

This paper reports a study into the main parameters of long-term contracts for the maintenance of roads. Weaknesses in existing methods and models of substantiation of the initial characteristics of contracts have been identified. It is established that the main reason for the transition to long-term contracts in the road sector is the need to improve the efficiency and effectiveness of road asset management. This determines the main goal to maintain the operational condition of all components of roads at a level that ensures the satisfaction of user requirements and contributes to the preservation of assets.

A simulation model for substantiating the parameters of long-term contracts for road maintenance has been built, which makes it possible to simulate forecast assessments of the characteristics of contracts. Underlying this study is the Monte Carlo method, as well as the triangular law of distribution, models of deterioration and restoration of the condition of road elements. Taking into consideration these models, it was established that the error in justifying the parameters of long-term contracts according to the devised method is up to 10 %.

The devised model was tested by applying the developed original LTCsimula program using an example of the section of a motorway with a length of 87.3 km with an average level of requirements. According to the results of the test, the assessment of the laws of distribution of value, as well as the amount of deductions and profits of a long-term contract, was carried out. The calculation results demonstrated the model's capability to determine the strategies for the maintenance of roads, taking into consideration the risk of implementing a contract with an error of up to 3.9 %.

The practical use of the devised simulation model makes it possible to improve the efficiency of operational maintenance of roads, as well as to save from 10 % to 40 % of the cost of road maintenance

Keywords: motorways, long-term contract, ultimate results, contract parameters, justification method

CONSTRUCTION OF A SIMULATION MODEL FOR SUBSTANTIATING THE PARAMETERS OF LONG-TERM ROAD MAINTENANCE CONTRACTS

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1. Introduction

The unsatisfactory level of maintenance of motorways causes a significant increase in the cost of transportation, a decrease in the level of safety and comfort of road traffic, and the level of environmental safety of roads. These factors negatively affect the socio-economic development of the state and the competitiveness of the economy.

The solution to those issues according to world experience is the so-called performance-based contracts (PBCs). A significant difference between conventional (annual) and long-term contracts is the change in the subject of purchase. Namely, the transition from the volumes of operations and services planned by the customer to the target levels of road performance (service levels) agreed in the long-term contract between the customer and executor.

Long-term contracts based on achieving and maintaining performance indicators are implemented to improve network management efficiency and road maintenance. They can provide a better operational condition of road elements that meets the needs of users. The advantage of such contracts is the construction of a mechanism to stimulate the implementation of innovative technologies by the performer, saving resources with stable long-term financing.

However, the task to substantiate the main parameters of long-term contracts for the maintenance of roads and to quantify their efficiency has not been investigated in detail in the world. The solution to this problem is in the field of devising a new methodology for assessing the impact of the main parameters of long-term contracts on the efficiency and effectiveness of road maintenance. The procedure should take into consideration the complex probabilistic nature of

the processes of deterioration and restoration of the operational condition of roads.

One of the most effective methodological approaches to building decision support systems in complex systems, taking into consideration risks and uncertainties, is simulation modeling. The simulation model of substantiation of parameters of long-term contracts as a result of multiple runs (repetitions) predicts various options for the development of the studied system. Based on the data obtained, recommendations necessary for road agencies to make decisions on network management are compiled. Thus, the relevance of research in this area is to implement the possibility of modeling the parameters for long-term contracts over time.

2. Literature review and problem statement

Study [1] proposed a method for optimizing resource costs for maintaining roads based on the levels of service (LOS). The authors of [1] defined LOS as a quality standard (QS) – the threshold level of the defective state of a road element, which should cause the execution of the corresponding action.

Paper [2] devised a «Guide to choosing the optimal level of service» describing in detail the optimization method LOS and the ASOP software (Algorithm for Selection of Optimum Policy).

To design a rational and consistent basis for choosing optimal LOS parameters, methods for analyzing decision-making were used [3]. A nonlinear algorithm with Boolean variables was applied. That algorithm is an effective tool for maximizing nonlinear functions when it is necessary to choose one of several alternative levels of service, as confirmed by studies reported in [3, 4].

However, the method described in [1–4] and the ASOP software are outdated and have significant drawbacks. In particular, the method reported in [4] does not take into consideration random factors and requires the use of a limited number of specified technologies.

According to the authors of study [5], compiling a long-term contract can be considered a problem within the «principal – agent» system, in which the principal (customer) pays the agent (contractor) for the provision of services. Contracts serve to coordinate the interests of the agent, taking into consideration the principal while the latter pursues his interest. The authors of [5] propose PBC as an effective means to ensure the lowest cost of the life cycle of a motorway. This provides contractors with incentives for the preventive performance of work and the application of innovative engineering solutions. The model from [5] focuses on maximizing the contractor's profits. However, the contractor's problem in the mathematical model is a certain choice of actions to maintain a section of the road at every step of the decision. That requires a significant amount of contractor time to process network maintenance strategies.

Theoretical studies [6–9] proposed a mathematical model based on agency theory in order to analyze road infrastructure management systems. A given model uses the quality indicators of the road condition to establish payment to the contractor. It is assumed that the principal (road administration) can measure the results of the agent's activities only indirectly – by verifying the achievement and support of the LOS indicators by the contractor. It is also assumed that there is a relationship between the efforts of the agent and the levels of operational quality. The analysis of the

optimal incentive mechanism was performed on the basis of a series of parameters characterizing the economic environment and specific conditions of road infrastructure [8]. In that model, the principal's objective function is the social welfare function, which the principal tries to maximize by selecting the parameters that determine the mechanism of remuneration of the contractor. Social benefits derived from road operation, depending on LOS, can be measured using several indicators that are adopted in the model as independent variables. However, the models given in [6] include only static correlation equations, which are not enough to carry out simulations. Paper [7] reports a mechanism for payment under contracts but requires clarification of the risk model. The models described in [8] are not described in detail by time parameters, which makes it difficult to take into consideration the risks of long-term maintenance of roads. In [9], analytical methods and simulations are used that require a large number of input parameters.

The authors of [10, 11] proposed a two-stage PBC simulation model. The structure of that model divides PBC variables into controlled inputs (variable solutions), uncontrolled inputs, and target results. The simulation model was built on the basis of system dynamics. Its goal was to solve the task of devising a strategy for the road administration and the contractor to achieve fair and optimal payments to stakeholders depending on the term of the contract. However, an analysis of [10] revealed that it considers only concession contracts of public-private partnerships. Defects that are the subject of maintenance of roads, given in [11], are not considered at all.

Our review of literary sources showed that studies [1–11] do not propose an effective model for substantiating the parameters of long-term contracts since there is no sufficient experience for statistical conclusions and, accordingly, retrospective results.

3. The aim and objectives of the study

The aim of this study is to build a simulation model for substantiating the parameters of long-term road maintenance contracts, which makes it possible to optimize the decision-making process on road network management strategies under conditions of risk and uncertainty.

To accomplish the aim, the following tasks have been set:

- to determine the essence, main advantages, and disadvantages of long-term contracts for the maintenance of roads;
- to determine the main parameters of long-term contracts;
- to build a mathematical model for substantiating the parameters of a long-term contract;
- to construct a simulation model for assessing the effectiveness and risks of long-term contracts;
- to determine the parameters of the contract for the maintenance of a motorway according to the devised model.

4. The study materials and methods

The object of this study is the process of modeling the parameters of the levels of road maintenance under the imposed restrictions.

We determined the parameters of long-term contacts on operational maintenance of roads according to the Monte Carlo method, triangular distribution law, models of deterioration

and restoration of the condition of road elements. The main hypothesis of this study assumes that an effective approach to the maintenance of roads requires the introduction of long-term contracts, which necessitates a rational justification of their parameters for the customer and the executor of works. Such an approach makes it possible to improve the economic efficiency of maintenance of the road network up to 40%. The main assumption of this study is to take into consideration the theory of risks and the probabilistic nature of the processes of degradation and restoration of elements of motorways. This makes it possible to consider the task of substantiating the parameters of long-term contracts for road maintenance, taking into consideration the modeling of time and feasibility studies. The simulation model built has been implemented in the Excel environment (USA) in the form of our original software ARLTC (Ukraine) and LTCsimula (Ukraine). Such implementation makes it possible to evaluate the laws of distribution of value, the amount of deductions and profits of a long-term contract for an actual object. We tested the model in two versions with a deviation of 3.9% from the basic values at different levels of requirements for a motorway, which confirms the adequacy of the model with a maximum error of 10%.

5. Results of building a simulation model to justify the parameters of long-term contracts for road maintenance

5.1. Defining the essence of long-term contracts for road maintenance

In countries with varying degrees of economic development in the field of road operation, a relatively new form of contracts is used – long-term contracts based on the resulting indicators of road quality (PBC), in particular, the levels of service. The practical implementation of long-term contracts makes it possible to achieve savings from 10% to 40% of the cost of maintenance work compared to the conventional model [12–15]. According to the cited studies, it was found that the cost of road repairs increases six-fold if the maintenance of roads is neglected for three years, and by 18 times if maintenance work is not carried out for five years.

PBCs include minimum levels of performance of elements of the components of motorways – the specifications for the levels of service (LOS), which must be provided by the contractor. The contractor is free to decide what to do, when to do it, how to do it, where to do it; carry out work and/or services independently or subcontracting in order to maintain the condition of roads according to the specifications over the entire period of the contract.

PBC's performance is based on the fact that the contractor can work more efficiently when he has maximum freedom in choosing how the contract is executed («how»), therefore, the road agency (customer) must indicate only the desired result («what»).

Under PBC, work and maintenance services are paid, as a rule, monthly in the same amounts. For failure to reach the technical qualities of roads, payments are reduced. Large emergency, rehabilitation operations, and work on the modernization of road assets are paid on the basis of individual rates.

Conventionally, the main parameters of PBC are the duration; complexity; length, and technical parameters of the components of the roads serviced under the contract; specifications of the

levels of technical qualities that need to be achieved and maintained.

The main components of specifications for long-term contracts are [16]:

- a system of intrusion criteria (Triggers System);
- a set of standards (or rules) for the operational qualities of road elements (Performance Standards – PI);
- a system of road service levels (Level of Services – LOS).

The scheme for managing the condition of roads using long-term contracts based on resulting indicators is shown in Fig. 1.

Consumer properties of road elements include both user requirements for aesthetics, the comfort of movement, accessibility to the service sector, environmental impact, road safety, and transport and operational qualities. Compliance of consumer qualities of roads with the levels of service specified in the specifications of long-term contracts is a criterion for PBC efficiency.

The peculiarity of PBC is that the contractor is fully responsible in case of non-compliance with service levels. He is also responsible for own mistakes in assessing infrastructure wear; selection of the necessary technical project, characteristics and materials that do not meet regulatory requirements; in the planning and organization of works (services).

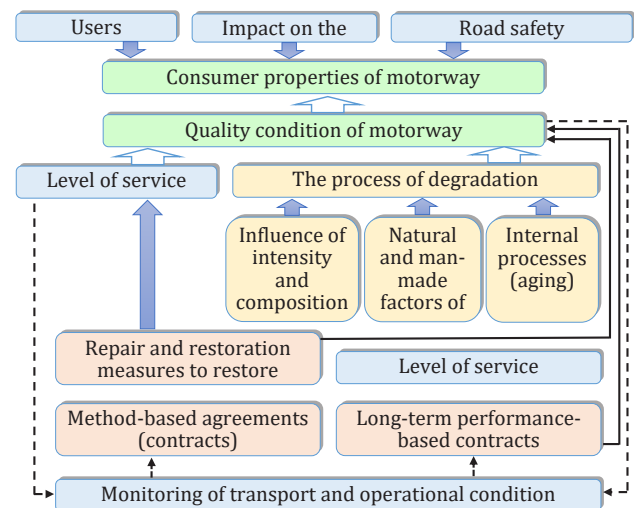


Fig. 1. Road condition management scheme using long-term performance-based contracts [16]

PBCs require the application of the principle of fair risk-sharing between the customer (customer) and the agent (executor). The expected remuneration is proportional to the level of risk that contractors will bear. The nature of risk distribution is shown in Fig. 2.

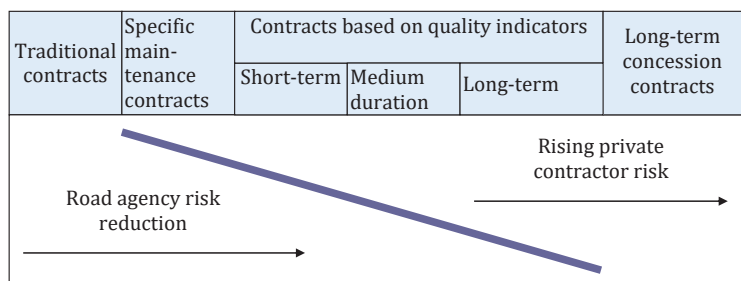


Fig. 2. Distribution of risks between the customer and contractor according to different models of contracts

The central concept of PBC is the minimum levels of operational qualities of road elements. The purpose of their introduction is primarily to satisfy road users with accessibility, comfort, speed, and traffic safety. In addition, they make it possible to reduce the total costs of road users and the road agency, which reduces the cost of the life cycle of assets in general.

The levels of performance established in the contract are achieved through the implementation of service levels that must meet the purpose, be clearly defined, objectively measured, available for understanding, relevant legislation, regulations, and regulatory documents.

Since the service levels set the time to eliminate defects, it is necessary to constantly monitor their availability, timeliness, and quality of elimination. Thus, the executor must carry out daily patrols, submit daily reports to the customer about defects and work done to eliminate them.

Defects can also be controlled only for part of the road network – along those control sections that can be selected randomly or determined by the customer. In this case, the result for the entire network is calculated by multiplying the number of observed defects by the ratio of the total length of the sites to the total length of the sections that were examined.

During the monitoring process, the observer records any defect: the type of defect, the date, time, location, and photos when the defect is detected, and after elimination. When the contractor or customer identifies a defect, the countdown to the elimination of the defect begins – the response period. If the contractor does not have time to eliminate the defect in the period allotted in the service level, the reduction of payments under the penalty system accepted in the contract is automatically calculated.

Payment and incentive systems include the following aspects:

- fixed periodic payments to the executor for support of the levels of performance of assets established in the contract;
- payments based on single rates and volumes of work, including emergency and unforeseen operations, as well as for periodic repairs;
- periodic fixed payments are reduced if the contractor untimely eliminates defects;
- repeated non-compliance with the same clause may increase the reduction in payments by means of the rules provided for in the contract;
- the contract is terminated ahead of schedule due to the failure to reach the established levels of service.

5. 2. Basic parameters of long-term contracts

Our analysis of world experience [1–15] of long-term contracts has revealed that simulation models are most often used to justify their main parameters.

Thus, for further research, the following basic parameters of a long-term contract are accepted (Fig. 3):

- completeness of the contract (all-inclusive or specific);
- duration of the contract, months;
- the length of serviced road sections, their administrative significance and category, km;
- contract operating levels of service;
- contractual levels of requirements for road sections;
- contractual operational levels of maintenance;
- the price of the contract;
- the cost of one penalty point.

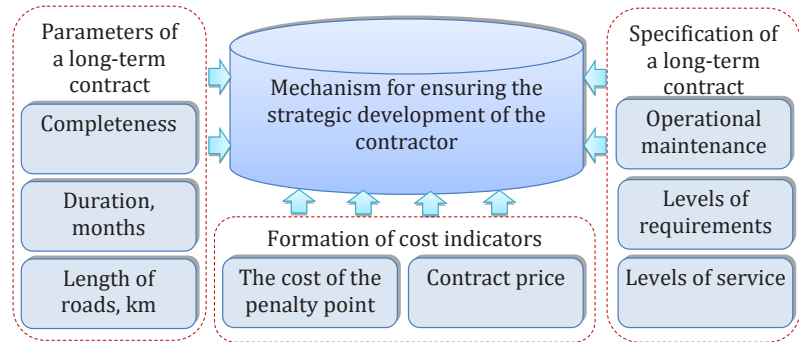


Fig. 3. The main parameters of a long-term contract

Basic parameters must be substantiated primarily because they set a certain framework of the contract, as well as the rules of the process of interaction between the customer and contractor.

The criterion of optimality of the contract for the customer is the maximum function of social welfare (public good), depending on the efforts of the executor, and the criterion for the optimality of the contract for the contractor is the maximum net profit from its implementation (Fig. 4).

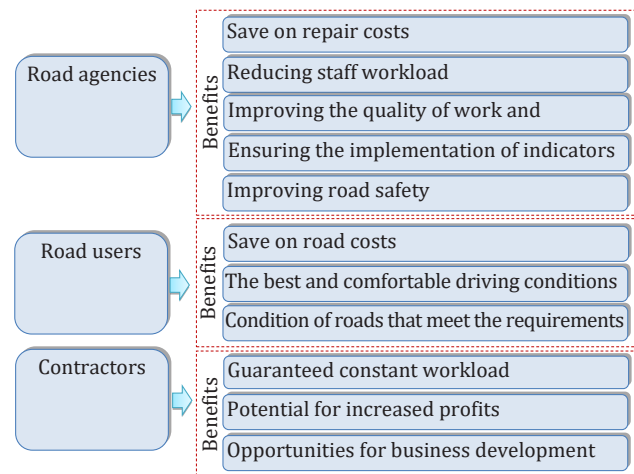


Fig. 4. Benefits of implementing long-term contracts

The contract price is a product of the consensus of the customer and contractor, which is achieved as a result of the purchase of works and/or services for repairs and maintenance of contract sections of roads.

Justification of the parameters of the long-term contract specification depends on the assessment of the impact of defects in the elements of the components of roads, which are eliminated by maintenance measures during the year. This issue is fundamental; it remains unresolved in the theory of road operation. Thus, when constructing a mathematical model for substantiating the parameters of a long-term contract, it is necessary to take into consideration the impact of the development of defects in the elements of road components.

5. 3. Construction of a mathematical model for substantiating the parameters of a long-term contract

Since the model of substantiation of the parameters of a long-term contract is based on the quality of roads, it should take into consideration the complex probabilistic nature of the processes of deterioration and restoration of the condition.

The model of deterioration of road elements is a model of the random process of defect occurrence inherent in each element of the road or part therein. The quantitative assessment of the occurrence of a defect of the j -th type in the i -th time interval of modeling (month) can be given by a system of equations:

$$d_{ji} = \begin{cases} 0, i \notin s_j, i \leq g_j, \\ d_j \cdot k_j(t) \cdot \delta_j, i \in s_j, \end{cases} \quad (1)$$

$$d_i = \sum_{j=1}^{j=N} d_{ji}, \quad (2)$$

where d_{ji} is the number of defects of the j -th type in the i -th time interval, $[d \in N]$; d_i is the total number of defects of all types in the i -th time interval; s_j is the season of the year of elimination of defect of the j -th type; g_j is the number of the last month of the warranty period in which the defect cannot occur (for cumulative defects); t_j is the number of years after the repair of the element of the road to which the j -th defect belongs; $k_j(t)$ is the coefficient depending on the number of years t_j after repair of the road element to which the j -th defect belongs; δ_j is the sign of preventive measure, which takes the value of 1, if the defect is cumulative and its occurrence is prevented, otherwise, it takes a value of 0; N is the number of types of defects.

The model of the process of restoring the operational condition of road elements for one case of the j -th type of defect in the i -th interval of modeling time (month) can be set as follows:

$$C_j = W_j, \quad i \in s_j, \quad (3)$$

$$P_j = \begin{cases} F[\tau_{Mj}, \tau_{Kj}] \cdot Cb_p, i \in s_j, (\tau_{Mj} - \tau_{Kj}) > 0 \\ 0, i \in s_j, (\tau_{Mj} - \tau_{Kj}) \leq 0 \end{cases}, \quad (4)$$

where C_j is the cost of eliminating one case of the j -th type defect, monetary unit; W_j is the cost of work to eliminate one case of a defect of the j -th type in the season of the year, monetary unit; P_j is the fine for one case of exceeding the contractual response period, monetary unit; $F[\tau_{Mj}, \tau_{Kj}]$ is the function of the number of penalty points for exceeding the response period (set according to the specification of operational service levels); τ_{Kj} is the contract response period, day; Cb_p is the cost of one penalty point, monetary unit; s_j is the season of the year.

Payment to the contractor is effected by the customer in monthly payments depending on the timeliness of elimination of defects in road elements. For the untimely elimina-

tion of the defect, the contractor is charged the amount of deductions for payment, the amount of which depends on the number of cases of elimination of defects with a delay and the duration of the delay.

For each operational level of service in the contract, customers set the number of penalty points for exceeding the duration of elimination of the defect for a certain period (usually per unit of time, for example, 24 hours). The number of penalty points (k_p) is fractional (for example, 0.25, 0.5, 1, 1.5, 2) and depends on the degree of impact of the defect on safety, speed, and comfort of movement, road safety, environment, etc.

Depending on the degree of excess of the duration of the time of elimination of the defect of the response period of the service level under the contract, the intervals of time for eliminating the defect and k_p , which increase the number of penalty points, are set to the number of defects recorded in each interval (Table 1).

The number N of the time interval of the actual (model) elimination of the i -th defect is determined from the formula:

$$N = \left\lceil \frac{\tau_{Mi}}{\tau_{Ki}} \right\rceil, \quad (5)$$

where τ_{Ki} is the response period under the contract, day (or hour); τ_{Mi} is the actual duration of elimination of the defect, day (or hour).

As a criterion for assigning the main characteristics of the contract, the maximum net present value of the performer's profit is used:

$$D_{NPV} = \sum_{t=0}^T \frac{C_t - [Cs_t + E_t + P_t]}{(1+i)^t} \Rightarrow \max, \quad (6)$$

under the constraints:

$$\sum_{t=1}^T \frac{C_t - P_t}{(1+i)^t} > \sum_{t=0}^T \frac{Cs_t + E_t}{(1+i)^t}, \quad (7)$$

where T is the duration of the contract, month; C_t is the monthly payments for works and services under the contract in the t -th month, monetary unit; P_t is the amount of deductions for penalty points accrued for the t -th month, monetary unit; i is the monthly discount rate adjusted for the inflation index; Cs_t – the cost of work and services under the contract in the t -th month, which is determined by the estimated calculation of the contractual price, monetary unit; E – other expenses: funds to cover administrative expenses, funds to cover risks, funds for risk insurance, taxes, fees, other mandatory payments that are established by the current legislation, which are determined according to the estimated calculation of the contractual price, monetary unit.

Table 1

Distribution of defects depending on the time of their elimination

Defect elimination time intervals	$0 < \tau_M \leq 1\tau_K$	$\tau_K < \tau_M \leq 2\tau_K$	$2\tau_K < \tau_M \leq 3\tau_K$	$3\tau_K < \tau_M \leq 4\tau_K$	$\tau_M > 4\tau_K$
Number of defects eliminated	d_1	d_2	d_3	d_4	d_5
Coefficients of increase of penalty points k_p	k_{p1} not applicable (non-existent)	$k_{p2}=1$	$k_{p3}=2$	$k_{p4}=3$	$k_{p5}=4$
Number of cases of elimination of defects taking into account k_p	$Q_1=d_1$	$Q_2=k_{p2} \cdot d_2$	$Q_3=k_{p3} \cdot d_3$	$Q_4=k_{p4} \cdot d_4$	$Q_5=k_{p5} \cdot d_5$

The amount of deductions for accrued penalty points P_t is determined from the formula:

$$P_t = \sum_{j=1}^{D_{t,j}} \left[Cb_t \cdot n_j \cdot \sum_{i=2}^{i=5} Q_{t,j,i} \right], \quad (8)$$

where Cb_t is the cost of one penalty point in the t -th month, which, if necessary, is reviewed every year of the contract, monetary unit; n_j is the value of the penalty point (including fractional) for a defect of the i -th type for exceeding the actual response period for the elimination of the defect over the response period under the contract per unit of time; $Q_{t,j,i}$ is the number of cases of defects exceeding the response time when eliminating the defect of the j -th type in the i -th excess interval in the t -th month.

For further research, the mathematical model built to substantiate the parameters of long-term contracts became the basis of an imitation model for assessing their effectiveness.

5.4. Simulation model for assessing the effectiveness and risks of long-term contracts

In our study, we accept that the «ex ante» phase includes the stages of preliminary bidding and signing of the contract while the «ex post» phase is the stage of contract execution. However, as early as in the «ex ante» phase, the contractor and the road administration need to assess the possible economic efficiency and risks of the contract, therefore, to perform the «ex post» phase modeling. Such an assessment is proposed to be made using a simulation model using expert judgments, which is built on the basis of the following considerations:

- the presence of many types of defects, which requires the use of a significant number of levels of service in the contract specification;
- random occurrence and progress of defects in time, the randomness of their number;
- random duration of elimination of defects;
- the presence of small values of the ratios «signal – noise» in cumulative damage (less than 15) – the inverse value of the coefficient of variation, which does not allow the use of classical Newtonian mechanics to predict the accumulation of damage;
- the lack of historical data on the actual time of elimination of defects (damage), therefore, statistical models of forecasting such time. This predetermines the need to apply expert judgments on the parameters of the presumptuous distributions of the actual time of elimination of defects, the actual cost, and the actual random number of defects at certain time intervals.

The proposed evaluation method is implemented on the basis of data representation in two-dimensional tables with their successive transformation. This is due to the introduction of expert assessments of the parameters of triangular distribution laws with respect to time, cost, and volume parameters of the levels of servicing defects followed by simulation [17, 18], according to the scheme shown in Fig. 5.

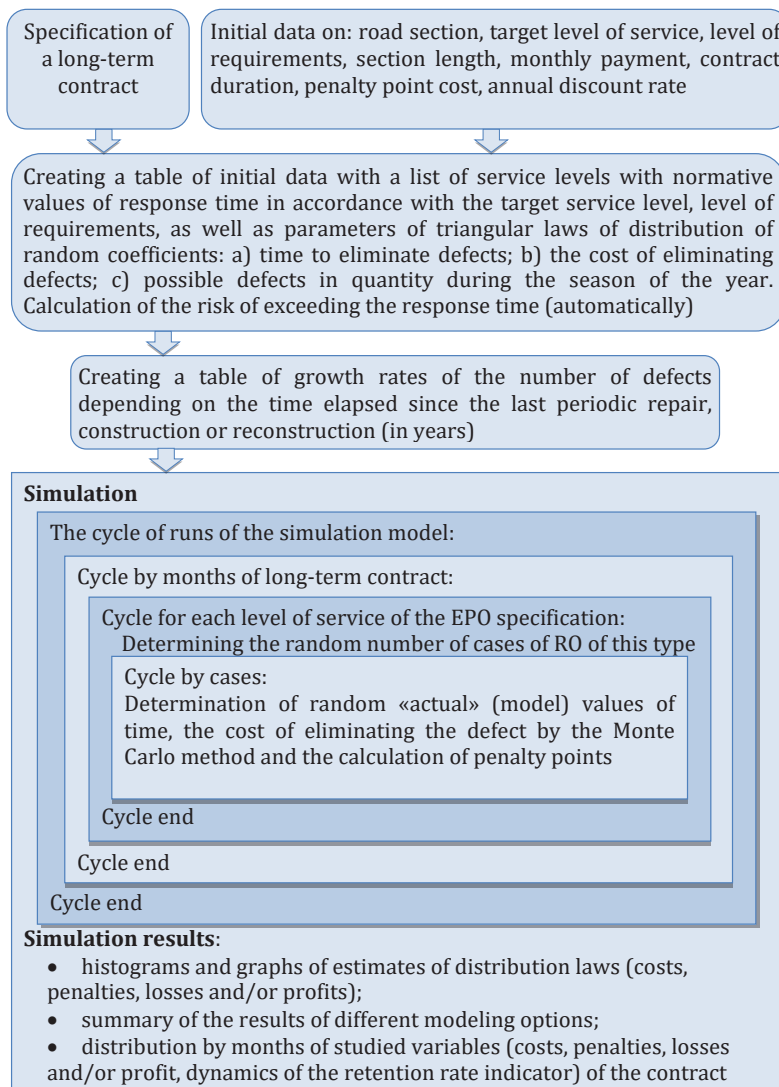


Fig. 5. Contract pre-assessment scheme

The simulation of random variables is carried out by the Monte Carlo method using the formulas of the triangular distribution law with the lower limit a , the upper limit b , and the mode c , where $a < b$ and $a < c \leq b$.

Since the actual period of elimination of the defect in the contract is accidental, it is necessary to determine the parameters of the distribution laws for all levels of service, as well as to take into consideration the random nature of the cost of eliminating each case of the defect and the number of cases. Thus, the problem of finding rational values of the main parameters of contracts is multidimensional and time-consuming.

The schematic diagram of simulation modeling of parameters of long-term contracts is shown in Fig. 6.

To assess the risk of exceeding the response period, from the set of historical data on the elimination of the defect, three estimates of duration are selected:

- a – minimal;
- b – maximal;
- c – most likely.

In the case of lack or absence of historical data on the time of elimination of the defect, these three estimates of the duration of work to eliminate the defect are determined by road maintenance experts.

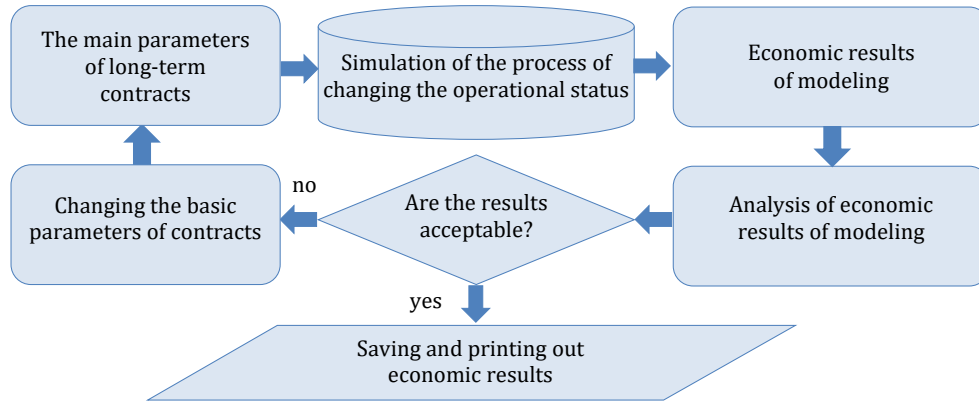


Fig. 6. Schematic diagram of simulation

During the justification of the response period under the contract, it is necessary to check the fulfillment of the following condition:

$$t_K \leq t_N, \tag{9}$$

where t_K is the response period under the contract, day; t_N is the normative response period, day.

The analytical procedure for assessing the risk of exceeding the response period of the level of service under the contract is carried out in the following sequence:

- estimates of the duration of defect elimination are determined: a, b, c ;
- set $t_{i,j}$ – the term of response under the contract to eliminate the j -th defect of the i -th element of the road or part thereof;
- the value of the probability $F(t_{i,j}^A)$ of completion of work within the term of response under the contract $t_{i,j}^A$ is calculated according to the formula of the triangular law of distribution of the random amount of time to eliminate the defect:

$$F(t_{i,j}^A) = \begin{cases} 0, & t_{i,j}^A < a, \\ \frac{(t_{i,j}^A - a)^2}{(b-a)\{c-a\}}, & a \leq t_{i,j}^A \leq c, \\ 1 - \frac{(b - t_{i,j}^A)^2}{(b-a)\{b-c\}}, & c \leq t_{i,j}^A \leq b, \\ 1, & b < t_{i,j}^A; \end{cases} \tag{10}$$

– calculate the risk of exceeding the response period under the contract:

$$R_{i,j} = 1 - F(t_{i,j}^A). \tag{11}$$

Evaluation of the parameters of the triangular laws of distribution of three random coefficients in this study is proposed to be carried out by interviewing experts through a template that is formed on the basis of the ARLTC software that we developed in the Excel environment. The program includes the automatic formation of an expert survey questionnaire, which contains the sample values of the relevant assessments of the parameters to be edited by the expert. A fixed template is a datasheet for simulation modeling.

The process of simulation modeling (evaluation of the parameters of triangular distribution laws) is automated in the LTCsimula software that we developed.

5. 5. Results of determining the parameters of the contract for the maintenance of a motorway according to the devised model

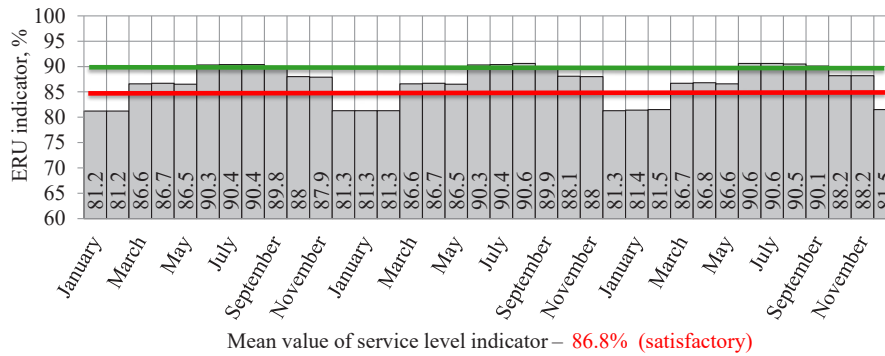
To determine the adequacy of the proposed model, a section of the motorway with a length of 87.3 km with an average level of requirements was chosen as an example. The monthly payment under the contract is 1,200 thousand monetary units; duration, 36 months; the cost of a penalty point is 1.0 thousand monetary units.

With the help of the LTCsimula software, an assessment of the laws of distribution of value, the amount of deductions and profits of a long-term contract was determined; the corresponding charts were constructed for two options (Table 2, Fig. 7, 8).

Table 2

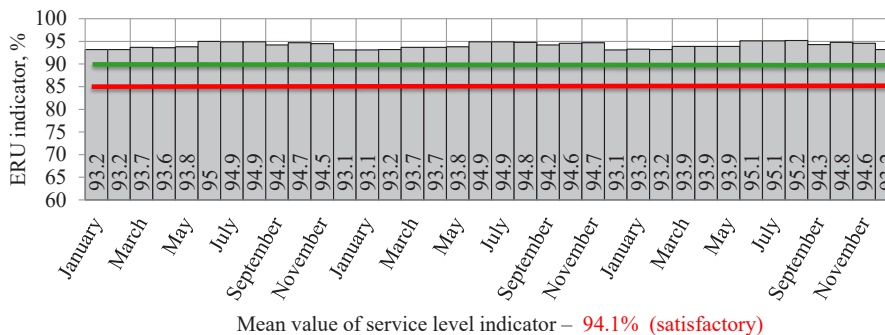
Evaluation of the laws of distribution of the studied economic indicators of the long-term contract in two variants

Group of indicators	Indicator name	Variant 1	Variant 2
Reduction of the payment amount	Average amount, thousand monetary units	3,282.00	2,286.00
	Standard deviation, σ	270	145
	Variance factor (V_{ar}), %	7.14	6.35
	The average number of penalty points	4,676	2,710
	Per 1 km, thousand monetary units, annually	14.46	8.73
Costs	Average amount, thousand monetary units	38,638.00	38,446
	Standard deviation, σ	1,001	999
	Variance factor (V_{ar}), %	2.6	2,6
	Per 1 km, thousand monetary units, annually	146.77	146.80
Profit	Average profit, thousand monetary units	1,429.00	2,922.00
	Standard deviation, σ	1,226.55	1,114.08
	Variance factor (V_{ar}), %	85.00	38.13
	Per 1 km, thousand monetary units, annually	5.46	11.16
Economic efficiency, EE, %		3.7	7.6



Mean value of service level indicator – 86.8% (satisfactory)

Fig. 7. Indicator of the level of maintenance of a long-term contract according to the first option (in the figure, the bottom limit of the indicator modeling is indicated by the red line, the upper one is green)



Mean value of service level indicator – 94.1% (satisfactory)

Fig. 8. Indicator of the level of maintenance of a long-term contract for the second option (in the figure, the red line indicates the lower limit of modeling the indicator, green – upper)

In Table 2, the difference between options 1 and 2 is that they specify different parameters of triangular laws for the distribution of the duration of the elimination of defects for part of the service levels. The first option specifies larger maximum parameters *b*, exceeding the value of 1, and in the second – smaller.

Thus, with smaller parameters of the upper limit for assessing the duration of elimination of defects at other stable parameters, the economic efficiency achieved was 3.9 % higher than at higher valuation values.

The next step is the process of assessing the risk of the implementation of the contract, which is proposed to be carried out according to the scheme shown in Fig. 9.

The risk of making a profit is greater than shown in the scheme is $0.9000 \cdot 100 \% = 90 \%$, so the probability of making a higher profit is 10 %.

Similarly, it is possible to assess the risks separately for the actual cost of eliminating defects and the amount of deductions.

Thus, the simulation model built makes it possible to simulate various strategies for the maintenance of roads, taking into consideration the risk of the contract.

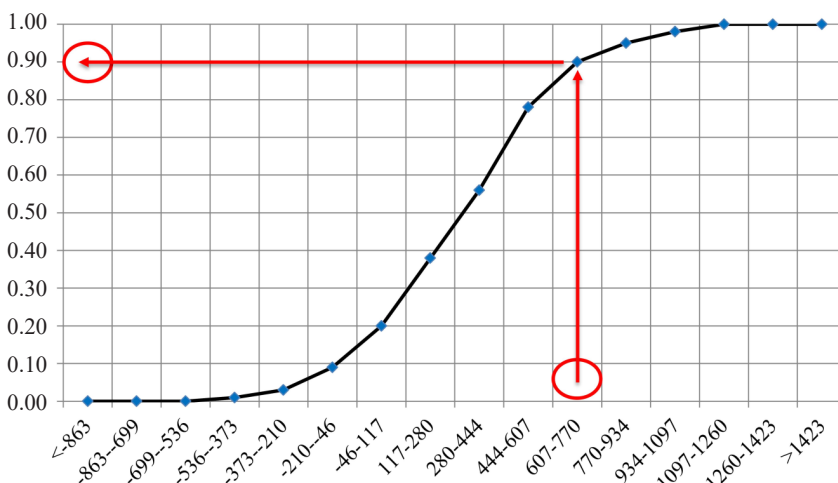


Fig. 9. Scheme for determining the risk of profit from the implementation of a long-term contract based on an assessment of the integral distribution law

6. Discussion of results of testing the simulation model for assessing the effectiveness and risks of long-term contracts

Our analysis of the advantages, disadvantages, and effectiveness of the use of long-term contracts for the maintenance of roads, based on quality indicators, has made it possible to determine the main issues related to modeling their parameters in the «ex post» phase (Fig. 1).

Our analysis of the experience of long-term contracts in world practice has made it possible to determine that in order to substantiate the main parameters of contracts (Fig. 3, 4), it is necessary to build an effective simulation model that is based on risk theory.

We have constructed a mathematical model for substantiating the para-

meters of a long-term contract (6), (8), which, unlike the conventional approach, is based on the quality of roads and takes into consideration models describing the processes of deterioration (1), (2) and restoration of condition (3), (4).

When developing the model, it is taken into consideration that the management of road assets is a systematic process of maintenance, modernization, expansion of road assets using engineering principles and reliable business practices for the effective and effective distribution and use of resources. The main purpose of building the model is to provide clearly defined levels of asset retention to meet public expectations. Thus, it is established that the main advantages of the devised model are the constant maintenance of roads at a high level. This makes it possible to reduce the cost of the life cycle of assets and reduce the cost of road users. The model enables the monitoring and tracking of performance, which contributes to transparency in decision-making and the ability to predict the consequences of financing, as well as reduce financial, operational, and legal risks.

The basis for determining the parameters of the laws of distribution of the desired random variables (the actual time for eliminating defects, the actual cost of work, losses, or profits) in the mathematical model built is the triangular distribution of random variables (10). This mathematical model serves as a prerequisite for substantiating the parameters of a long-term contract in the «ex post» phase, which is the basis of the corresponding simulation model (Fig. 5, 6).

Automation of calculations according to the devised model is carried out in the Excel environment in the form of our original software ARLTC and LTCsimula. Economic efficiency in modeling the parameters of a long-term contract showed a deviation of 3.9 % from the base values (Table 2, Fig. 7, 8). Such an error has been tested for adequacy, taking into consideration the theory of risks, which determines the reliability of the model (Fig. 9).

Features of the developed software could be used both in the preliminary justification of the cost of a long-term contract for the maintenance of motorways and in different phases of the contract.

The limitations of the use of the developed simulation model are that when making calculations, the impact of unpredictable costs is not taken into consideration. This may be the subject of further advancement of our study.

7. Conclusions

1. Our analysis of the experience of assessing the main parameters of long-term contracts showed that most often simulation models based on system dynamics are used to justify them. It has been established that to solve this problem, it is necessary to use a number of analytical mathematical models

based on systems of differential equations in partial derivatives, dynamic programming models, and game theory. The theoretical basis for the research of long-term contracts is the theory of the agency, together with the theory of road operation, taking into consideration the asymmetry of information between the road administration (principal) and the contractor (agent) and their relationship to risk. It is determined that the transition from internal servicing of assets by own personnel in conventional contracts to long-term contracts with the private sector can save from 10 % to 40 % of the cost of road maintenance.

2. It is proposed to use such parameters as the completeness of the contract, duration of validity, length of road sections, operational levels of service, levels of requirements for road sections, operational levels of maintenance, contract price, and cost of one penalty point for modeling long-term contracts. It is determined that these parameters must be substantiated for the formation of interaction between the customer and contractor, taking into consideration risk and uncertainty. The accepted criterion of optimal contract for the customer is the maximum function of public welfare and the criterion of optimal contract for the contractor – the maximum net profit from its implementation.

3. It has been determined that when building a model for justifying the parameters of a long-term contract, it is necessary to take into consideration the complex probabilistic nature of the processes of deterioration and restoration of the condition of roads. Since the task of preliminary risk assessment and economic efficiency of long-term contracts is a complex multidimensional problem with many uncertainties, the model predetermines the use of expert assessments. To determine the parameters of the laws of distribution of the desired random variables (the actual time to eliminate defects, the actual cost of work, losses, or profits), a triangular distribution of random variables is used. The constructed mathematical model of substantiation of the parameters of a long-term contract is the basis for devising a tool for predicting its future implementation – an imitation model of the «ex post» phase.

4. The simulation model is implemented in the Excel environment in the form of ARLTC and LTCsimula software that we developed. This implementation of the solution has made it possible to simplify the assessment of the economic and time parameters of contracts under the triangular law of distribution. However, this implementation can only be considered a prototype of industrial versions of the relevant software in this area.

5. The LTCsimula program was used to evaluate the laws of distribution of value, the amount of deductions and profit of a long-term contract for an actual object for two options of its implementation. We determined that the economic efficiency in modeling showed a deviation of 3.9 % from the base values at different levels of requirements for the motorway. This discrepancy was assessed from the point of risk theory; we have proved the adequacy of the model with a maximum error of 10 %.

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