Scheduling of construction works in the formation of technological processes of railway construction using a genetic algorithm

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Abstract. The article is devoted to solving the task of scheduling construction works in the formation of technological processes of railway construction by the method of evolutionary modeling. Scheduling of construction works is the task of optimizing the amount of subcontracting involved to ensure maximum utilization of the construction contractor's own resources. The purpose of the task was to determine the sequence of work during the construction of railway track objects (roadbed, upper structure of the track, culverts). The solution of the task required taking into account project limitations: resource, technological, and information. The specifics of the activities of construction contractors and subcontractors required taking into account the time limit that set the time interval: early and late start of construction work. The set of restrictions and the dimension of the task contributed to the attraction of a genetic algorithm for its solution. A mathematical model was developed for this purpose. The model allowed us to assess the fitness function of individuals (solutions), taking into account the dynamic nature of the distribution of own and subcontracting resources for construction work. The results of solving the task were obtained in automated mode. Analysis of the results of the solution allowed us to determine the advantages of the genetic optimization method for obtaining the most effective solution to the task of scheduling construction works.

1. Introduction

The task of scheduling construction works within the framework of forming technological processes (TP) of railway construction belongs to the class of multi-criteria tasks for managing complex systems. The time to find solutions to such tasks increases exponentially depending on its dimension. Traditional methods of solving the task of finding a rational solution have a number of disadvantages. For example, combinatorial methods and mathematical programming methods require long calculations when studying large-dimensional tasks. In addition, these methods have difficulties in finding the optimum for the case of a dynamic constraint system that changes at each scheduling stage [1-3]. The application of the method presented in this paper takes into account the dynamic nature of the task; however, the search based on it is random and does not always allow you to find the optimal solution. At the same time, the use of evolutionary (genetic) optimization makes it possible to overcome the identified disadvantages of traditional methods, including significantly reducing the duration of the solution search to a quadratic dependence on the task dimension.
2. Materials and methods
The general statement of the task of scheduling construction works can be formulated as the task of determining the sequence of works that meets the design requirements (restrictions) and the minimum time for their implementation. Project requirements that affect the work plan being developed will be resource, technological, and information constraints. Analysis of the activities of construction (contracting) organizations (CCO) requires taking into account the time limit, which sets the time interval: early and late start of construction work [4, 5].

The technological process consists of a set of complex technological processes (CTP). However, when forming a technological process (TP) from CTP, simple technological processes (STP) are distinguished, taking into account their resource supply (labor resources, technical means, materials). STP occupy a central position in the hierarchy of TP (Figure 1) and are the most optimal for the design of technology and organization of railway construction [6].

![Figure 1. The structure of the technological process.](image)

It should be noted that in some cases, when solving certain scheduling tasks, different sets of restrictions are taken into account, namely, all the above restrictions, with the exception of the time limit. However, special attention is paid to technological and resource constraints [3].

The objects of optimization are also different. The classical objective function (OF) in a scheduling task is to reduce the time required to complete work. In some works, OF is presented as the total time of deviations from the planned deadlines [4].

However, optimization of work performed by construction (subcontracting) organizations (CSO) has not yet been reflected in research activities, and this task is relevant for almost all CCO. Next, the activity of CCO will be considered and the task of calendar scheduling for the formation of TP will be defined, taking into account the performance of work by CSO.

We denote the scheduling period \( t \in [0, T] \), where \( t \) - time point in the scheduling interval; \( T \) - duration of the scheduling period. The set of CTP is given: \( CTP = \{ CTP_i \} \), \( i = 1, N \), where \( CTP_i \) - \( i \)-th CTP; \( N \) - number of CTP. The set of STP included in the CTP: \( STP = \{ STP_j \} \), \( j = 1, L \), \( \sum_{i=1}^{N} L_i = L \), where \( STP_{i,j} \) \( j \)-th STP of \( i \)-th CTP; \( L \) - number of STP within the technological process. Construction work cannot be performed without the involvement of labor resources and technical means of CCO. To do this, the following symbols are used. The set of labor resources is available in the CCO: \( KW = \{ KW_r \} \), \( r = 1, R \), where \( KW_r \) - number of people in the construction team \( r \); \( R \) – number of construction teams in CCO. The set of labor resources of CSO will be considered unlimited in order to determine the allocated volume of third-party resources by attracting, if necessary, several specialized construction organizations. Thus, it allows you to remove the resource restriction of scheduling during the task solution.
The set of labor resources is required to perform STP of each CTP: \(KWS = \{KWS(i, j, r)\}\), where \(KWS(i, j, r)\) is the number of labor resources of the team to perform STP. Multiple durations of STP within TP: \(KD = \{KD(i, j)\}\), multiple costs of performing STP per day: \(CW = \{CW(i, j)\}\).

The set of technical means is available in CCO: \(KT = \{KT_m\}\), \(m = 1, M\), where \(KT_m\) – number of technical means in the set \(m\); \(M\) - number of sets of machines in CCO. We will also assume that the set of technical means of CSO is infinitely large with conditions similar to the set of labor resources.

The set of technical means is necessary for performing STP of each CTP: \(KTS = \{KTS(i, j, m)\}\), where \(KTS(i, j, m)\) is the number of technical means included for performing STP. The set of durations of STP within TP: \(KB = \{KB(i, j)\}\), the set of costs of performing STP per day: \(CT = \{CT(i, j)\}\).

Plenty of time limitations began to perform STP: \(TS = \{TSB(i, j), TSE(i, j)\}\), where \(TSB(i, j)\) is the date of early run \(j\)-th STP \(i\)-th CTP; \(TSE(i, j)\) – late start date to completion \(j\)-th STP \(i\)-th CTP. This restriction by the developer of organizational and technological documentation (OTD) includes technological and information restrictions if they appear for any STP within TP.

The controlled parameters in the task under consideration can be represented as a set of moments when STP start: \(TB = \{TB(i, j)\}\). Now it is possible to solve the task of scheduling construction works taking into account the following optimization criteria:

1) minimization of the total cost of work performed by CSO:

\[
F_1 = \sum_{i=1}^{N} \sum_{j=1}^{L_i} \left(CW(i, j) \cdot V(i, j) + CT(i, j) \cdot V(i, j)\right) \rightarrow \min
\]

where \(V(i, j)\) is the amount of work performed by CSO \(j\)-th STP \(i\)-th CTP;

2) minimization of the total downtime of the team and technical means of CCO:

\[
F_2 = \sum_{i=0}^{T} \sum_{r=1}^{R} VF(t, r) + \sum_{i=0}^{T} \sum_{m=1}^{M} MF(t, m) \rightarrow \min
\]

where \(VF(t, r)\) – number of available resources of CCO construction team \(r\) at the moment \(t\), \(MF(t, m)\) – number of available technical means in the set of CCO \(m\) at the moment \(t\).

Let us consider the following OF \(F\) that takes into account the above optimization criteria:

\[
F = \phi_1 \cdot \frac{F_1^{ln}}{F_1} + \phi_2 \cdot \frac{F_2^{ln}}{F_2} \rightarrow \max
\]

where \(\phi_1, \phi_2\) – weight coefficients, \(\phi_1 + \phi_2 = 1\); \(F_1^{ln}, F_2^{ln}\) – initial values of objective functions obtained by expert evaluation of the developer of OTD of the start dates of STP.

3. The use of Matlab and applications Genetic Algorithm and Direct Search Toolbox

To find the optimal construction plan (STP) it is advisable to use a genetic algorithm (GA). The steps of using GA involves the implementation of the following stages: 1) selecting the encoding method of the task solution (phenotype) in individual chromosome (genotype); 2) defining valuation method fitness function (FF) decisions; 3) description of the genetic operators; 4) determination of the laws of survival of the decision; 5) generation of initial population and GA.
Calculation of FF of individuals in a population can be performed in various ways described in [7-9], for example, by analytical methods, using simulation, artificial neural networks, and fuzzy logic systems. However, based on the works [10, 11], analytical methods for calculating FF are preferred for solving scheduling tasks taking into account resource constraints. Although this method is not without drawbacks. This approach does not allow us to take into account the dynamic nature of the behavior of the task being solved. However, the capabilities of the Matlab system (technical computing language) and the Genetic Algorithm and Direct Search Toolbox application allow you to simulate dynamic resource allocation for evaluating FF of a solution. At the same time, it is possible to limit the random search space and enhance optimization by taking into account the dynamically changing constraints of the scheduling task. The algorithm for applying the system and application during process optimization is shown in Figure 2.

Figure 2. Algorithm for genetic optimization of the technological process using the Matlab system and the Genetic Algorithm and Direct Search Toolbox application.

The genetic optimization method used has the following features:
1) integration of expert, conceptual and evolutionary approaches;
2) focus on a wide class of scheduling tasks that allow you to configure the ready-made solution of the task for specific conditions by setting the parameters of GA;
3) support for a specific method for solving the scheduling task using GA based on the description of encoding the phenotype of an individual into a genotype.

The practical implementation of the method of genetic optimization using the Matlab system is carried out to solve the task of scheduling CTP in the framework of technological modeling in CCO during the construction of railway tracks objects (roadbed, upper structure of the track, culverts) to
plot the Big ring of the Moscow railway (Moscow region, Russia). The purpose of scheduling is to minimize the downtime of teams, as well as to minimize the cost of work performed by CSO, as part of TP. The development of an evolutionary model for solving this task required the study of various options for encoding the solution into an individual chromosome: encoding a sequence of STP [10, 11], encoding priorities of STP [10], encoding rules for assigning priorities to STP [11], encoding calendar start dates [11]. As a result, the method of encoding start dates was chosen, due to the lack of redundancy in encoding and the ability to take into account time constraints.

Assessment of FF for solving the task of executing STP within TP using the formula (3) was performed in the Genetic Algorithm and Direct Search Toolbox application, taking into account the dynamic distribution of own and subcontracting resources for STP. Controlled parameters (input data) of the model represent the start dates of STP. The following parameters were set for GA during genetic optimization. First, the population size is 10 individuals. Second, individual size – 175 genes (5 genes for encoding each of the 35 simple technological processes under consideration); third, applied genetic operators – roulette-based reproduction, five-point crossover, five-point mutation with a probability of 10%, inversion with a probability of 5% [11]; fourth, algorithm stop criterion – 10 generations change; fifth, generation of a random initial population.

As a result of using the Matlab system and the Genetic Algorithm and Direct Search Toolbox application for genetic optimization, the values of FF of individuals in the population and the values of OF of the task depend on the change of generations. Figure 3 left shows the change in the minimum objective function value of task (1) under genetic optimization, and the right – change the maximum value of FF individuals of GA (3) in the course of its implementation. The graphs show that the best solution was achieved in the 7th generation.

**Figure 3.** Dependence of the target function of the scheduling task and the fitness function of the individual of the genetic algorithm on the change of generations.

Histograms of OF (1) and (2) of the task solutions obtained using the genetic optimization method are shown in Figure 4 in comparison with OF of the original construction plan drawn up by the developer of OTD based on existing experience and qualifications.

**Figure 4.** Changing the values of the objective functions of the task depending on the solution method.
Analysis of solutions to the scheduling task found by various methods has shown the effective operation of the genetic optimization method. Its application allowed reducing by 68% (3 times) the cost of work performed by CSO, within TP, by 3% of a simple team within seven months.

4. Conclusion
The paper presents the theoretical results of the study and the possibilities of practical application of evolutionary modeling to solving tasks of construction scheduling in the formation of technological processes of railway construction.

Scheduling of construction works is the task of optimizing the amount of subcontracting involved to ensure maximum utilization of the construction contractor's own resources. The purpose of the task was to determine the sequence of work during the construction of railway facilities. The solution of the task is carried out taking into account the project limitations: resource, technological, and information. The analysis of the specifics of the activities of construction contractors and subcontractors required taking into account the time limit that set the time interval: early and late start of construction work. The set of restrictions and the dimension of the task contributed to the attraction of a genetic algorithm for its solution. A mathematical model was developed for this purpose. The development of the model allowed us to evaluate the fitness functions of individuals (solutions), taking into account the dynamic nature of the distribution of own and subcontracted resources for construction work.

As a result of the study, it was found that the automated solution of construction scheduling tasks using evolutionary modeling significantly increases the efficiency of the solution found. To solve the task, we used a genetic algorithm for directed search in the solution space. At the same time, the dynamic nature of the distribution of own and subcontracted resources for construction work was taken into account.

The introduction of evolutionary modeling tools in the development of technological processes of railway construction contributes to the operational scheduling of construction works. A construction contractor receives a new tool aimed at ensuring the production and economic efficiency of its activities.

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