METHOD OF EVALUATION OF ROAD ROUTINE MAINTENANCE STRATEGIES

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Abstract. *The current unsatisfactory condition of most roads in Ukraine causes a significant increase in the cost of transportation, reducing 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, the competitiveness of its economy and defense capabilities. The need to solve the problem of unsatisfactory condition of roads led to the reform of the road management system of Ukraine, the implementation of which paved the way for the strategic development of road maintenance enterprises (RME). The mechanism of ensuring the strategic development of road maintenance enterprises in the maintenance of roads can be implemented through the introduction of long-term agreements (contracts), in which payment for services and works directly depends on the RME clearly set requirements to maintain the final quality indicators of road performance. The problem of substantiation of measures to ensure the strategic development of road maintenance enterprises and quantification of their economic effectiveness in the application of long-term contracts in the selection of contractors and contracts (ex ante) and contract implementation (ex post) is insufficiently studied not only in Ukraine but also in the world. The method of evaluating the effectiveness of the road maintenance strategy is based on the application of a simulation model of the road maintenance process. A discrete-event simulation model with system time "Δt" has been developed (ex post). It is not necessary to record the moments of occurrence of the defect and its elimination.The most difficult issue is the quantification of the impact on public benefits of the parameters of service levels set within the operational maintenance of roads. The impact of only a small number of defects on the value of the public welfare function is sufficiently studied and can be quantified, but such defects are eliminated by capital and current average repairs. For defects that are remedied by retention, the impact on the welfare function is less obvious. There are no models for assessing such impacts. The input parameters of the simulation model are the main parameters of the long-term contract. These include length of road sections; duration of the contract; amount of monthly payment for the performance of works and provision of road maintenance services; cost of one penalty point for the operational condition of road sections; contractual level of maintenance. Random variables are modeled according to triangular distribution laws, the parameters of which are set by the expert method, due to the complete absence of statistical observations. The output of the simulation model is to estimate the probabilistic distributions of random values of costs of works and services, amounts of deductions for payment of RME, loss or profit, the dynamics of these values in the contract period and the dynamics of the retention rate and their derivatives. It is shown that the operational state of road elements is formed under the influence of two processes: degradation process, i.e. the occurrence and development in time and space of defects of road elements, which are the result of external and internal factors. The process of degradation of each element can be cumulative, discrete and discrete-continuous; renovation process - elimination of defects of road elements by RME forces through repair and maintenance of road elements. Two road maintenance strategies were explored: support strategy (corrective), which is to eliminate defects in road elements when they reach the level of intervention; anticipation strategy (preventive), which consists in the early execution of certain works, when the causes of cumulative defects are eliminated before the defects reach the level of intervention.*

Keywords: *management, method of evaluation, road routine maintenance strategies.*

JEL Classification: C02, L90, L91, R40

Formulas: 4; fig.: 1; tabl.: 0; bibl.: 6

Introduction. The current unsatisfactory condition of most roads in Ukraine causes a significant increase in the cost of transportation, reducing 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 Ukraine, the competitiveness of its economy and defense capabilities. The need to solve the problem of unsatisfactory condition of roads led to the reform of the road management system of Ukraine, the implementation of which paved the way for the strategic development of road maintenance enterprises (RME). The mechanism of ensuring the strategic development of RME in the routine maintenance of roads can be implemented through the implementation of long-term contracts, in which payment for services and works of the RME directly depends on clearly set requirements to maintain quality performance of roads.

However, the problem of substantiation of measures to ensure the strategic development of RME and quantification of their economic efficiency in terms of long-term contracts in the selection of contractors (ex ante) and contract implementation (ex post) is insufficiently studied not only in Ukraine but also in the world.

Literature review. The main provisions of this article are based on the works of O. Hart, B. Holmstrom, L. Hurwicz, J.-J. Laffont, E. Maskin, R. Myerson, J. Tirole, P, Pakkala, C. Queiroz, A.S. Soliño, N. Stankevich, G. Zietlow and many others.

A.S. Soliño proposed an analytical optimization model of the contractor incentive mechanism in a long-term contract, based on solving a system of differential equations in partial derivatives by the criterion of maximum social welfare function, but this model does not contain time variables and has strict constraints utility of the contractor, which must have a third derivative. The model operates with a small number of independent variables - levels of service (LOS) [1, 2, 3, 4]. Model cannot display the dynamics of the road maintenance process.

An example of a model with a variable time is the model of D. Gupta, A. Vedantam, J. Azadivar [5] with an optimization algorithm by the induction method. The general approach for distress prediction is based upon the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) pavement performance predictions (MEPDG), but to perform computations quickly Closed Form Solutions (CFS) have been developed. CFS predict a single value for each distress at the end of project design life. Monte-Carlo simulations are run on the CFS with the design specifications as input to predict the as-designed distress. The as-designed distress is then used to predict the remaining service life of the pavement. Similarly, Monte-Carlo simulations are run using as-built specifications as input to estimate the remaining service life. Predicted Life Difference (PLD) is calculated as the difference in service life predicted for as-designed and as-built specifications. Based on the PLD, either a penalty or a bonus (I/D) is assigned to the contractor on a lot-by-lot basis. These are weighted for different distress types and added to obtain total penalty/bonus. Finally a ride quality I/D based on the International Roughness Index (IRI) is add. Model is used for periodic repair of the road surface. Only two types of defects are taken into account - rutting and a alligator/fatigue cracking for hot mix asphalt.pavement.

The purpose of study [6] was to determine the duration of performance-based contracts that best optimize payments for both parties, namely the government (service users) and the private sector as service providers (performers). None of them can get more profit or benefit when the other is in a difficult situation. To do this, a simulation model was developed based on the approach from the standpoint of system dynamics of Jay Forrester. A systematic dynamic approach fits into the development of performance-based contracts, which have features of complexity, ranging from multi-actor, multi-sectoral and long-term participation. The complexity of long-term contracts is classified as dynamic complexity because it has many possible events.

The model [6] is also based on game theory. None of the construction projects is without risk. The risk must be shared between the parties involved in such a way that neither party is harmed. A study was conducted on the distribution of risk between the parties involved in construction contracts, as well as in a state of stability. The results of statistical analysis show that most are made by scientists from countries such as China, the United States, Australia and the United Kingdom. Researchers have found that many conclusions in which decision-making benefits only one party to the construction contract, i.e. the owner, and the other is not profitable. This causes a lot of legal controversy, the implementation of irrational construction projects in general. The distribution of risk between the parties to the construction contract should be based on the theory of cooperative games, in which the decision is made taking into account the needs of all stakeholders [6, p. 4434].

The analysis of the work [6] showed that it considers concession contracts of public-private partnership. Defects that are subject to road maintenance are not considered. Qualitative categories (such as low, medium, high) are used.

The above suggests that simulation models of deterioration and restoration, maintenance of road conditions are, according to the author of this article, the most promising area of development as part of the mechanism to stimulate road maintenance, but they must take into account the specific nature of defects inherent in maintenance of all elements of highways.

Aims. The aim of the study is to propose a method of probabilistic evaluation of the strategy of road maintenance by applying a simulation model of the road maintenance process.

Methods. The main methids of the study is computer experiment using the author's simulation model of the road maintenance process.

Results. In order to take into account public benefits and, through them, public welfare, the impact of which cannot currently be measured and assessed for most levels of defect maintenance, an approach is proposed that sets a lower limit on performance as a constraint that guarantees a certain level of public serviceability. benefits.

A discrete-event simulation model with system time "Δt" has been developed, which is a component of the mechanism for ensuring the strategic development of

RME (ex post) and a tool for its study. In each of the intervals "Δt" there is a random number of events for the elimination of defects, and in the middle of "Δt". It is not necessary to record the moments of occurrence of the defect and its elimination.The most difficult issue is the quantification of the impact on public benefits of the parameters of service levels set within the operational maintenance of roads. The impact of only a small number of defects on the value of the public welfare function is sufficiently studied and can be quantified, but such defects are eliminated by capital and current average repairs. For defects that are remedied by retention, the impact on the welfare function is less obvious. There are no models for assessing such impacts.

The operational state of the elements of roads is formed under the influence of two processes:

– degradation process, i.e. the occurrence and development in time and space of defects of road elements, which are the result of external and internal factors. The process of degradation of each element can be cumulative, discrete and discrete-continuous;

– process of restoration - elimination by RME forces of defects of road elements by performance of works on repair and rendering of services on the maintenance of elements of roads.

The basis of the simulation model is the forecast model, which determines the mathematical relationships between the numerical variables of the forecast of the selected financial indicators: value, penalty, profit and the level of maintenance.

As a basic model for analysis, the models of Π_{NPV} profit and penalties $Ш_t$ are proposed:

$$\Pi_{NPV} = \sum_{t=0}^{T} \frac{В_t - (СР_t + ІВ_t + Ш_t)}{(1+d)^t}; \quad \sum_{t=1}^{T} \frac{В_t - Ш_t}{(1+d)^t} > \sum_{t=0}^{T} \frac{СР_t + ІВ_t}{(1+d)^t}, \qquad (1)$$

where T is the duration of the contract, months; B_t – monthly payment for works and services in the t-th month, UAH; $Ш_t$ – amounts of deductions for penalty points accrued for the month, UAH; d is the monthly discount rate adjusted for the inflation index; CP_t – cost of works and services under the contract in the t-th month, UAH; IB_t – other expenses: funds to cover administrative expenses, funds to cover risks, funds for risk insurance, taxes, fees, other mandatory payments established by current legislation, UAH.

The cost of works and services in the *t*-th month is determined by the formula:

$$– \qquad CP_t = \sum_{i=1}^{E_t} \sum_{j=1}^{D_{t,i}} \left(C_{i,j}(t^y_{i,j}) \cdot n_{t,i,j} \right), \qquad (2)$$

where E_t is the number of road elements that are serviced in the t-th month; $D_{t,i}$ – the number of types of defects of the i-th element of the road in the t-th month; $t^y_{i,j}$ – duration of elimination of one defect of the j-th type of the i-th element, days; $C_{i,j}(t^y_{i,j})$ – the cost function of the work or service to eliminate one defect of the j-th type of the i-th element, which depends on the selected elimination technology; $n_{t,i,j}$ – the number of defects of the j-th type of the i-th element in the t-th month.

The amount of deductions for penalty points $Ш_t$ is determined by the formula:

$$Ш_t = \sum_{i=1}^{E_t} \sum_{j=1}^{D_{t,i}} \left[cb_t \cdot P_{i,j}\left(q_{t,i,j}\right)\right], \quad (3)$$

where cb_t – the cost of one penalty point in the t-th month, which may be revised each year of the contract, UAH.; $q_{t,i,j}$ – the number of the interval of exceedances of the response period at elimination j-th defect of the i-th element in the t-th month; $P_{i,j}(q_{t,I,j})$ – the function of calculating the number of penalty points adopted at the conclusion of the contract, which depends on the number of intervals of exceeding the response period when eliminating the j-th defect of the i-th element, $P_{i,j}(0) = 0$.

It is accepted that the process of performing works and services to eliminate defects is under the influence of random factors. Their impact on the duration, cost, penalties, profit and level of service is proposed to be assessed through three sets of triangular laws of distribution of random variables, which are characterized by three parameters of values: *a* - minimum; *b* - maximum; *c* is the most probable. The model ("actual") value is determined by the Monte-Carlo method according to the known formulas of the triangular distribution law as a function of a uniformly evenly distributed in the range from 0 to 1 random number obtained using a random number generator.

When the "actual" (model) value of the duration of elimination of the defect exceeds the response period stipulated in the contract, the RME is charged a deduction from the amounts of payment (fine).

$$У = cb \cdot n \cdot \sum_{i=1}^{i=5} (k_i^{ш} \cdot q_i), \quad (4)$$

where У – penalty, UAH; n – fractional number of penalty points per unit time of excess; cb – the cost of 1 penalty point, UAH; $k_i^{ш}$ – coefficient to the penalty for delay in execution; q_i – the number of units exceeding the response time

Maintenance are considered: support strategy (corrective), which is to eliminate defects in road elements when they reach the level of intervention; anticipation strategy (preventive), which consists in the early execution of certain works, when the causes of cumulative defects are eliminated before the defects reach the level of intervention.

Discussion. A method for evaluating road maintenance strategies has been developed, based on the application of a simulation model of the road maintenance process, which makes it possible to predict estimates of probabilistic laws of distribution of economic results - cost, fines, profit and road retention level.

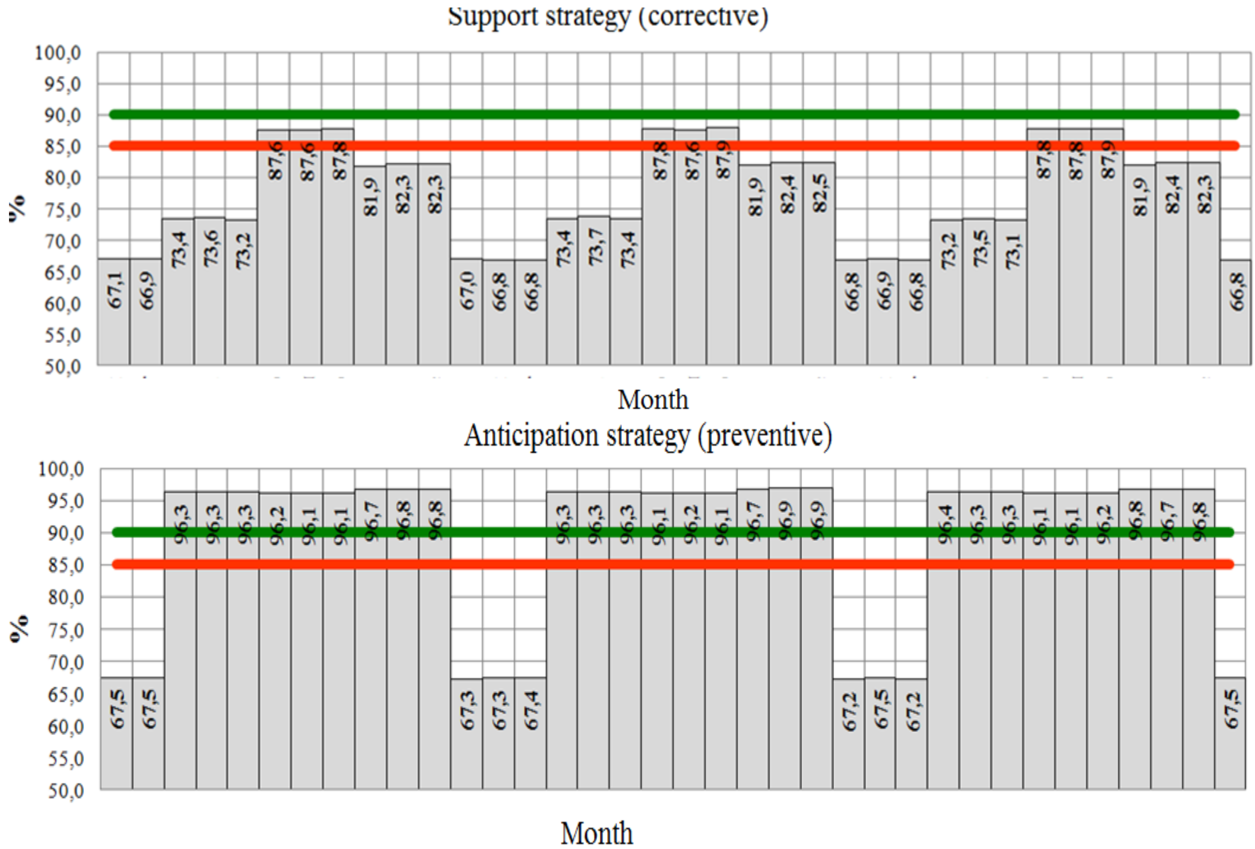

Figure 1. Diagrams of indicators of the level of retention, % – part of defects that are eliminated without exceeding the contractual response period

Conclusions. Based on the results of the study, it is possible to draw blunt conclusions. It is shown that the operational state of road elements is formed under the influence of two processes: degradation process, i.e. the occurrence and development in time and space of defects of road elements, which are the result of external and internal factors. The process of degradation of each element can be cumulative, discrete and discrete-continuous; renovation process - elimination of defects of road elements by RME forces through repair and maintenance of road elements. Two road maintenance strategies were explored: support strategy (corrective), which is to eliminate defects in road elements when they reach the level of intervention; anticipation strategy (preventive), which consists in the early execution of certain works, when the causes of cumulative defects are eliminated before the defects reach the level of intervention.

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