GENETIC ALGORITHM AS OPTIMIZATION METHOD RELATIONSHIP "TIME - COST" TO IMPLEMENT PERFORMANCE BASED ROAD MAINTENANCE CONTRACTS

ГЕНЕТИЧНИЙ АЛГОРИТМ, ЯК МЕТОД ОПТИМІЗАЦІЇ ВІДНОШЕННЯ «ЧАС – ВАРТІСТЬ» ДЛЯ РЕАЛІЗАЦІЇ ДОВГОСТРОКОВИХ КОНТРАКТІВ ЗАСНОВАНИХ НА КІНЦЕВИХ ПОКАЗНИКАХ

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Abstract. In the given article:

1) describes the main groups of optimization methods relations «time-cost»;
2) determined the most optimal and efficient method of optimization;
3) the principle of the genetic algorithm is given;
4) the analysis of the work of J. Magalhães-Mendes, as an example of the effectiveness of GA.

Object of study – genetic algorithm.

Objective – perform analysis of genetic algorithm and experience of its use as a method of optimization of relations – «time-cost» to ensure successful implementation of BRMC for the operational maintenance of highways of Ukraine.

Research method – analytical, historical, terminological, functional.

In this article the analysis of groups of methods that are used to optimize the relationship of "time-cost». As a result of analysis, it was determined that genetic algorithm (GA) is the most optimal and effective method of optimization. Analyzed the operation principle of GA. The work of the GA consists of the following steps (blocks): problem statement; creation of the initial population; to calculate or estimate the fitness of a population; selection; crossing; mutation; creation of a new population (NP); check the new population; selection of the final optimal answer. To obtain the final optimal result, a new population (new generation) is a test of fitness again. If the NP meets the set requirements then it is accepted as the final optimal solution. If NP does not meet the requirements of the task - passes the stages of selection, crossing, mutation and test again until meet the requirements of the task. For a better understanding of the effectiveness of using GA for optimization of relations – «time-cost», was performed review and analysis of HA, which was proposed by J. Magalhães-Mendes. The author compares his model with two contemporary models developed by the authors, Gen M., Cheng R. and Zheng D. X. M., Ng S. T., Kumaraswamy M.M. A comparative analysis was performed based on real tasks, which consisted of seven operations, and several modes of execution. In the result of the analysis, it was determined that the model proposed by J. Magalhães-Mendes gave the best answer already for three generations, whereas the other two models in only six. This model solved the task with the lowest ultimate cost, which amounted to 225 500 $. On the basis of this work it can be concluded that GA can be quite effective

method of solving the optimization problem of the relationship of "time-value", which in turn will allow us to fulfil the BRMC in the road sector of our state.
Key words: based road maintenance contracts, operational road maintenance, optimization, genetic algorithm.

Formulation of the problem.

For successful use performance based road maintenance contracts (in the future - BRMC) in the maintenance of roads (in the future - MR) of Ukraine, you must perform a thorough and quality optimization the main indicators of the contract. These include the time required for the implementation of the contract and its cost. Optimization of "time-cost" is a very complex process, therefore there is a need to analyse the main methods that are used currently in the industry. In previous studies were analyzed, three major groups of optimization methods: mathematical, heuristic and metaheuristic. As a result of the analysis showed that the most effective and progressive is metaheuristics methods (evolutionary algorithms), namely genetic algorithms (hereinafter GA). For effective use of GA as an optimization method «time-cost» with the aim of introducing BRMC in the field of MR Ukraine, there is a need for a detailed study of its features and properties.

Analysis of recent researches and publications.

As a result of the analysis and study of major publications and literary sources, it was determined, that the following researchers used the use of genetic algorithms to substantiate managerial decisions: Trivedi, M.K., Sapan, N., Panchenko, T.V., Yeremeev, A.V., Kanin, O.P., Lantukh-Lyashchenko, A.I. and other. However, it was discovered that it is precisely the application of genetic algorithms to justify the relation "time-cost" insufficient attention was paid to researches of domestic scientists.

Setting objectives.

The main task of this article is to analyze the foreign experience of using genetic algorithms to optimize the «time-cost» ratio with the purpose of effective use and successful implementation of the BRMS in the road sector of Ukraine.

Presenting main material.

To optimize the "time-cost" relationship, there are such basic methods as: mathematical, heuristic and metaheuristic.

Mathematical methods are based on the definition of the main parameters of the problem and solving it using linear, nonlinear, integer, and dynamic programming. The advantage of this method is the high level of accuracy and accountability, the disadvantage is the need for a large number of calculations and significant time costs.

Heuristic methods solve problems using successive algorithms. This method is very simple and allows you to quickly make the necessary decision, but this method lacks mathematical validity, and the lack of global optimization.

Metheuristic methods, in contrast to the previous ones, are more flexible due to the harmonious combination of the previous ones. This creates the evolutionary algorithm. Such evolutionary algorithms include: genetic algorithm, optimization algorithm "ant colony", optimization of "particle swarm", algorithm "search harmony", multipurpose optimization approach and others. A large number of GA studies indicate its great efficiency in resolving the issue of optimization.

Genetic algorithms are efficient global algorithms and methods of search and optimization, which are based on the laws of natural selection and the further use of the best possible solutions to problems through the accumulation of information from the search space and adaptation to the most optimal option [1,2].

For the first time the GA was proposed by John Holland in 1975, he based his method on the principle of natural selection of Charles Darwin [3]. GA solves a number of such tasks: optimization tasks; scheduling; definition of the shortest way to solve the problem; layout tasks; bioinformatics; creation of artificial life and others [4].

Since GA is based on the principle of natural selection, Charles Darwin, for solving the optimization problem, operates with such basic concepts as population and its chromosomes. That is, the GA operates on a population of individuals in the chromosome (the genotype) which introduced the possible correct answer (phenotype) that is a solution to the problem [4]. The working principle of GA is shown in figure 1.

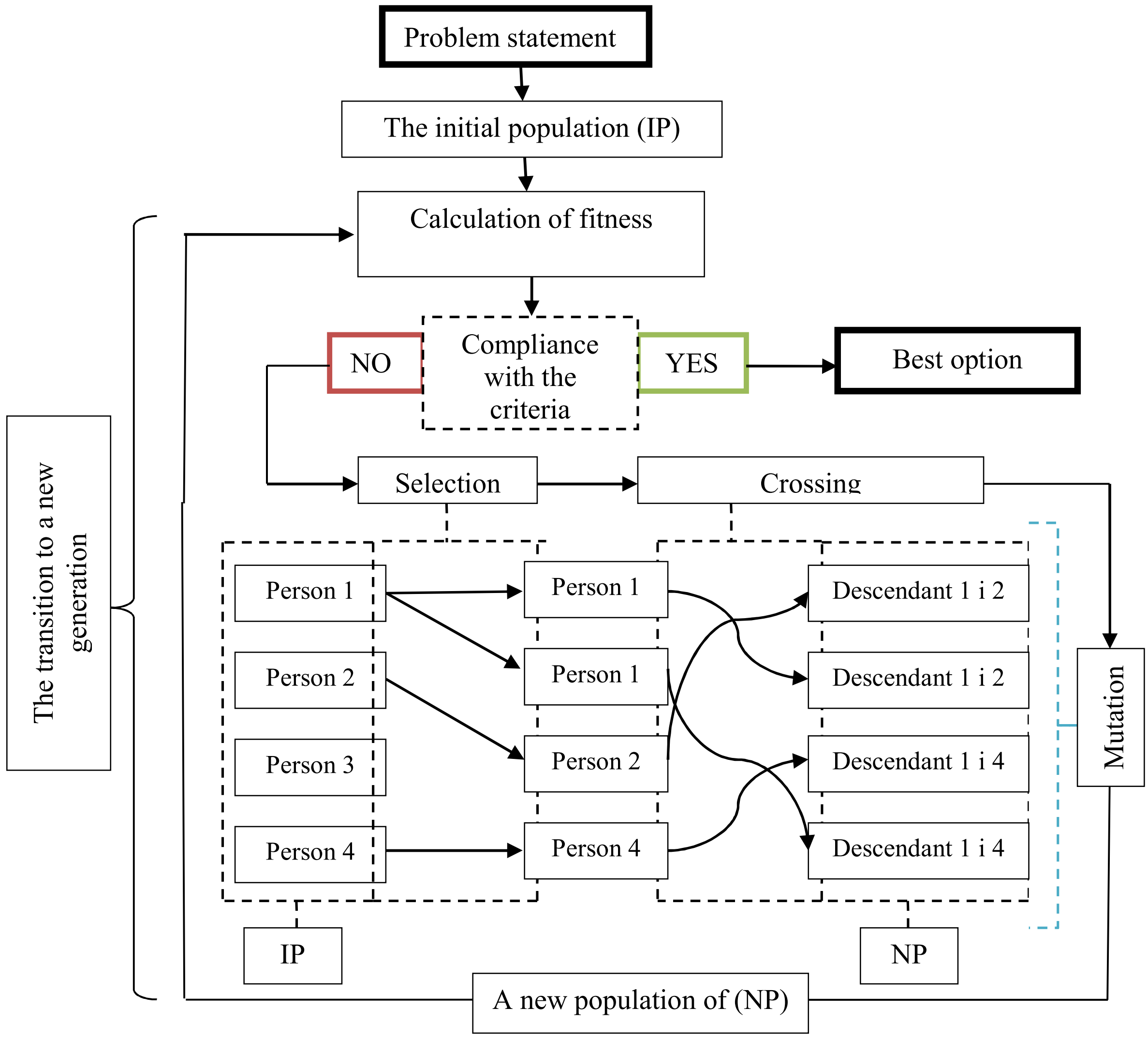

Figure 1 – The principle of the genetic algorithm [adapted from 1,4,5]
Рисунок 1 – Принцип генетичного алгоритму [адаптовано з 1,4,5]

In General, the work of the GA consists of the following steps (blocks) [1,4,6]:

1. Problem statement. This step defines the basic requirements and the conditions of the problem on the basis of which will form the requirements for populations. The final answer and solution of the problem must satisfy the set requirements.
2. The formation of the initial population. After the task is set up, an initial population, which has a source chromosome, is randomly formed.
3. Calculation of fitness or population estimation. In order to determine the correspondence of the population of the population to the requirements, the initial population (IP) must pass the unit "calculation of fitness" or "population estimation". If the IP meets the fitness criterion, ie, it corresponds to the optimal solution, then this model is accepted as the final answer, if there are no following GA operators such as selection, crossing, mutation.
4. Selection. At this stage, based on the evaluation of IP selects the fittest of her face for the passage of the operator "the crossing". This operator and its properties greatly affect the average time to receive results and the scatter in independent stages of the process of evolution.
5. Crossing. After the selection of the most suitable persons in the operator crossover is performed crossing between persons of the IP resulting in the formation of the so-called descendants (new offspring). The genetic information data of the descendants created by the combination and intersection of the information of the chromosomes between their "parents".
6. Mutation. After passing the crossing, a new descendants form a new population (NP), part of which is mutated with a random change in their genotype.

After the "mutation" of NP is again the block of "calculation of fitness", which assess the criteria of fitness of NP demands. If the requirements are met, the resulting model is the final and most optimal if no – NP is again an operator "selection", "crossing" and "mutation". Thus all actions are performed until obtaining the desired result.

For a better understanding of the effectiveness of using GA in the optimization process, consider an example based on the study «Multiobjective Genetic Algorithm-Based for Time-Cost Optimization» author's J. Magalhães-Mendes. For optimization, the author used a hybrid (multi-objective) genetic algorithm. GA is responsible for the procedure of development of chromosomes.

To solve the problem, each chromosome undergoes the following phases [7]:

1. The parameters of the transition.
2. Transition process.
3. The decoding between the first and second level.
4. The quality of chromosomes.

Each chromosome represents a solution for the problem and generates a vector of random keys (numbers). Each solution encoded as the initial chromosome (initial level) and has $mn+n$ genes, where n is the number of assets and m is the number of execution modes [7]. The transition between the first and second levels is to select options for the construction of mj for each j activities for each asset. Due to the transition of the resulting chromosome, which consists of $2n$ genes (second level). In this vipadku we do not consider requirements for type, quantity and quality of resources necessary to implement the tasks [7]. The structure of chromosomes and the transition to the second level are given in table 1.

Table 1 – Structure of chromosomes and transition to the second level [adapted from 7]
Таблиця 1 – Будова хромосом та перехід на другий рівень [адаптовано з 7]

First level			**Transition**	**Second level**		
Action 1	Regime 1	Gene $_{11}$	→	Action 1	Regime 1	Gene $_{11}$
	Regime 2	Gene $_{12}$	1			
	……….	………				
	Regime m	Gene $_{1m}$	2			
	Delay 1	Gene $_{1m+1}$	→		Delay 1	Gene $_{1m+1}$
Action 2	Regime 1	Gene $_{21}$	1	Action 2		
	Regime 2	Gene $_{22}$	→		Regime 2	Gene $_{22}$
	……….	………				
	Regime m	Gene $_{2m}$	2			
	Delay 2	Gene $_{2m+1}$	→		Delay 2	Gene $_{2m+1}$
……	…………..	………		……	…………..	………
Action n	Regime 1	Gene $_{n1}$	→	Action n	Regime 1	Gene $_{n1}$
	Regime 2	Gene $_{n2}$	1			
	……….	………				
	Regime m	Gene $_{nm}$	2			
	Delay n	Gene $_{nm+1}$	→		Delay n	Gene $_{nm+1}$
Note:1 – gene is selected with the highest priority; 2 – automatically goes to the second level.						

Decoding is performed using formula 1 [7]:

$$PRIORITI_j = \frac{LLP_j}{LCP} \times \left[\frac{1+gene_{mj}}{2}\right], \quad (1)$$

where, LLP_j – is the longest path from the start of activity j to the end of the contract; LCP – is the length of the critical path of the contract; m_j – is the selected mode of activity j; *gene jm+1* - is the delay when planning activities; j=1,…n.

The delay time needed for each activity is determined by using the formula 2 [7]:

$$Delay\ time = gene_{jm+1} \times 1{,}5 \times MaxDur, \quad (2)$$

where, $MaxDur$ – is the maximum duration of all activities; 1,5 – the coefficient of a delay (determined experimentally).

Scheme of generation schedules is the basis of most heuristic approaches. There are several species of them, in [7] the author proposes to use a parameterized active schedule. In this case, the layout consists of charts that take into account that none of the resource is not idle more than a pre-specified period. If the period is zero will receive a schedule without delay.

Local search is moving from solution to solution in the space candidates in the direction of the optimal solution or the stopping criterion. In [7] proposed to use the inverse and direct search path. Moving forward from the beginning of the contract then act in the opposite direction trying to find the best solution.

In [7] proposed to use the proportional model (roulette wheel). This approach is characterised by a stochastic selection process. If fi is the fitness of individual in the population, the probability of election is determined by formula 3:

$$p_i = \frac{f_i}{\sum_{i=1}^{N} f_i}, \quad (3)$$

where, j=1,…n.

After nominees are chosen, the crossing taking place between the re-sampled (selection) chromosomes randomly. The mutation operator is applied to each offspring of the population with a pre-determined probability, which in this example is 5%. Not paying attention to the complexity of the parameter settings of genetic algorithm research [7] it is proved that using this method you can be get high accuracy data with low error calculations: population size – 5 x number of activities; the mutation probability is 0.05; 1% of the previous chromosomes move on to the next generation; stopping criterion of 50 generations.

Performing an objective assessment and verification of the effectiveness of this method can be carried out by comparing with similar methods of other leading specialists, by conducting optimization of the real problem. For comparison selected two models of authors Gen M., Cheng R. [8] and Zheng D. X.M., Ng, S.T., Kumaraswamy M.M. [9]. To compare for the source data took the table that was specified actions, regimes and their corresponding duration and cost of the work (table 2).

The results of calculations by the first and second method are 6 generations when the third 3-generation costs 225 500$, which is lower than in the previous year. Analyzing obtained data we can conclude that the proposed model J. Magalhães-Mendes [7] already for 3 generations gives better results than other methods. Therefore, this method is quite effective for solving the issue of optimization of the relationship of "time-cost".

As you can see, GA is a very progressive and effective method of solving the issue of optimization of the relationship of "time-cost". In recent years, more and more researchers use GA for solving various problems, and to optimization problems. For example, studies of J. Magalhães-Mendes is possible to note that GA is a very flexible method, even despite a certain heaviness of making the settings of the model. The properties of GA can be used to solve the optimization problem of the relationship of "time-value" in BRMC, because of their length and a feature run MR require a flexible enough model to account for the many factors that can influence the cost and time of implementing contracts.

Summary

On the basis of this study and the work performed we can draw the following conclusions:

1. To solve the optimization problem of the relations of time value you can use the following methods: a mathematical, heuristic and metaheuristic.

2. The most modern and efficient methods are metaheuristics, in particular, evolutionary algorithms, among which the most progressive and flexible is genetic algorithm, which by its nature is a method of search and optimization that is based on the laws of natural selection and further use of the most optimal solutions to problems using the accumulation of information from the search space and adaptation to the most optimal variant. For the first time genetic algorithms proposed by John Holland in 1975, which was based on the principle of natural selection of Charles Darwin.

3. Traditionally, the operation of the genetic algorithm consists of the following stages (blocks): statement of the problem; create initial population; calculate or estimate the fitness of a population; selection; crossbreeding (crossover); mutation; new population; check for new populations; the selection of the final optimal answer.

Table 2 – Timing and cost of each option and mode of operation [adapted from 7]
Таблиця 2 – Терміни та вартість кожного варіанту та режиму роботи [адаптовано з 7]

Number of the action (work)	Regime	Variant	Direct cost, $
1	2	3	4
1	-	1	23000
		2	18000
		3	12000
2	1	1	3000
		2	2400
		3	1800
		4	1500
		5	1000
3	1	1	4500
		2	4000
		3	3200
4	1	1	45000
		2	35000
		3	30000
5	2.3	1	20000
		2	17500
		3	15000
		4	10000
6	4	1	40000
		2	32000
		3	18000
7	5.6	1	30000
		2	24000
		3	22000

Data from Table 2 was used to perform calculations and compare methods (Table 3).

Table 3 - Results of calculations [adapted from 7]
Таблиця 3 - Результати розрахунків [адаптовано з 7]

Method	Population number	Time, days	Cost, $
1	2	3	4
Gen M., Cheng R. [8]	0	83	243 500
	1	80	242 400
	2	80	261 900
	3	79	256 400
	4	79	256 400
	5	***79***	***256 400***
Zheng D. X.M., Ng, S.T., Kumaraswamy M.M. [9]	0	73	251 500
	1	73	251 500
	2	73	251 500
	3	66	236 500
	4	66	236 500
	5	***66***	***236 500***
J. Magalhães-Mendes [7]	0	73	233 000
	1	68	225 500
	2	***63***	***225 500***

4. The genetic algorithm proposed by J. Magalhães-Mendes for the solution of the optimization problem indicates the flexibility of genetic algorithms and the complexity of their settings. However, this work points to the significant efficacy of HA in comparison with the models presented in the works of Gen M., Cheng R. and Zheng D. X. M., Ng S. T., Kumaraswamy M.

5. The analysis of foreign experience of the use of genetic algorithms to solve optimization problems of the relationship of "time-value" indicates its flexibility and efficiency, which may allow to solve the optimization problem in BRMC for their successful use in MR in the road sector of Ukraine.

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ГЕНЕТИЧНИЙ АЛГОРИТМ, ЯК МЕТОД ОПТИМІЗАЦІЇ ВІДНОШЕННЯ «ЧАС – ВАРТІСТЬ» ДЛЯ РЕАЛІЗАЦІЇ ДОВГОСТРОКОВИХ КОНТРАКТІВ ЗАСНОВАНИХ НА КІНЦЕВИХ ПОКАЗНИКАХ

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В даній статті:

1) розглянуті основні групи методів оптимізації відношення «час-варітстсь»;
2) визначений найбільш оптимальний і ефективний метод оптимізації;
3) наведений принцип роботи генетичного алгоритму;
4) виконано аналіз робота J. Magalhães-Mendes, як приклад ефективності ГА.

Об’єкт дослідження – генетичний алгоритм.

Мета роботи – виконати аналіз генетичного алгоритму та досвіду його використання, як методу оптимізації відношення «час-вартість» з метою успішного впровадження ДККП для експлуатаційного утримання автомобільних доріг України**.**

Метод дослідження – аналітичний, історичний, термінологічний, функціональний.

В даній статті виконаний аналіз груп методів, які використовуються для оптимізації відношення «час-варітість». В результаті аналізу було визначено, що генетичний алгоритм (ГА) є найбільш оптимальним та ефективним методом оптимізації. Було виконано аналіз принципу роботи ГА. Робота ГА складається з таких етапів (блоків): постановка задачі; створення початкової популяції; розрахунок або оцінка пристосованості популяції; селекція; схрещення (кросовер); мутація; створення нової популяції (НП); перевірка нової популяції; вибір остаточної оптимальної відповіді. Для отримання остаточного оптимального результату нова популяція (нове покоління) проходить блок перевірки пристосованості знову. Якщо НП задовольняє поставлені вимоги, то вона приймається як остаточне оптимальне рішення. Якщо не відповідає вимогам задачі - проходить етапи селекції, схрещення, мутації та перевірки заново до моменту задоволення вимог поставленої задачі. Для кращого розуміння ефективності використання ГА для оптимізації відношення «час-вартість», було виконано розгляд та аналіз ГА, який був запропонований J. Magalhães-Mendes. Автор порівнює свою модель з двома сучасними моделями розробленими авторами: Gen M., Cheng R. та Zheng D. X.M., Ng, S.T., Kumaraswamy M.M. Порівняльний аналіз виконувався на основі реально поставленої задачі, яка складалася з семи операцій та декількох режимів виконання робіт. В результаті проведеного аналізу було визначено, що модель запропонована J. Magalhães-Mendes дала оптимальну відповідь вже за три покоління, тоді коли інші дві моделі лише за шість. Дана модель вирішила задачу ще й з найменшим значенням кінцевої вартості, що склало 225 500 доларів США. На основі виконаної роботи можна зробити висновок, що ГА може бути достатньо ефективним методом вирішення задачі оптимізації відношення «час-вартість», що в свою чергу дозволить якісно реалізувати ДККП в дорожній галузі нашої держави.
Ключові слова: довгострокові контракти засновані на кінцевих показниках, експлуатаційне утримання доріг, оптимізація, генетичний алгоритм.

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