UDC 004.942:625.7/8
DOI: 10.15587/2706-5448.2021.225532
Article type «Reports on Research Projects»

Anna Kharchenko,
Oleh Zaviyskyy,
Vitalii Tsybulskyi,
Serhii Zavorotnyi

DEVELOPMENT OF METHODS FOR PARAMETERS OF LONG-TERM CONTRACTS OPTIMIZATION FOR OPERATIONAL ROAD MAINTENANCE

The object of research is the processes of cost, duration and quality management in long-term contracts for the maintenance of roads. The presented work is based on the use of project management theory. The main hypothesis of the study is the application of methods for optimizing the parameters of long-term contracts for the maintenance of roads. Features, advantages and problematic issues concerning the use of long-term contracts based on quality indicators in the road sector are considered. The world and domestic experience of introduction of long-term maintenance of highways is analyzed. The main approaches to optimization of parameters are defined and the mathematical model of management of processes of cost, duration and quality in long-term contracts is developed. Based on the model, two methods of mathematical solution of the optimization problem of the proposed parameters have been developed. A mathematical experiment based on the example of the project of long-term maintenance of roads on the final quality indicators, the results of which showed that the adaptive capacity of projects by the second method is less flexible than the first. But the second method achieved better performance to minimize time parameters with averaging at 5 %. Optimization of parameters of long-term contracts for maintenance of roads has a multiplier effect, which is expressed in reducing administrative costs of the customer, reducing the responsibility of road services, creating conditions for stable financing of road works, satisfaction of road users, building strong partnerships between the customer and the contract. The results of calculations have practical value and can serve as a tool for making sound management decisions to determine the basic parameters of long-term contracts for the maintenance of roads based on quality.

Keywords: *optimization methods, long-term contract parameters, maintenance, financing for road works.*

Received date: 21.10.2020
Accepted date: 14.12.2020
Published date: 26.02.2021

1. Introduction

In modern world practice, a wide variety of approaches to the maintenance of highways are used. The most common is withholding under a traditional contract (by type of work), in which payment is made for the amount of work performed. Many studies have shown that the complexity of the formation of contracts is caused by the inefficiency of traditional methods. This has led to the rapid development of new types and models of road maintenance contracts around the world.

The author of [1] points out the drawback of such systems in which the customer is fully responsible for the risks of projects, including those associated with the introduction of new technologies and materials. Thus, both public and private organizations maintain a large number of additional personnel to monitor the risks of road maintenance contracts.

In the United States, the American Association of Civil Engineers (ASCE) has published a report on the study of road infrastructure, in which American researchers expressed their critical view of the existing types and models of long-term contracts [1].

The main issues that generated this negative response from researchers were:

– inability of contractors to use modern innovations and innovations;

– constant growing costs of road maintenance;

– significant responsibility is assigned to road agencies, while contractors do not bear responsibility and do not provide any guarantees regarding the condition of roads during maintenance, that is, there is a risk of not reaching the required operational condition.

According to world experience, the solution to these problems can be the so-called long-term contracts based on final quality indicators, which must, in turn, be optimized in terms of time, duration and cost for their effective implementation, for example, in Ukraine.

The object of research is the processes of cost, duration and quality management in long-term contracts for the maintenance of highways. *The aim of research* is to develop methods for optimizing the parameters of long-term contracts for the maintenance of highways.

2. Methods of research

End-of-Line Long Term Contracts (LTC) are an agreement (contract) between a government road agency and a contractor. On the LTC basis, the contractor ensures the

ISSN 2664-9969

maintenance of highways at the appropriate level on time, specified in the contract. The State Highway Agency is contractually obligated to make payments on time, subject to the quality indicators. According to studies [2], these indicators include: the strength of the road surface, roadside management, road safety and others.

The author of the publication [3] notes that in traditional contracts for the maintenance of highways, the contractor is responsible for the work that is determined by the customer and receives payments for the performance of single (local works). In [4], it is noted that evolutionary in the use of long-term contracts based on final indicators is the transfer of responsibility for determining the materials, technologies and methods of production of work that must meet quality indicators from road agencies to contractors.

The author of work [5] is considered an ideologist in the use of long-term contracts in world practice. In Ukraine, this direction was one of the first to be investigated by the research team of the Department of Transport Construction and Property Management of the National Transport University (NTU, Kyiv, Ukraine) [6]. Researchers have completed a number of scientific works, developed a number of regulatory documents and proposed appropriate software solutions [7].

In [7], the complexity of the implementation of the LTC and the need to create a modern information and analytical system for the management of long-term contracts based on final indicators for the maintenance of highways are noted.

LTC feature is the terms of payment for services, which should depend on the achievement of the quality indicators stipulated in the contract, namely, the fact that the work performer (contractor) receives payment not for the volume of work performed, but for achieving these indicators [8]. According to the experience of different countries of the world, the contract may provide guarantees for its implementation in the amount of the full value of the contract. Thus, the performers of the work are responsible both during the period of the contract and after. Therefore, any defects that may arise after the end of the contract must be repaired by the contractor who held the section of the road under the contract.

The first steps to implement the LTC in Ukraine began in 2005. During this period, with funds from the European Bank for Reconstruction and Development (EBRD), the State Agency for Roads of Ukraine (Ukravtodor) carried out a thorough analysis of the road sector and prepared a «Plan for Reforming the Road Network Management System» [9]. The plan was developed to introduce long-term contracts based on end-points for road maintenance. Thus, according to the second loan agreement «Repair of the Kyiv – Chop highway», concluded between Ukraine and the EBRD, after the completion of the repair work, a pilot LTC project is being implemented on the section of the M-06 Kyiv-Chop highway [10] (Fig. 1).

Taking into account the world experience of using long-term contracts for the maintenance of highways, the contract developers took into account such features of the LTC as:

– execution of financial payments for the process of management and maintenance of highways;
– definition of service levels (quality indicators);
– fulfillment of the full amount of payments for reaching service levels;
– using a system of penalties to achieve service levels and stimulate the quality of work;
– non-interference in the process of choosing materials and production technology of the customer's work (Fig. 2).

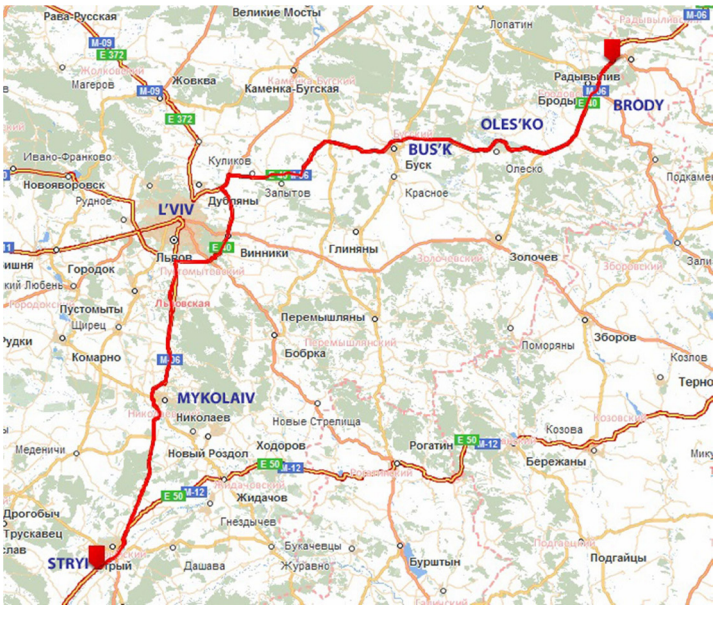

Fig. 1. Layout of the M-06 Kyiv-Chop highway section, which is contained in the first pilot contract in Ukraine

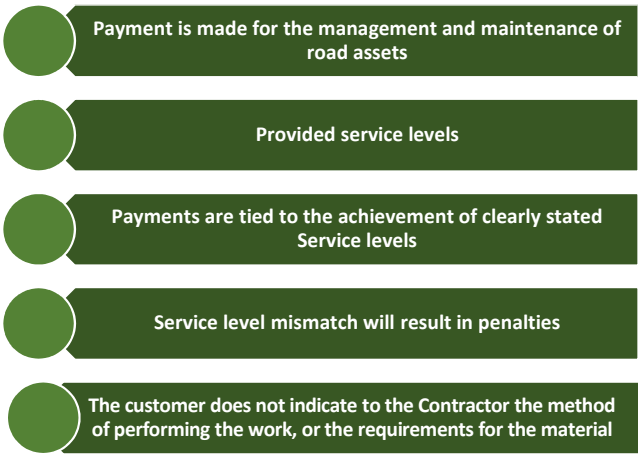

Fig. 2. Features of the implementation of the first pilot contract in the road industry of Ukraine

As it is known, the main feature of long-term contracts for road maintenance is the use of the concept of service levels. Service levels are indicators of the condition of road elements. The contractor is paid for the achievement of these particular service levels, not for the volume of work, unlike traditional contracts.

In accordance with the concluded contract, according to [11], the following works were envisaged:

– elimination of existing defects and bringing the road to a state in which it can be maintained by measures for

the current maintenance and periodic repairs (Fig. 3);
– arrangement of the lighting system;
– establishment of weather stations;
– arrangement of weight control points;
– operational maintenance based on the LTC;
– winter operational maintenance ba-sed on LTC;
– periodic repairs;
– emergency work.

a

b

Fig. 3. An example of improving the condition of a section of the M-06 Kyiv-Chop highway, km 434+230 – km 621+500: *a* – before; *b* – after

On the basis of the work done and the process of implementing the pilot LTC in Ukraine, the following features are noted:
– these contracts require long-term financing, which was not possible for the creation of the Road Fund;
– LTCs require improvement of the regulatory framework, in order to avoid conflict situations during the implementation of contracts;
– the need to develop the competitiveness of a capable market of road maintenance services [9].

Fig. 4 shows two models of road maintenance. According to Fig. 4 it can be noted that when using the classical approach to the maintenance of roads, their condition deteriorates significantly before reconstruction, requires a large amount of both labor and financial resources.

The largest challenges in the implementation of long-term contracts for the maintenance of highways is the selection of optimal parameters based on the influence of various factors, that is, the implementation of optimization of the LTC parameters. In [12], the main factors that most of all affect the LTC contracts are considered, based on international experience. The optimization of the parameters of LTC contracts is based on three factors – time, cost and quality. The interconnection process in the parameters itself is described by the function:

$$F = \{X, Y, Z\}, \tag{1}$$

where X – optimized time value (T); Y – optimized cost value C); Z –optimized quality value (Q).

The objective function that determines the time can be expressed using the formula:

$$MinT = \max_{Lp \in L} \sum_{i \in Lp} \sum_{j=1}^{Mj} d_{ij} x_{ij}, \tag{2}$$

where d_{ij} – duration of the i-th work when performing the j-th option; x_{ij} – index variable of the activity of the i-th work when performing the j-th option. If x_{ij}=1, then the activity and performs the j option, if x_{ij}=0 – the activity and is performed. L – set of all possible paths in the network {1,2, ..., p}; L_p – sequence of actions on the p-th path; m_i – the number of the contract option for activity i, for i=1,..., N.

The cost of projects consists of direct (all costs within the project) and indirect costs (costs during the implementation of the project).

The objective function, which reflects the total cost of the project, can be expressed using the formula:

$$\min C = \sum_{i=1}^{N} \sum_{j=1}^{m_j} c_{ij} + ICxT, \tag{3}$$

where cij – cost of the i-th work of the j-th option; IC – indirect costs of work per day.

Quantifying quality is a very difficult task. Some quality indicators were determined in [12].

The objective function expressing the quality of the project can be expressed using the formula:

$$\max Q = \sum_{i=1}^{N} wt_i \sum_{l=1}^{L} wt_{i,l}\, g_{i,j,l}\, x_{ij,} \tag{4}$$

where $q_{i,j,l}$ – indicator of the quality of work l in work i, using the j-th option of using resources; $w_{ti,l}$ – quantitative value of the quality indicator (l) in comparison with other indicators in work i; w_{ti} – value of the work compared to other types of work for the project.

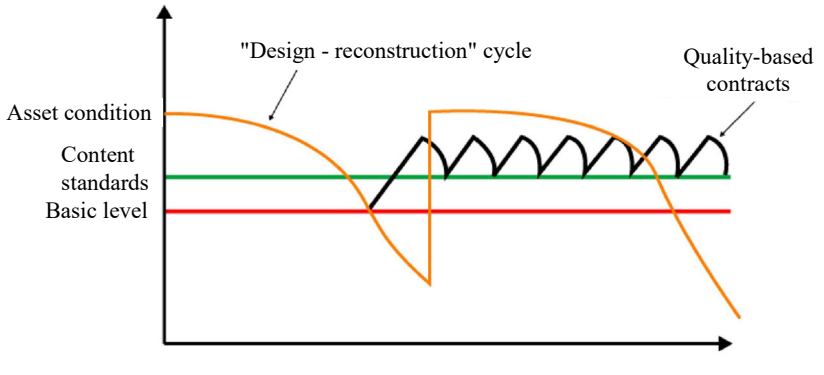

Fig. 4. Condition of assets under traditional contract and contract based on final indicators [2]

ISSN 2664-9969

To perform multi-objective optimization, it is possible to use one of the methods [12].

Method No. 1. Optimization by the first method is as follows:

$$\min Z = \left[\begin{array}{l} W_t \cdot \left[\frac{T - T_{\min} + \gamma}{T_{\max} - T_{\min} + \gamma} \right] + W_c \cdot \left[\frac{C - C_{\min} + \gamma}{C_{\max} - C_{\min} + \gamma} \right] + \\ + W_q \cdot \left[\frac{Q_{\max} - Q + \gamma}{Q_{\max} - Q_{\min} + \gamma} \right] \end{array} \right], \quad (5)$$

where W_t, W_c and W_q – adaptive values of time, cost and quality.

Adaptive values of time, cost and quality are determined by the formulas:

$$W_t = \frac{V_t}{V}; \quad (6)$$

$$W_c = \frac{V_c}{V}; \quad (7)$$

$$W_q = \frac{V_q}{V}, \quad (8)$$

where V_t, V_c та V_q – time, cost and quality criteria.

The time criterion is determined by the formulas:

$$V_t = \frac{T_{\min}}{T_{\max} - T_{\min}}; \quad (9)$$

$$V_c = \frac{C_{\min}}{C_{\max} - C_{\min}}; \quad (10)$$

$$V_q = \frac{Q_{\max}}{Q_{\max} - Q_{\min}}, \quad (11)$$

where $T_{\min}$, $C_{\min}$, $Q_{\min}$, $T_{\max}$, $C_{\max}$ and $Q_{\max}$ – the minimum and maximum time, cost and quality values.

The cumulative criterion V is determined by the formula:

$$V = V_t + V_q + V, \quad (12)$$

where T, C and Q – time, cost and quality targets in the corresponding decision sequence.

Method No. 2. The objective function for the second method is:

$$\min U = \left[\begin{array}{l} W_t \cdot \left[\frac{T - T_{\min}}{T_{\max} - T_{\min}} \right]^2 + W_c \cdot \left[\frac{C - C_{\min}}{C_{\max} - C_{\min}} \right]^2 + \\ + W_q \cdot \left[\frac{Q_{\max} - Q}{Q_{\max} - Q_{\min}} \right]^2 \end{array} \right]^{1/2}, \quad (13)$$

where W_t, W_c and W_q – adaptive values of time, cost and quality.

The adaptive values of the parameters are determined by formulas (6)–(8).

3. Research results and discussion

On the basis of the proposed methods for optimizing the parameters, a mathematical experiment was carried out on the basis of an example of a project for the long-term maintenance of roads in terms of final quality indicators.

Fig. 5–7 show the average value of indicators of time, cost and quality according to calculations by the proposed methods.

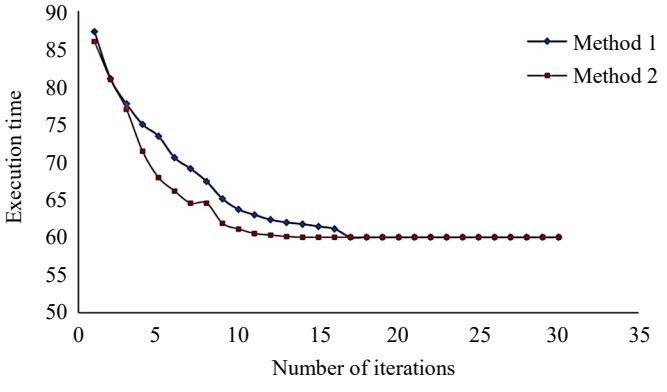

Fig. 5. Average value of contract duration

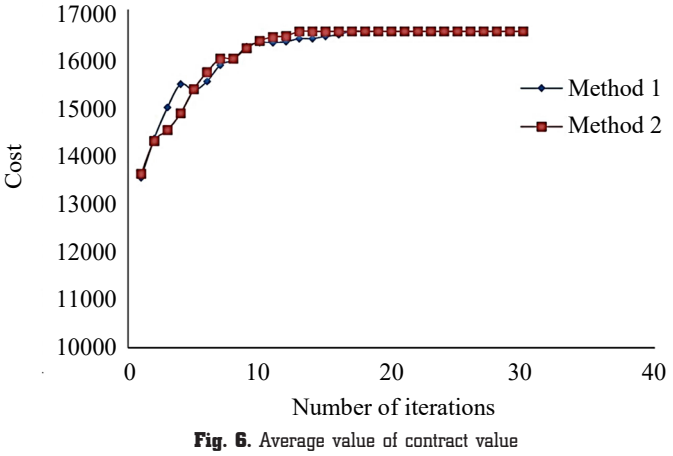

Fig. 6. Average value of contract value

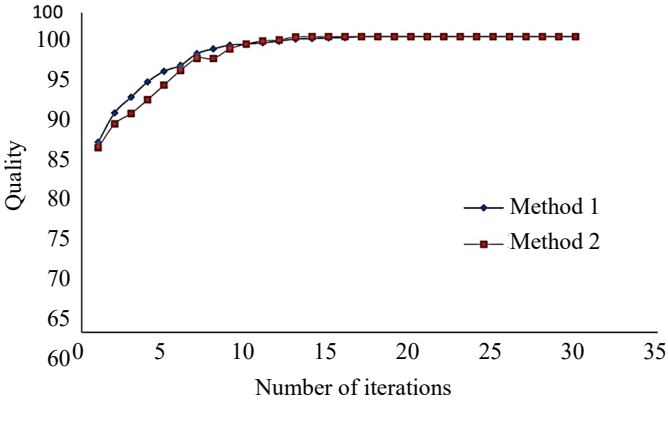

Fig. 7. Average value of contract quality

According to Fig. 5–7, the mathematical experiment according to the method No. 2 shows the achievement of the best indicators for minimizing the time parameters in comparison with the method No. 1 with a standard deviation of 5 %. Average optimized cost for both methods is comparable by comparison. However, it should be noted

that the adaptive capacity of the LTC projects according to method No. 2 is less flexible than the first one.

4. Conclusions

A mathematical experiment was carried out on the basis of an example of a project for long-term maintenance of roads in terms of final quality indicators. There were comparative results of calculations using the two methods, which indicated a high adaptive ability of projects using the first method. In turn, according to the second method, it is possible to achieve the best indicators of minimizing time parameters with a deviation of 5 %. The model was tested for adequacy with a calculated algorithm error of about 3 %.

Parameters of long-term contracts are justified. They are based on final indicators, using the methods of multi-purpose optimization tasks, serve to increase the efficiency of managerial decision-making, has a multiplier effect and leads to:

– reduction of administrative costs (by optimizing road repair work);

– reduction of the responsibility of road services (by shifting a number of tasks that were previously performed by the road service to the contractor);

– creation of prerequisites for stable financing (due to the conclusion of a contract for a significant period, which allows for more accurate cost planning);

– user satisfaction with the quality of roads (due to predetermined optimized quality indicators specified in the contract and must be met by the contractor during the contract, compliance with these indicators directly affects the contractor's profit, since non-compliance is controlled by a system of penalties);

– creation of strong partnerships between the customer and the contractor (due to the pre-defined obligations of the parties and incentives for the contractor to work in a high-quality manner and overfulfillment of plans);

The results of this research can be realized by introducing long-term contracts for the maintenance of roads in countries with limited funding for the road sector.

References

1. Hancher, D. E. (1999). Contracting Methods for Highway Construction. *Transportation Research Board. TR News, 205,* 10–14.
2. Mulmi, A. D. (2016). Assessment of Performance Based Road Maintenance Practices in Nepal. *Open Journal of Civil Engineering, 6 (2),* 225–241. doi: http://doi.org/10.4236/ojce.2016.62021
3. Radović, N., Mirković, K., Šešlija, M., Peško, I. (2014). Output and Performance Based Road Maintenance Contracting – Case Study Serbia. *Tehnički vjesnik, 21 (3),* 681–688.
4. Singh, P., Oh, J. E., Labi, S., Sinha, K. C. (2007). Cost-Effectiveness Evaluation of Warranty Pavement Projects. *Journal of Construction Engineering and Management, 133 (3),* 217–224. doi: http://doi.org/10.1061/(asce)0733-9364(2007)133:3(217)
5. Zietlow, G. (2007). *Cutting Costs and Improving Quality through Performance-Based Road Management and Maintenance Contracts – The Latin American and OECD Experiences.* Birmingham (UK): University of Birmingham (UK) Senior Road Executives Programme Restructuring Road Management Birmingham.
6. Kanin, O. P., Sokolova, N. M., Kharchenko, A. M., Shpyh, A. Yu., Makovska, Yu. A., Shkarivska, N. Yu. (2014). *MR V.3.2-02070915-844:2014 «Metodychni rekomendatsii z upravlinnia stanom avtomobilnykh dorih na osnovi dovhostrokovykh kontraktiv z potochnoho dribnoho remontu ta utrymannia dorih za pokaznykom rivnia yikh obsluhovuvannia».* Kyiv: Ukravtodor, 51.
7. Kanin, O. P. (2015). Informatsiino-analitychna systema upravlinnia dovhostrokovymy kontraktamy na osnovi rivniv obsluhovuvannia dorih. *Avtomobilni dorohy i dorozhnie budivnytstvo, 94,* 112–123. Available at: http://publications.ntu.edu.ua/avtodorogi_i_stroitelstvo/94/112-123.pdf
8. Kharchenko, A. M., Kanin, O. P., Sokolova, N. M. (2013). Evoliutsiia rozvytku ta perevahy zastosuvannia dovhostrokovykh kontraktiv, zasnovanykh na kintsevykh pokaznykakh, u dorozhnii haluzi. *Visnyk Natsionalnoho transportnoho universytetu, 28,* 496–504.
9. *Vprovadzhennia kontraktiv na osnovi kintsevykh rezultativ v Ukraini. Dosvid ta perspektyvy rozvytku* (2019). Available at: https://nadu.com.ua/vprovadzhennya-kontraktiv-na-osnovi-kinczevih-rezultativ-v-ukra%D1%97ni-dosvid-ta-perspektivi-rozvitku/
10. *Yevropeiskyi bank rekonstruktsii ta rozvytku (YeBRR)* (2016). Available at: https://ukravtodor.gov.ua/4489/mizhnarodne_spivrobitnytstvo_ta_investytsii/yebrr/yevropeiskyi_bank_rekonstruktsii_ta_rozvytku_yebrr.html
11. *Spilni z mizhnarodnymy finansovymy orhanizatsiiamy proekty v dorozhnii haluzi.* Available at: https://mtu.gov.ua/files/Спільні%20з%20міжнародними%20фінансовими%20організаціями%20проекти%20в%20дорожній%20галузі.pdf
12. Anderson, A., Russell, J. (2001). *Guidelines for warranty, multi-parameter and best value contracting.* NCHRP Report No. 451, National Cooperative Highway Research Program. Washington.

Anna Kharchenko, *PhD, Associate Professor, Department of Transport Construction and Property Management, National Transport University, Kyiv, Ukraine, e-mail: anna-x3@ukr.net, ORCID: http://orcid.org/0000-0001-8166-6389*

Oleh Zaviyskyy, *PhD, Egis Ukraina LLC, Kyiv, Ukraine, e-mail: olegzav73@ukr.net, ORCID: http://orcid.org/0000-0002-3883-0259*

Vitalii Tsybulskyi, *Senior Lecturer, Department of Materials Resistance and Mechanical Engineering, National Transport University, Kyiv, Ukraine, e-mail: mega.sopromat@ukr.net, ORCID: http://orcid.org/0000-0003-3150-3965*

Serhii Zavorotnyi, *Postgraduate Student, Department of Transport Construction and Property Management*
National Transport *University, Kyiv, Ukraine, e-mail: seregazavorotnyi@gmal.com, ORCID: http://orcid.org/0000-0002-2139-8877*