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APPLICATION OF THE GAME THEORY IN CONSTRUCTION ACTIVITY

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Statement of the problem. In construction production failure of one type of works can entail that of all other works and loss of a considerable amount of money. Therefore if there is a delay in a construction project, it is necessary to understand what kind of work (a performer) has led to that. The paper is devoted to a new approach to an optimal distribution of penalties in construction activity and application programming based on it. For modeling this situation the game theory is suggested.
Results. The developed module of the application allows one to calculate an optimal distribution of penalties for works which have led to failure of a project and to edit a project graph. The results obtained through the course of the work with the program can be used for further engineering calculations.
Conclusions. When using the new approach to an optimal distribution of penalties in construction activity, the application on the basis of the game theory is developed. This application is improved by the interaction between the customer and the contractor that promotes a rational use of the money allocated for the implementation of a construction project.

Keywords: organization of construction, project management, penalty, software, algorithm, macroprogramming language.

Introduction. In modern society as there is an annual population growth and not enough construction objects, reconstruction and replanning are becomingly increasingly common.

Construction companies and designing enterprises oversee each of these stages. A delay in any of them might cause a delay in the others as well as a great loss of funds. Therefore if there happens to be a delay in a project, it is necessary to understand which component (contractor) contributed to that. For penalty distribution in modeling this scenario, a game theory can be employed.

Most of the research dealing with project management focuses on project delays. So, in [16] delayed project tasks involving taxation are discussed and certain regulations regarding fine distribution are set forth.

The authors [15, 17, 18] in some studies are suggesting some regulations for placing fines in delayed projects, but they contain a range of specific constraints and limitations, which put a certain restriction on how they are applied. These studies offer a theoretical approach to gaming that is present in the analysis of the main distribution problem.

In [1, 20] where delayed projects as well as quick-speed ones are looked at with their analysis on defining project gaming involving the task at hand and a nuclear as a solution specified in a joint distribution of fines.

In [3] random and non-decreasing functions of fines and incentives are discussed. As in [4—6], this article analyzes delayed project tasks with a linear fine function. Unlike this one, project gaming involving project tasks is determined using taxation tasks. For that "payment capacity" following any delay affecting not only the delay itself but also the overall structure of a project as involving a series of tasks is evaluated.

1. Game theory and finding an optimal fine distribution. In order to improve the communication between the executor and the project manager, contractor and customer, a tool has to be designed that visualizes a construction project, i.e. actual, planned time and penalties imposed in case of delay.

For that an application for designing a graph of construction project works and optimal distribution of penalties among the executors [11].

The application has to be in compliance with the following requirements:

— optimal penalty distribution for delays;

— editing the graph of a construction project.

For implementing this, a so-called game theory including construction and assembly works is applied. The game theory is a section of mathematics where mathematical models of conflict decision-making, i.e. conflicts of interests where each party is seeking to have their say in an ongoing conflict [1, 13, 14].

For optimal penalty distribution the cooperative game theory is considered where the goal is to optimally distribute the prizes between the winning players having different kinds of agreements among them. The cooperative game theory entails the concept of a project task that occurs when there is a difference between an actual and planned timeline of a construction project [2].

The maximum penalty for delays equals the time of delay. A project task in this case can be described using the following three: $(\{N_1, \ldots, N_m\}, p, r)$.

Let us assume that the function $\max\{p, r\}$ is an actual timeline following the completion of a construction project. Then $D(\max\{p, r\}) - D(p)$ specifies a maximum penalty for all the delays. In [12, 19] we looked at how relevant this model is. It is suggested that according to [1, 2], the vector b is defined as

$$b_i = \max_{\tau: N_\tau \ni i} \min\{d(i), (D(N_\tau, \max\{p, r\}) - D(p))_+\} \forall i \in N, \quad (1)$$

where N is the amount of work involved in a construction project; i is project work; p is a planned timeline of work; r is an actual timeline of the project; $d(i)$ is a delay in the completion of the project; $D(p)$ is a planned timeline of a construction project; N_τ is a life cycle of a project.

Let us look at an example of a graph of a construction project (Fig.1) where the planned time $p: N \to \mathbb{R}_+$ is defined as $p(\mathrm{A}) = 2$, $p(\mathrm{B}) = 3$, $p(\mathrm{C}) = 15$ and $p(\mathrm{D}) = 13$, the actual time $r: N \to \mathbb{R}_+$ is defined as $r(\mathrm{A}) = 9$, $r(\mathrm{B}) = 5$, $r(\mathrm{C}) = 11$ and $r(\mathrm{D}) = 12$. Then the project task can be presented as $(\{N_1, N_2, N_3, N_4\}, p, r)$.

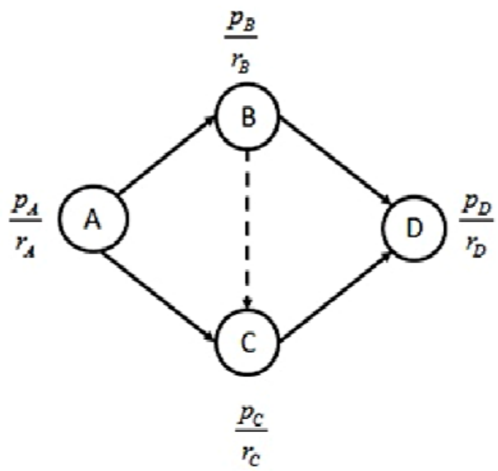

Fig. 1. View of a graph of a construction project

According to the suggested approach [7, 8] for identifying the optimal penalty we get the values from Table 1.

Table 1

Values for identifying the optimal penalty

N_τ	$D(N_\tau, p)$	$D(N_\tau, r)$	$D(N_\tau, \max\{p,r\})$	$D(N_\tau, \min\{p,r\})$
AC	17	20	24	13
AD	15	21	22	14
BC	18	16	20	14
BD	16	17	18	15

According to Table 1 *D* (*p*) =18 and *D* (*r*) =21. In this case a delay in a construction project is 3 units. Then according to (1) we get:

$$b_1 = \max\{\min\{d(A),(D(\{A,C\},\max\{p,r\})-D(p))_+\},\ \min\{d(A),(D(\{A,D\},\max\{p,r\})-D(p))_+\}\} =$$
$$= \max\{\min\{7,(24-18)_+\},\min\{7,(22-18)_+\}\} =$$
$$= \max\{\min\{7,6\},\min\{7,4\}\} = \max\{6,4\} = 6,$$

$$b_2 = \max\{\min\{d(B),(D(\{B,C\},\max\{p,r\})-D(p))_+\},\ \min\{d(B),(D(\{B,D\},\max\{p,r\})-D(p))_+\}\} =$$
$$= \max\{\min\{2,(20-18)_+\},\min\{2,(18-18)_+\}\} =$$
$$= \max\{\min\{2,2\},\min\{2,0\}\} = \max\{2,0\} = 2,$$

$$b_3 = b_4 = 0.$$

$$E = \min\{D(p)-D(\min\{p,r\}),D(\max\{p,r\})-D(r)\} =$$
$$= \min\{18-15,24-21\} = \min\{3,3\} = 3.$$

We get that $C(\alpha)$ = 3α+3 is a joint financial penalty for the work A and B and also

$$c_{C(\alpha),b}(\{A\}) = \min\{3\alpha+3,6\} = 3\alpha+3,$$

$$c_{C(\alpha),b}(\{B\}) = \min\{3\alpha+3,2\} = 2.$$

Then for each work and agreement between them we have the function $c_{C(\alpha),b}$ (Table 2).

Table 2

Values for identifying the optimal penalty

S	$c_{C(\alpha),b}(S)$	{D}	0	{B, C}	2	{A, B, D}	3α+3
{A}	3α+3	{A, B}	3α+3	{B, D}	2	{A, C, D}	3α+3
{B}	2	{A, C}	3α+3	{C, D}	0	{B, C, D}	2
{C}	0	{A, D}	3α+3	{A, B, C}	3α+3	*N*	3α+3

2. Implementation and description of the application. The application for designing a construction project graph and calculating the optimal distribution of delay penalties consists of the client and service components and operates in the following manner. An input text file with actual and planned timeline for the work is uploaded into the calculation module giving the main idea of how the application works and then it is converted into an output text file. Then this output text file containing the calculated penalties gets into the data model that is fundamental to the project graph [4—6]. Then the information from the data model gets into the implementation interface where the graph can be changed by the user. From the implementation interface the graph information is further drawn in the SVG-modulus.

The architecture of the application is presented in Fig. 2.

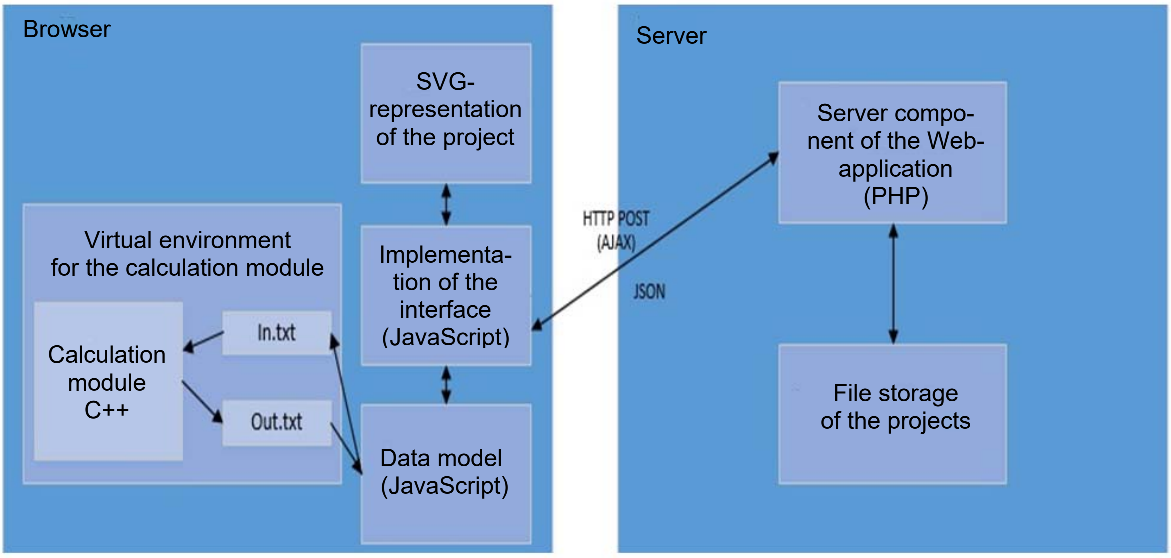

Fig. 2. Architecture of the application

If the user wants to open one of the ongoing projects, save, cancel or renew the project, the interface implementation module interacts with the server component of the application via the AJAX-query. The server component of the application refers to the project file storage. Then the graph gets from the file storage into the server component of the application and using the AJAX-query is directed into the interface implementation module. The information from the interface implementation module is directed for drawing into the SVG-presentation module.

3. Implementation of the program interface. The user enters the initial information into a new construction project template (Fig. 3).

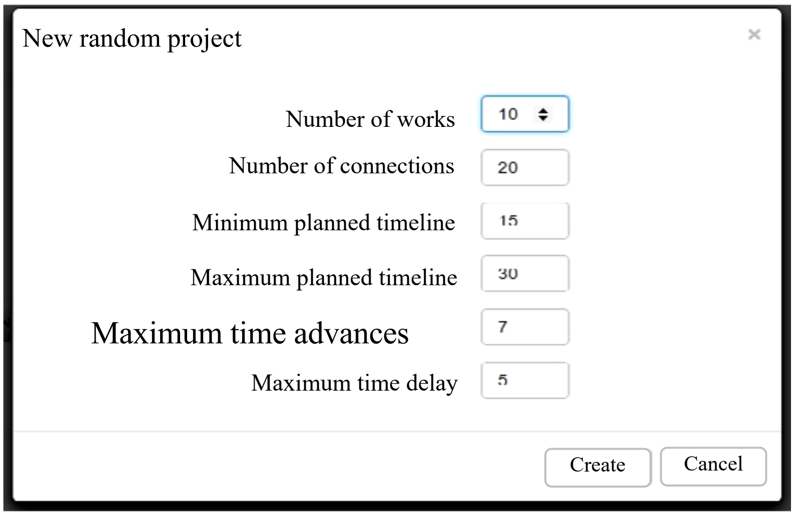

Fig. 3. Task of the initial data on the project

Then the graph of the project is generated where the works that had an impact on time delays and resulting penalties are in red and those executed ahead of time are marked in green (Fig. 4).

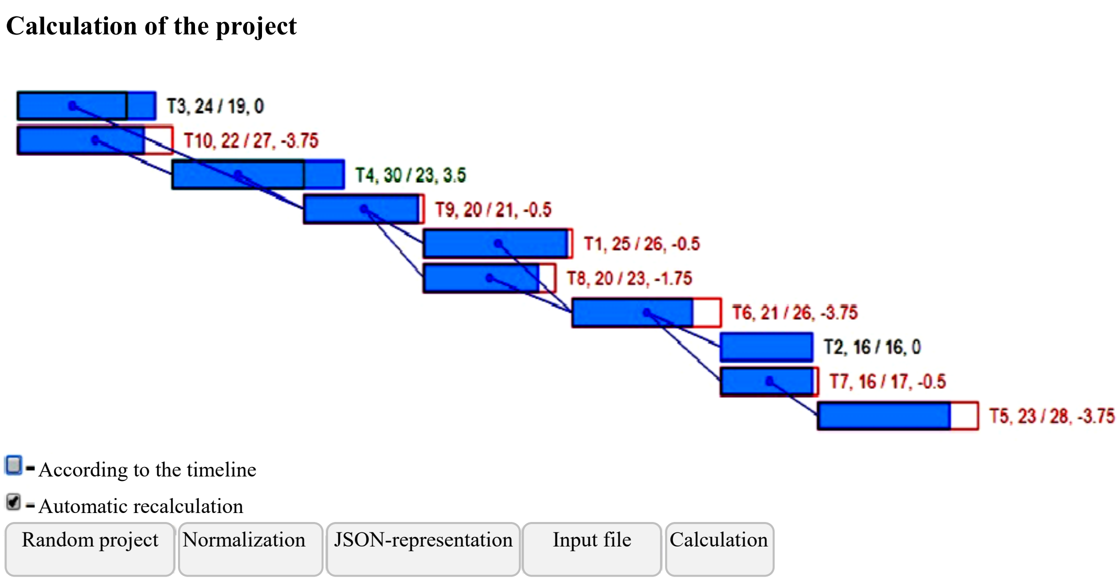

Fig. 4. Generation of the project graph

The user can also edit a construction project graph, i.e. add, cancel some of the components or connections between them (Fig. 5).

After the project graph has been edited, all of the values are recalculated and a new construction graph is designed. As well as the overall approach, this allows a wide range of taks including those facing the construction industry to be addressed. In this case modelling based on the game theory can be considered unified.

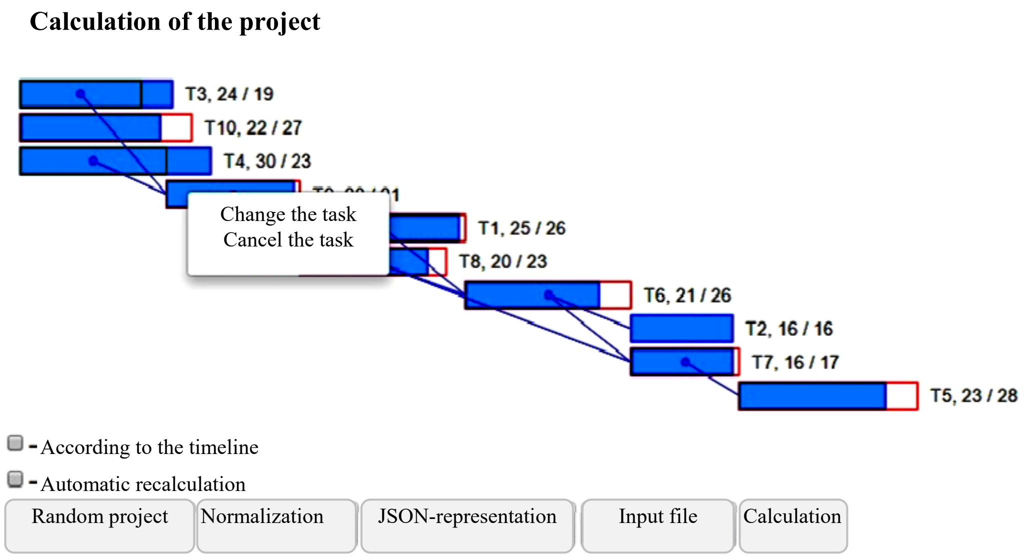

Fig. 5. Editing a project graph

The work entails the optimization of the function depending on a few variables. In [7, 9, 10] we looked at the possibility of using the macroprogramming language for that in construction industry as well as the relevance of the issue. It was also shown that the solution of the problem as well as the design and construction and assembly simply involves minimization of the function of costs in the calculation variant [9, 10, 18].

Conclusions. The paper deals with a new approach for identifying the optimal distribution of penalties in the construction industry as well as construction and assembly and development of the application based on it. This application improves the communication between the customer and contractor, which contributes to the rational use of funds allocated for a construction project. The game theory can be suggested as a means of modeling this scenario.

The developed module allows the optimal distribution of penalties for works and contractors that lead to disruptions of a project to be calculated and its graph to be edited if necessary.

The results obtained using the software can be instrumental in analyzing the results of further engineering calculations.

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