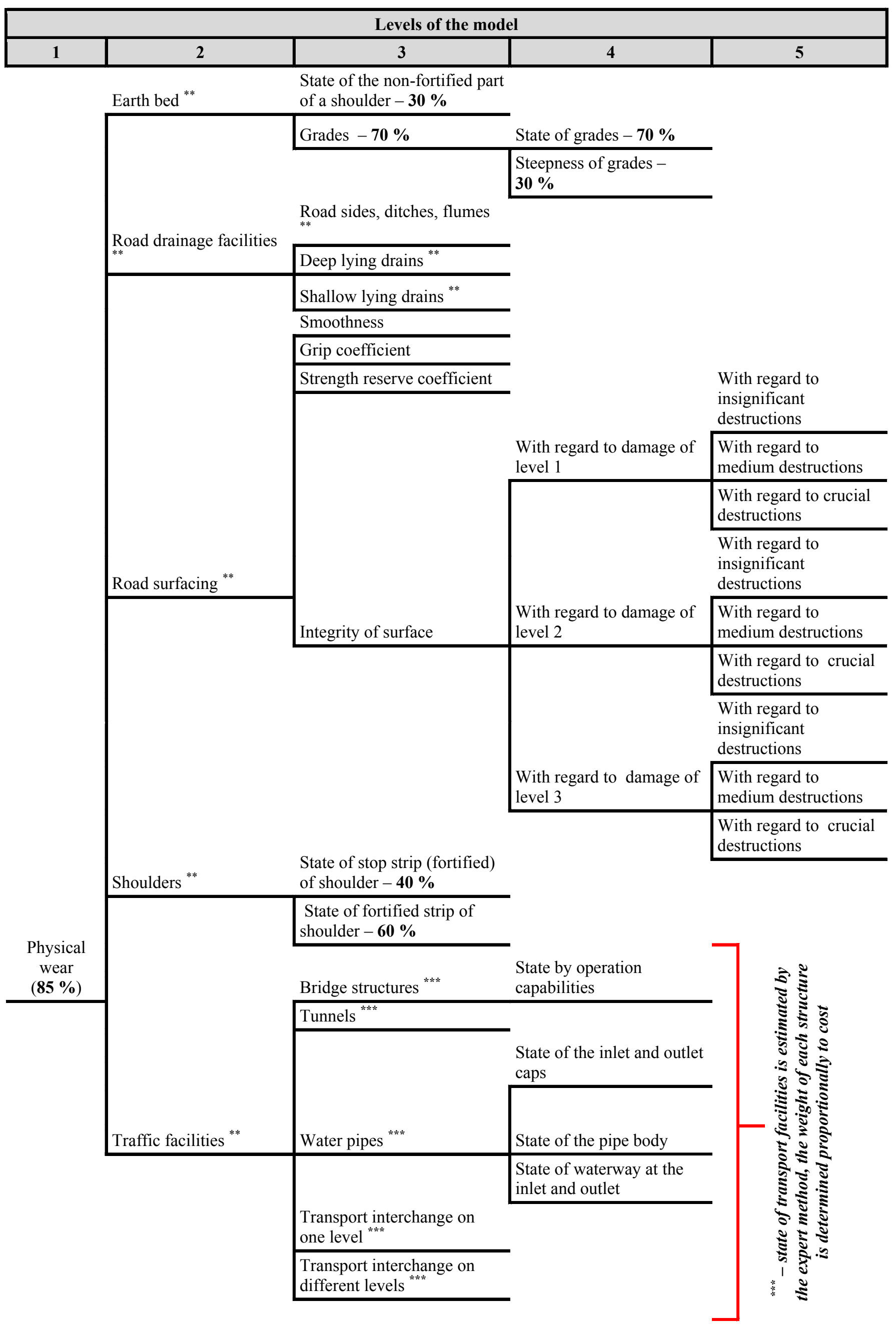

Fig. 7. Qualimetric model of the physical state of a motor road (part 1): ** – is determined in proportion to cost; *** – state of transport facilities is estimated by the expert method, the weight of each facility is determined in proportion to cost

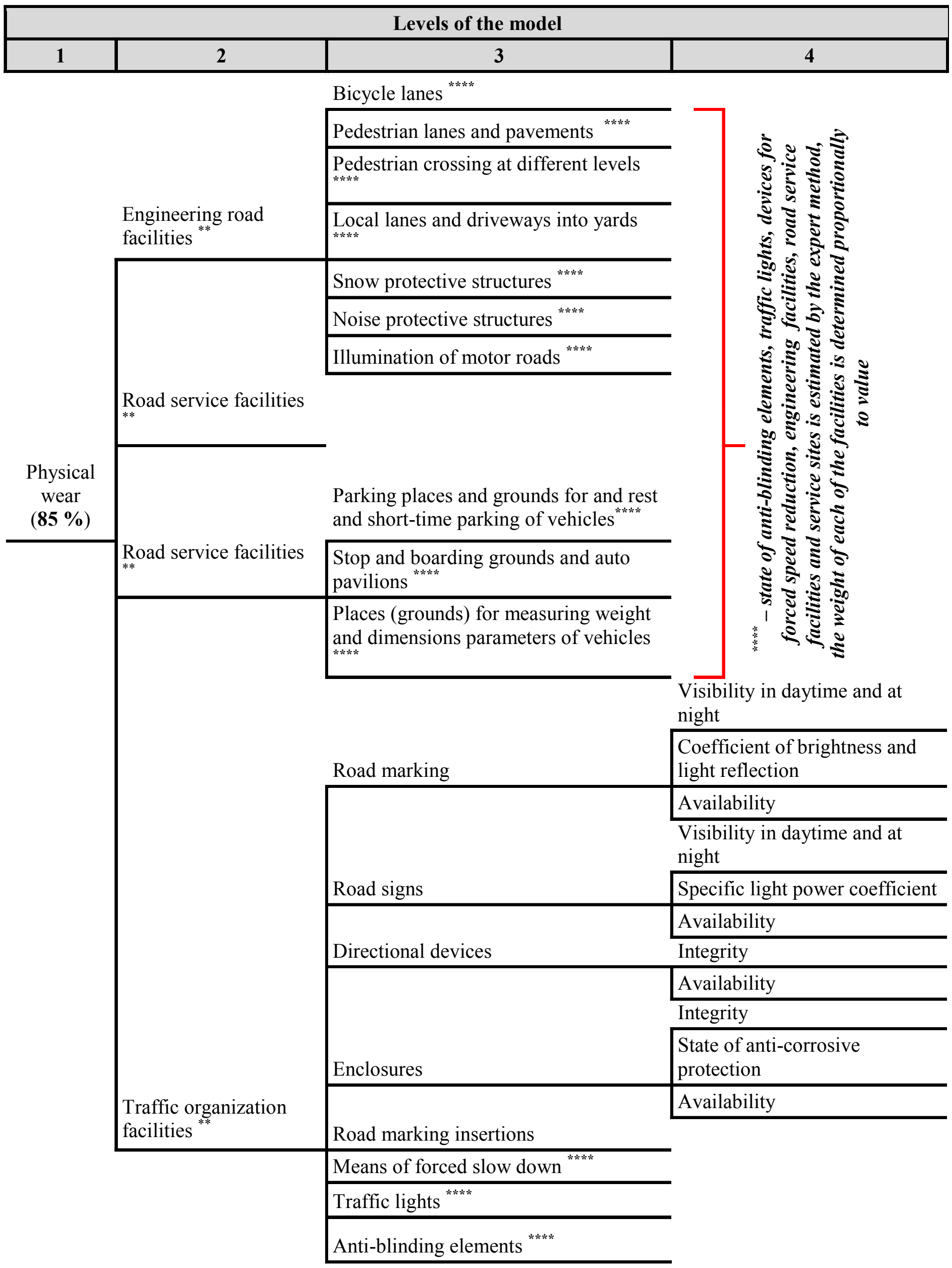

Fig. 8. Qualimetric model of the physical state of a motor road (part 2): **** — the state of anti-blinding elements, traffic lights, means of forced slow-down, engineering facilities, road service facilities and service sites are estimated by the expert method, the weight of each of the facilities is determined proportionally to the cost

Road drainage facilities are concentrated, so it is proposed to accept their weight in proportion to the estimated cost, and to assess their state by the expert method.

The fortified part of the road shoulder consists of the stop strip (unfortified) and the fortified strip of a road. The weight of these elements was determined by the expert method and made up, respectively, 40 % and 60 %.

The most common transport facilities on public roads are bridge structures, tunnels, drainage pipes, transport interchanges on one level and transport interchanges on different levels. These facilities have a high estimate cost and a long term of operation compared with most elements of a road. The state of transportation facilities is estimated by the expert method, the weight of each of the facilities is determined in proportion to cost. To obtain complete information about the current status of bridge structures, it is advisable to use databases of analytical expert systems and control over bridges that fully function in road industry in different countries.

Like transport facilities, the state of anti-blinding elements, traffic lights, the means of forced slow-down, engineering facilities, road service facilities and service sites are estimated by the expert method, the weight of each of the facilities is determined in proportion to cost.

It is necessary to consider separately the road bed and the means of traffic organization: marking, signs, enclosures, directing devices. These items are available on all, without exception, motor roads. They are directly affected by vehicles, weather-climatic factors, and the activity on the operational maintenance of roads. The state of these elements is constantly changing, and the operation period is relatively short. The positive aspect is that in the road sector of the system of objective indicators was developed and operates, which makes it possible to assess the compliance of road bed, markings, signs, enclosures and directing devices to traffic requirements. Information about the characteristics of the road bed can be obtained by using the program complexes of existing systems of surface state control [19].

The criteria of the state of road bed are its strength (characterized by the module of elasticity), smoothness (IRI index or equality by bumpometer), grip qualities (grip coefficient) and measure of damage by destructions and deformations. The requirements for these indicators for roads during putting into operation after construction or at accepting work after current repairs, as well as during the road operation, are regulated by normative documents.

Depending on the actual module of road bed elasticity, road organizations make managerial decisions regarding the appropriateness of capital repairs of a motor road section. Decisions on current average repairs are made based on analysis of indicators of smoothness and grip coefficient. Deformations and destructions are removed during the reconstruction, capital repairs current repairs, as well as operational maintenance (emergency works). That is why when assessing a motor road section, it is necessary to consider characteristics of the road bed in a clear sequence.

First of all, the compliance with the module of elasticity necessary for this technical category is estimated. This compliance is characterized by coefficient of strength reserve. If the elasticity module does not meet regulatory requirements, it is necessary to carry out the overhaul, but on condition that at least one of the remaining indicators is worse than the norm. The weight of coefficient of strength reserve was empirically determined at the rate of 60 %. This cost is accepted, if it is lower than admissible and at least one of the remaining indicators does not meet the requirements of the regulations. If the coefficient of strength reserve is sufficient, its magnitude is 0 %. While meeting the first condition, the remaining indicators are not considered further.

Calculation of differential indicators of strength for each kilometer (for category 1 – for direct and reverse directions separately) of a motor road is performed from the formula, interpreted from (5) by the method of equivalent relationships:

$$E_i = \frac{E_f}{E_n}, \tag{9}$$

where E_f is the actual cost of elasticity module; E_n is the normative admissible cost of elasticity module [13].

The essence of the method of equivalent relationships is the comparison of actual data on the parameter of the model with the reference (normative) cost.

It is appropriate to carry out analysis of performed calculations in the tabular form (Table 1) or in the form of a matrix of indicators.

Table 1

Differential indicators of strength

Direct traffic			Reverse traffic		
Beginning km+	End km+	E	Beginning km+	End km+	E
i_0	i_1	E_1	i_0	i_1	E_1
i_1	i_2	E_2	i_1	i_2	E_2
…	….	…	…	….	…
i_{n-1}	i_n	E_i	i_{n-1}	i_n	E_i

Differential indicator of strength of the totality of sections with incompliance of parameters with the established regulatory requirements is calculated from formula:

$$E = \frac{\sum_i^n \left(\left(E_i \cdot k_l\right) \cdot n'\right)}{\sum n'} \left| \begin{array}{l} E_i < 1 \to E_i, \\ E_i \geq 1 \to E_i = 1, \end{array} \right. \tag{10}$$

where n is the number of sections with incompliance of parameters with the established regulatory requirements, $\{n \in N\}$; n' is the number of sections with the same value of an indicator, $\{n' \in N\}$; k_l is the coefficient of proportionality of the section length (accepted as 1.0 for the section of 1 km, calculated proportionally for the sections of smaller length), $k_l \in [0;1,0]$.

Then, it is necessary to consider the grip coefficient, because smoothness depends on existence of defects on the surface. Incompliance of the grip coefficient with current requirements is the criterion for making managerial decisions regarding the current average repair. The weight of this indicator was established by the expert method at the level of 30 %. If the grip coefficient is lower than the permissible, the indicators of smoothness and of the measure of damage by deformations and destructions are not considered in the future.

Calculation of differential indicators of grip coefficient for each lane, every direction, and every kilometer of a motor road is performed from the formula, interpreted from (5):

$$\phi_i = \frac{\phi_f}{\phi_n}, \tag{11}$$

where ϕ_f is the actual value of grip coefficient; ϕ_n is the standard admissible value of grip coefficient according to current traffic safety regulations [18].

The results of calculations are given in Table 2.

Table 2

Differential indicators of grip coefficient

Direct traffic			Reverse traffic		
Beginning km+	End km+	φ	Beginning km+	End km+	φ
i_0	i_1	φ_1	i_0	i_1	φ_1
i_1	i_2	φ_2	i_1	i_2	φ_2
…	….	…	…	….	…
i_{n-1}	i_n	φ_i	i_{n-1}	i_n	φ_i

Differential indicator of grip coefficient for the totality of sections with incompliance of parameters with the established regulatory requirements is calculated from formula:

$$\varphi = \frac{\sum_i^n \left(\left(\varphi_i \cdot k_l\right) \cdot n'\right)}{\sum n'} \left| \begin{array}{l} \varphi_i < 1 \to \varphi_i, \\ \varphi_i \geq 1 \to \varphi_i = 1, \end{array} \right. \tag{12}$$

where n is the number of sections with incompliance of parameters with the established regulatory requirements, $\{n \in N\}$; n' is the number of sections with the same value of an indicator, $\{n' \in N\}$; k_l is the coefficient of proportionality of the section length (accepted as 1.0 for the section of 1 km, calculated proportionally for the sections of smaller length), $k_l \in [0;1,0]$.

At the next stage of the model construction, we should consider the indicator of smoothness. It should be noted that a higher numeric value of this indicator means worse state of the surface. In addition, if the smoothness does not meet the requirements, and there are surface defects on a section, this parameter should be re-measured after removal of defects. It was determined with the use of the expert method that the weight of smoothness must be accepted at the rate of 30 %, if there are no surface defects on the section, and at the rate of 20 %, if there are such defects. If there some defects and smoothness is unsatisfactory, the weight of these indicators is added.

Calculation of differential indicators of smoothness of road surface is performed for every lane, every direction, and every kilometer from the formula, interpreted from (5):

$$S_i = \frac{S_n}{S_f}, \tag{13}$$

where S_n is the standard permissible value of the indicator of smoothness according to current traffic safety regulations [18]; S_f is the actual value of smoothness indicator.

The results of calculations are given in Table 3.

Table 3

Differential indicators of smoothness

Direct traffic			Inverse traffic		
Beginning km+	End km+	S	Beginning km+	End km+	S
i_0	i_1	S_1	i_0	i_1	S_1
i_1	i_2	S_2	i_1	i_2	S_2
...	....	...	...	....	...
i_{n-1}	i_n	S_i	i_{n-1}	i_n	S_i

Differential indicator of smoothness for the totality of sections with the incompliance of parameters with the established regulatory requirements is calculated from formula:

$$S = \frac{\sum_i^n \left((S_i \cdot k_l) \cdot n' \right)}{\sum n'} \left| \begin{array}{l} S_i < 1 \rightarrow S_i, \\ S_i \geq 1 \rightarrow S_i = 1, \end{array} \right. \tag{14}$$

where n is the number of sections with incompliance of parameters with the established regulatory requirements, $\{n \in N\}$; n' is the number of sections with the same value of the indicator, $\{n' \in N\}$; k_l is the coefficient of proportionality of the section length (accepted as 1.0 for the section of 1 km, calculated proportionally for the sections of smaller length), $k_l \in [0;1,0]$.

It is common to characterize destructions and deformations (defects) of the road bed by the measure of its damage by this or that type of defects [20]. In addition, its spread on the road of the length of one kilometer (in percentage of the total length of sections with this type of destructions or deformations) is taken into account. Classification of destructions and deformations includes fifteen kinds (Table 4), each type has three levels.

Each indicator is assessed visually by the group of experts, which should consist of at least five people. Then, the weighted average indicator is determined.

Table 4

Types of deformations and destructions of road bed of non-stiff type

Code	Type of destructions and deformations	Code	Type of destructions and deformations	Code	Type of destructions and deformations
1	Shelling	6	Rutting	11	General transverse cracks
2	Crumbling	7	Sagging	12	Cracks network
3	Holes	8	Breaks	13	Longitudinal cracks
4	Ridge	9	Destructions of edges of road bed	14	Slanting cracks
5	Displacements	10	Destructions of deformation joints	15	Exfoliation of thin-layered final part of surfacing

First of all, the determined characteristics of the damage must be averaged with regard to damage levels from formula, %:

$$D^m_{i-(i+1)} = \begin{cases} 0,25 \cdot D_1 + 0,5 \cdot D_2 + D_3, \\ D_1, D_2, D_3, D^m_{i-(i+1)} \in [0;100], \\ \left\lceil D^m_{i-(i+1)} \right\rceil, \end{cases} \tag{15}$$

where D_1, D_2, D_3 are the measure of damage of a section by deformations (destructions) of the first, second and third levels, respectively, %; $D^m_{i-(i+1)}$ is the averaged value of the measure of damage of a road section from km i to km (i+1) by the deformation (destruction) of type m, %; $\{i \in n\}$; n is the number of sections with incompliance of parameters with the established regulatory requirements; $\{n \in N\}$; $\{m \in N\}$.

At the next stage, all types of defects within separate i-th-kilometer sections are averaged.

The averaged value of the measure of damage of a section from km i to km (i+1) by all existing types of deformations (destructions) is calculated from formula:

$$\sum_{II}^{I} D_{i-(i+1)} = \begin{cases} 0,5 \cdot D^I_{i-(i+1)} + 0,7 \cdot D^{II}_{i-(i+1)} + D^{III}_{i-(i+1)}, \\ D^{II}_{i-(i+1)}, D^{III}_{i-(i+1)}, D_{i-(i+1)}, \sum_{III}^{I} D_{i-(i+1)} \in [0;100], \\ \left\lceil \sum_{III}^{I} D_{i-(i+1)} \right\rceil, \end{cases} \tag{16}$$

where $D^I_{i-(i+1)}$, $D^{III}_{i-(i+1)}$, $D^{III}_{i-(i+1)}$ is the sum of averaged values of the measure of the road section damage from km i to km (i+1) by deformation (destruction) of I (insignificant), II (medium) and III (crucial) types, respectively, %; $\{i \in n\}$; n is the number of sections with incompliance of parameters with the established normative requirements; $\{n \in N\}$.

The insignificant type of destructions and deformations include those that do not affect traffic safety, are local in nature, indicate a reduction of separate indicators of the material of road structure – type 1, 2, according to [20] (Table 4).

The medium type of destructions and deformations includes those that do not affect traffic safety, but indicate the beginning of decreasing the strength of a road structure – type 11, 13–15 (Table 4).

The crucial type of destructions and deformations includes those that significantly affect traffic safety and indicate the loss of bearing ability by the structure – type 3–10, 12 (Table 4).

Calculation for category I of a road is performed for each direction separately.

Then, we perform calculation of diffraction indicator of a measure of damage of the totality of motor road section with the non-conformity of parameters with the established regulatory requirements separately for each of the experts from formula:

$$D^{\text{експ. k}} = \frac{\sum\limits_{1}^{i} \frac{\left(\sum\limits_{III}^{I} D_{n-(n+1)}\right)}{100} \cdot l_i}{L}, \tag{17}$$

where l_i is the length of the i-th section with incompliance of parameters with the established normative requirements; $\{i \in n\}$; n is the number of sections with non-compliance of parameters with the established normative requirements; $\{n \in N\}$; L is the total length of the estimated road; k is the assigned conditional number of the expert, $\{k \in N\}$.

Calculation is performed separately by each of the experts, then the weight-average for a road section is determined:

$$\bar{D} = \frac{\sum\limits_{1}^{r} D^{\text{expert k}}}{r}, \tag{18}$$

where r is the number of experts, $\{r \in N\}$.

Then it is necessary to determine the adequacy of the experts' judgements using the standardized methods for estimation of errors (method of checking the consistency of opinions by concordation coefficient, by the rank correlation of Spearman, Kendall, etc.) [10]. The previous studies enable us to state confidently that expert methods have the error of up to 5–10 %, which corresponds to the errors of the methods for instrumental measurements.

5. Results of testing the developed model of weights of parameters

Based on the developed model, we carried out assessment of a motor road of category III. The source data for determining weights by cost methods are the chapters of consolidated estimated cost calculations of a motor road construction (Table 5).

First, the cost method by consolidated estimation calculation of the cost of the construction of a motor road in prices of today (2018) was used (Fig. 9).

Physical (operational) wearing of motor road	Earth bed	24.94	%
	Artificial structures	15.99	%
	Road surfacing	16.87	%
	Road situation	42.20	%

Fig. 9. Fragment of calculation of the weight of parameters of the model by the cost method

Since we used in testing an existing object (not a new one), it was decided to perform additional calculations using the method for restoration costs value, which is also included in the group of cost methods. To do this, the cost model was constructed according to the data of estimate costs in prices of 2008, which was re-calculated by indices of the Ministry of regional development into prices of 2018 (Fig. 10).

Physical (operational) wear of a motor road	Earth bed	23.87	%
	Artificial facilities	14.68	%
	Road surfacing	23.03	%
	Road situation	38.41	%

Fig. 10. A fragment of calculation of parameters weight by the method of restoration costs value

In the study, were used the same source data in the form of estimates documentation for both methods, but obtained different results (Fig. 11).

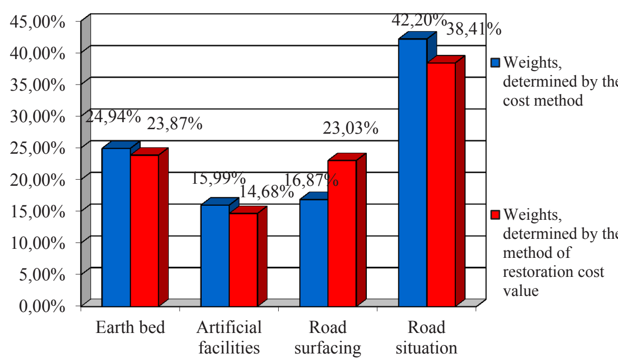

Fig. 11. Diagram of weight factors for construction of the model of quality state of the physical (operational) wear of a motor road, obtained by two cost methods

Table 5

The source data for determining the weights by cost methods

No. by order	Chapter of consolidated estimated cost calculation	Cost, determined in prices of 2018, thousands of c.u.	Recalculated indexed cost from prices of 2008 into prices of 2018, thousands of c.u.	Weight, %	
				By the cost method	By the method of restoration cost value
1	Earth bed	6,067.99	8,758.04	24.94	23.87
2	Artificial facilities	3,889.29	5,385.83	15.99	14.68
3	Road surfacing	4,104.28	8,449.39	16.87	23.03
4	Road situation	10,266.71	14,089.82	42.20	38.41
	Total	24,328.27	36,683.08	100	100

The difference between using the two methods was caused by a number of factors of the influence on the formation of the estimated cost of the construction of a motor road in different years. Specifically, it is the application of different standards of estimated costs, a change of the technology of execution of works, the use of different material and technical resources, as well as the use of integrated construction cost indices by the method of restoration cost value.

The agreement of the methods based on cost, applied to the calculations, was performed by the proposed method of subjective weighting of end results from formula (7) using MS Excel. To do this, a linear regressive dependence from type was constructed:

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_k x_k, \qquad (19)$$

where Y is the values of functions; x_1, x_2,..., x_k are the independent variables; a_0, a_1, a_2, ..., a_k are the coefficients of approximation of available data.

Since only two methods, including formula (7) and (19), were used in approximation, we obtain the equation:

$$m_i = z_0 + z_1 m_1 + z_2 m_2. \qquad (20)$$

Using the method of least squares, the evaluation of the parameters of the equation was performed, and coefficients of approximation of available data were determined:

$$\begin{cases} \sum_{i=1}^{n} m_i = z_0 \times n + z_1 \sum_{i=1}^{n} m_{1i} + z_2 \sum_{i=1}^{n} m_{2i}, \\ \sum_{i=1}^{n} (m_i \times m_{1i}) = z_0 \sum_{i=1}^{n} m_{1i} + z_1 \sum_{i=1}^{n} m_{1i}^2 + z_2 \sum_{i=1}^{n} m_{2i} \sum_{i=1}^{n} m_{1i}, \\ \sum_{i=1}^{n} (m_i \times m_{2i}) = z_0 \sum_{i=1}^{n} m_{2i} + z_1 \sum_{i=1}^{n} m_{1i} \sum_{i=1}^{n} m_{2i} + z_2 \sum_{i=1}^{n} m_{2i}^2. \end{cases} \qquad (21)$$

Calculation results are shown in Fig. 12.

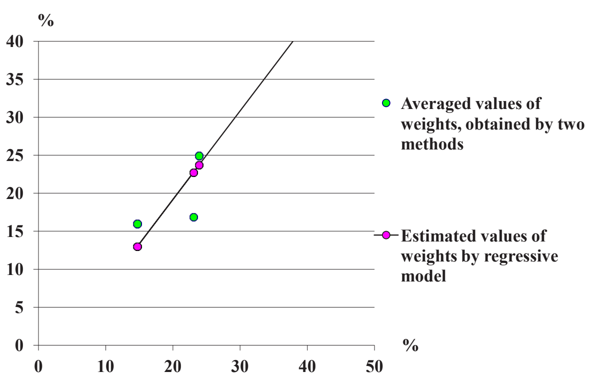

Fig. 12. Graphic representation of the results of calculations of available data approximation

Summarizing expert estimates, empirical approaches and the cost method for determining the weight of separate elements, it is possible to obtain the full qualimetric model of the quality state of a motor road (Fig. 13).

Then we performed the evaluation of a free member of regression and analyzed the adequacy of the proposed approach using standard errors, determination coefficient and F-criterion of Fisher. The results of the performed analysis showed that the standard error is 0.05 (5 %). The determination coefficient made up 0.894, which means that the consistency of the constructed model with the actual data. The significance of the relationship is tested by using F-criterion of Fisher. The calculation cost of F-criterion was calculated with probability of 0.95 and 9.39, which almost corresponds to the tabular cost (9.55) with degree of freedom 3 and an error of 0.06 (6 %).

6. Discussion of results of constructing a model of weights of parameters of assets as part of the information and management system

The performed testing of the model of weights of parameters of road-transport assets revealed that:

1) the proposed fundamental approaches to the construction of a multi-level hierarchical system of the indicators for assessment of a motor road section make it possible to fully take into consideration the specifics of the road asset;

2) the performed decomposition of the model of estimation of the quality state of a motor road by the hierarchy methods made it possible to substantiate the indicators and characteristics of a motor road, which will subsequently influence the reliability of monetary evaluation;

3) the developed concept of determining the weights of parameters of road-transport assets is based on the rational combination of methods, models and techniques, which as a result can be proved by relatively low calculation error;

4) the constructed model of the weights of parameters of road-transport assets makes it possible to increase substantially the criterion of confidence of the qualimetric model for monetary evaluation of a motor road, which in future will be a criterion for making effective well-grounded managerial decisions concerning road- transport assets based of the information and management system of monetary evaluation.

Traditional approaches to determining parameters of the model of estimation of assets, unlike the proposed ones, do not take into consideration the specificity of the assets of the road-transport sector. The proposed model was developed taking into consideration the specific features of the parameters and characteristics of road assets, and is also based on the integrated approach to rational combination of methods for determining and substantiation of the weights of parameters and characteristics. It makes it possible to obtain high reliability of calculation, low error in results of application of expert methods and coordinate the cost methods. The disadvantages of application of the developed model may include conditional subjectivism, because a part of the weights is still determined based on the opinion of experts, and the errors in determining the levels and parameters of a qualimetric model. The specified disadvantages can be neutralized, taking a rational number of experts in the group and evaluating a model at the output using the methods of error estimation and regressive analysis. Additionally, it is proposed to establish the level of competence of experts. When applying a combination of cost methods, we propose to carry out coordination of the results of analytical calculations. In the study, we analyzed the adequacy of the proposed approach using standard errors, determination coefficient and F-criterion of Fisher. According to the results of the conducted analysis, we can conclude that the model is adequate with the standard error of 5 %. The significance of relationship by F-criterion of Fisher was established with probability of 0.95 and has a divergence with the tabular value of 6 %, which proves the validity of the model.

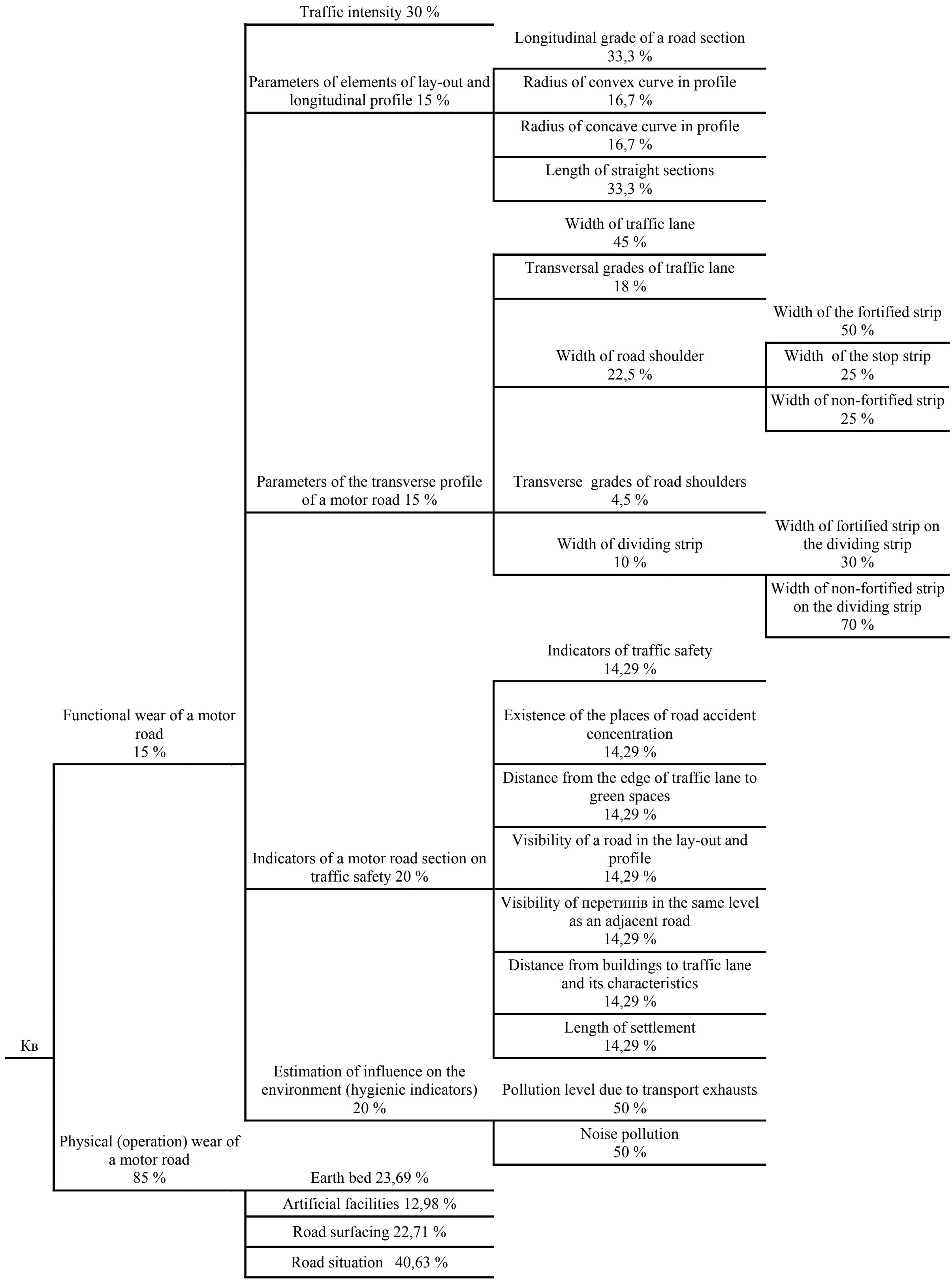

Fig. 13. Qualimetric model of the quality state of a motor road (using the example of a road of category III)

The results of these scientific studies will be applied in the development of the information and management system of monetary evaluation of a road-transport complex, the goal of operation of which is substantiation of rational management decisions as for road assets.

7. Conclusions

1. The selection of parameters of physical and functional wear of road assets using the example of a motor road was performed, which made it possible to construct

a multilevel hierarchical system of indicators of the object's evaluation. The nomenclature of indicators of the quality state of an object, which includes, respectively, four and five levels of properties for functional and physical wear of a motor road section was substantiated. The indicators and parameters were selected according to the modern regulatory requirements in road construction.

2. The groups of methods for determining weight factors of indicators of the quality state of a motor road of the higher technical category for the cost assessment were analyzed. It was found that the most appropriate methods are the cost method, the expert method and the method of equivalent relationships, which were selected to appropriate properties. The rational combination of these methods was determined by the separation of the specific features of characteristics, parameters and properties of structural elements of the evaluation object – a motor road section.

3. Based on the expert and analytical approaches, the weight factors of the indicators of quality state of the model for the roads of higher technical categories were determined. A complete universal model that makes it possible to estimate the quality state of an object by its physical and functional wear was constructed. The adequacy of the proposed model is proved by the standard error of 5 % and the significance of the relationship by F-criterion of Fisher, which was established with probability of 0.95 and proves the reliability of the developed model.

The developed complete universal qualimetric model of monetary evaluation of a motor road is the basic parameter of the information and management system for monetary evaluation with substantiation of managerial decisions regarding road- transport assets.

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