

Effective Distribution of Financial Resources of the Megaproject

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Abstract. The object of this study is a long-term capital-intensive investment megaproject with many participants and high risks of implementing their projects. The length of procedures for harmonizing investment projects of participants and the difficulty of coordinating their actions to achieve the megaproject's goals necessitate the creation of an adequate resource management tool. A step-by-step algorithm is proposed. The algorithm was tested on real economic information of the East Siberian Oil and Gas Complex megaproject and showed its ability to work. The general applicability of the algorithm is demonstrated.

Keywords: Network model · Megaproject · Resource allocation · Step-by-step algorithm

1 Statement of the Problem

For oil and gas companies, the problem of developing new regions with complex geological and natural conditions is urgent. In this regard, the importance of large innovative projects for the integrated development of oil and gas fields and the effective use of the main hydrocarbon transportation is growing. In order to choose an effective strategy for the implementation of innovative projects, a toolkit is needed to evaluate a variety of alternative combinations of new investment projects and schemes for their financing. The object of this study is the strategy for the implementation of a major investment megaproject. An example of such a megaproject is the development of the East Siberian Oil and Gas Complex (ESOGC) [9,10].

It is assumed that the development of the megaproject is presented in the form of an oriented graph G_{ij} without contours [2]. The duration t_{ij} of the performance of each work (i, j) of the network model G_{ij} is a random variable whose allocation parameter includes the investment resources c_{ij} allocated for this work. For each work (i, j) the lower boundary $a(i, j)$ (optimistic time)

and the upper boundary b_{ij} (pessimistic time) of the execution time are given. The works of the megaproject G_{ij} are grouped according to the projects G_k , $1 \leq k \leq n$, where n is the number of projects in the model. Each of the G_k projects has a deadline D_k of its end, as well as the minimum and maximum permissible probability of completion of the project during this period (P^* and P^{**} accordingly).

The main idea of the problem of allocating resources between n projects is to increase the probability of their completion in the target time frame D_k for given initial volumes of the megaproject G_k investment resources C . If any of the projects G_k at the time $t \geq 0$ can not be completed within the prescriptive time with an acceptable probability, then a redistribution of the remaining investment resources $\sum_{k=1}^n C_k(t)$ between the projects of G_k .

2 Formal Description of the Network Model

We introduce the notation: C - the initial volume of investment resources of the megaproject for the implementation of all projects;

C_{kt} - investment resources (budget) allocated to the k -th project at the moment $t \geq 0$, $C_{k0} = C_k$;

$T_k(C_{kt})$ - the random duration of the k -th project on the basis of the budget allocated to it C_{kt} ;

D_k - the target date for the implementation of the k -th project;

$(i, j)_k \in G_k$ - work (i, j) included in the k -th project;

c_{ijk} - budget allocated for the implementation of work $(i, j)_k$ of the project G_k ;

$c_{ijk \min}$ - the minimum budget value, allowing to perform the work $(i, j)_k$;

$c_{ijk \max}$ - the maximum budget value, allowing to perform the work $(i, j)_k$;

η_k - priority coefficient (degree of importance) of the k -th project.

As the objective function, the sum of the products of the priority project coefficients and the probabilities of their completion in the appropriate legislative terms is used. It is necessary to determine the values at which the objective function is maximal:

$$\sum_{k=1}^n \{\eta_k P_k(C_{kt})\} \rightarrow \max, \quad (1)$$

$$P_k(C_{kt}) = P(t + T_k(C_{kt}) \leq D_k)$$

under conditions

$$P_k^* \leq P_k(C_{kt}) \leq P_k^{**}, 1 \leq k \leq n \quad (2)$$

$$\sum_{k=1}^n C_{kt} = \sum_{k=1}^n C_k(t) \quad (3)$$

where

$C \leq \sum_{k=1}^n C_k$ - initial volume of investment resources of the megaproject for

realization of all n projects;

$P_k(C_{kt}) = P(t + T_k(C_{kt}) \leq D_k)$ - the probability of completion of the k -th project on time D_k with the allocated budget C_{kt} ;

$P_k^* = P_k(C_{kt}^*)$ - the probability of completion of the k -th project on time D_k with the allocated investments C_{kt}^* ;

$P_k^{**} = P_k(C_{kt}^{**})$ - the probability of completion of the k -th project on time D_k with the allocated investments C_{kt}^{**} ;

$C_k(t)$ - the remaining unused investment resources for the k -th project at time $t \geq 0$.

The proposed algorithm for solving the problem (1)-(3) is based on the PERT (Program Evaluation and Review Technique) method. The PERT method is generally intended for the calculation of schedules that have certain structures set by unambiguous technological processes. The activity time spans are assumed to follow a general Beta distribution [5,1,3,7,8].

The traditional PERT method uses only the activity time means to calculate the critical path, reducing the stochastic model to a deterministic model. In PERT, three time estimates are required for each activity. The time estimates represent a pessimistic time, an optimistic time, and a most likely time for duration of the activity. The method assumes that the sum of the mean completion times of activities on the critical path is normally distributed. This allows the calculation of the probability of completing the project within a given time period. A single critical path is thus calculated and relied upon, where in reality, there may be numerous possible critical paths that exist. For a large network plan the probability that any given path could be the critical path may be very small.

PERT method yields results which are biased high. If network has multiple parallel paths with relatively equal means, PERT calculations will be considerably biased [6]. As a result, the time to complete a project calculated by the traditional PERT method is almost always too short [11].

In accordance with the PERT method, the solution of problem (1)-(3) is divided into two stages. The basic and auxiliary problems are constructed, for the solution of which an algorithm is developed.

3 Resolving the Problem of Resource Allocation for Network Projects

3.1 Approval

For all projects G_k , $1 \leq k \leq n$, we solve the auxiliary problem with $p = P_k^*$ and $p = P_k^{**}$ [2]. As a result, we obtain the values of P_k^* , P_k^{**} and the budget values C_{kt}^* and C_{kt}^{**} . Let us write the dependent between $P_k(C_{kt})$ and C_{kt} :

$$\frac{P_k(C_{kt}) - P_k^*}{P_k^{**} - P_k^*} = \frac{C_{kt} - C_{kt}^*}{C_{kt}^{**} - C_{kt}^*}$$

and expressing $P_k(C_{kt})$, we substitute in the objective function in the form

$$\sum_{k=1}^n \left\{ \frac{P_k^{**} - P_k^*}{C_{kt}^{**} - C_k^*} \cdot \eta_k \cdot C_{kt} + \frac{P_k^* \cdot C_{kt}^{**} - P_k^{**} \cdot C_{kt}^*}{C_{kt}^{**} - C_k^*} \cdot \eta_k \right\} \rightarrow \max$$

We denote by

$$\frac{P_k^{**} - P_k^*}{C_{kt}^{**} - C_k^*} \cdot \eta_k = \alpha_k, \quad \frac{P_k^* \cdot C_{kt}^{**} - P_k^{**} \cdot C_{kt}^*}{C_{kt}^{**} - C_k^*} \cdot \eta_k = \beta_k$$

and we transform the objective function of the original model (1) - (3) to the form (4)

$$\sum_{k=1}^n \{ \alpha_k \cdot C_{kt} + \beta_k \} \rightarrow \max \quad (4)$$

Since the value of β_k does not depend on C_{kt} , the objective function (4) will be simplified and we obtain the following model:

$$\sum_{k=1}^n \{ \alpha_k \cdot C_{kt} \} \rightarrow \max \quad (5)$$

with the previous limitations (2) and (3).

3.2 Algorithm for Solving the Main Problem

The problem (5) with constraints (2) and (3) is solved using the step-by-step algorithm.

At the first step, we allocate for each remaining unfinished project the corresponding minimum budgetary volume C_{kt}^* . Let's designate the remaining budget ΔC_t . We order the sequence $\{\alpha_k\}$ in decreasing order. We denote the new ordinal numbers of this sequence by symbols f_1, \dots, f_n . In the second step, we set $j = 1$ and compute $\gamma_j = \min\{(C_{f_j,t}^{**} - C_{f_j,t}^*), \Delta C_t\}$. At the third step for the project, we determine its final budget $C_{f_j,t}$. We are correcting the remaining budget ΔC_t in the fourth step.

If $\Delta C_t = 0$, then finish the calculation. Otherwise, then $j = j + 1$ and the condition $j \leq n$ is satisfied, then we continue the calculations with γ_j . Until we completely disassemble all the cases.

The optimality of the algorithm follows from the presence of a monotonically decreasing sequence $\{\alpha_{f_j}\}$, and also from the allocation to each next project f_j at the step of the maximum possible additional budget γ_j from the ΔC_t budget left at the disposal of the company.

3.3 The Formulation and Algorithm for Solving the Auxiliary Problem

Let consider an auxiliary problem for the case of one project:
for the given "reliability" p of the project G , $0 < p < 1$, find the minimum value

of the allocated budget C and values that satisfy

$$\text{Min}C = \text{Min} \sum_{\{i,j\}} c_{ij} \quad (6)$$

with constraints

$$P(T(C) \leq D) = p, \quad (7)$$

$$c_{ij \min} \leq c_{ij} \leq c_{ij \max} \quad (8)$$

In the first step, we determine the values of C_1 , C_2 and C_3 . We solve problem (6)-(8) for $C = C_1$, $C = C_2$ and $C = C_3$ (see [4]).

As a result of solving this problem, we obtain the project reliability values p_1 , p_2 and p_3 . Compare the values of p_1 and p_2 : if $\forall \varepsilon \geq 0$, $p_1 - p_2 < \varepsilon$, then finish the execution of the algorithm, otherwise go to the next step. Analyzing the inequality $p_1 < p < p_3$, if it is satisfied, then go to step 2, otherwise to step 3. At the final stage of the algorithm, the value $C = C_3$ is the minimum budget that ensures the "reliability" p of this project.

4 Implementation of the Algorithm

To solve the problem, we developed a step-by-step algorithm that is implemented using C++ methods in the programming environment of Microsoft Visual Studio. The algorithm was tested on real economic information and showed its ability to work. The distribution of investment resources for the construction of the seven sectors of the East Siberia-Pacific Ocean (ESPO) oil pipeline, which is the basis for the formation of the ESOGC megaproject was considered.

5 The Network Graph

The network graph of the construction and operation the ESPO pipeline is presented in the form of projects the construction of seven pipeline sections 1.1-1.7 (Fig. 1). Each of pipeline sections is described by the unified module of the technological sequence of work and directive events. Triangles denote the unified network modules of sections of the oil pipeline (1.1 Taishet - Ust-Kut, 1.2 Lensk - Ust-Kut, 1.3 Lensk - Olekminsk, 1.4 Olekminsk - Aldan, 1.5 Aldan-Tynda, 1.6 Tynda - Skovorodino, 1.7 Skovorodino - Nakhodka).

The unified module of the pipeline is given in Fig. 2. The unified pipeline module reflects five stages of the project: 1. development of feasibility study (feasibility study) - work (1,2); 2. examination and approval of the feasibility study - work (2,3); 3. preparation of the pipeline route - work (3,4); 4. construction of the linear part of the pipeline (1st phase) - work (4,6) and installation of pumping station (PS) (1st phase) - work (4,5); 5. construction of the linear part (2nd phase) - work (6,8) and installation of the PS (2nd phase) - work (6,7). The network graph geographically reflects the sections of the pipeline passing through the three oil and gas bearing areas of the East Siberian Oil

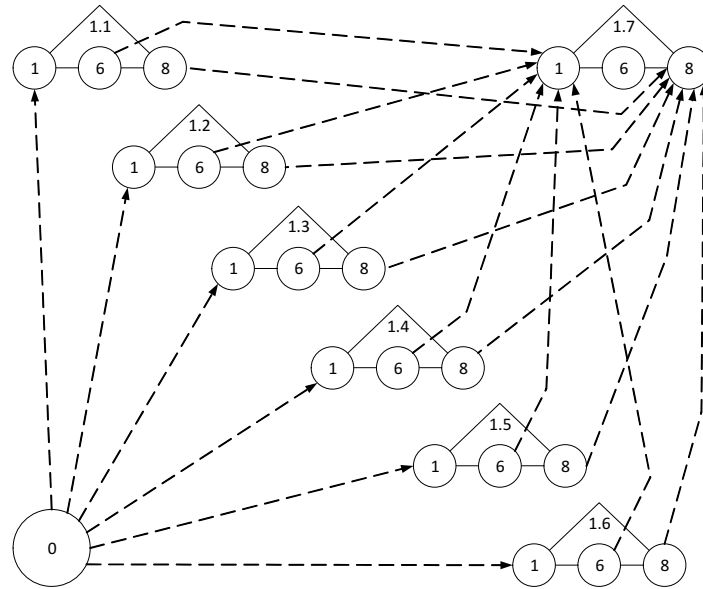


Fig. 1. Network model of construction and operation of the oil pipeline Eastern Siberia - Pacific Ocean

and Gas Complex (ESOGC) mega-project: Krasnoyarsk region (Taishet - Ust-Kut); The Republic of Sakha Yakutia (Lensk - Olekminsk, Olekminsk - Aldan, Aldan - Tynda); Irkutsk region and the Far East (Lensk - Ust-Kut, Tynda - Skovorodino, Skovorodino - Nakhodka).

6 Results

The universal method presented in this paper was used to calculate a more realistic duration for the construction of the seven sectors East Siberia-Pacific Ocean oil pipeline. Basic input data and calculated results of the resource allocation problem for network projects are presented in Table 1.

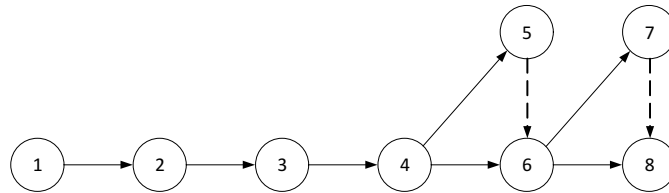


Fig. 2. The unified module of the pipeline

The initial volumes of investment resources of the megaproject were adopted in the amount of 11.861 bn rubles. The optimal allocation of resources for the pipeline section projects is determined on condition that the project are completed within the deadlines. The work schedule and the dynamics of investment distribution have been constructed.

Table 1. Input data and calculated investment volumes for pipeline sections at C=11.861 bn. Rub

Project number/ indicators	1	2	3	4	5	6	7
P_k^*	0.5	0.55	0.4	0.3	0.5	0.4	0.3
P_k^{**}	0.8	0.75	0.7	0.6	0.9	0.7	0.7
C_{kt}^*	923	1115	1667	2589	709	812	3685
C_{kt}^{**}	998	1224	1749	2699	743	863	3744
η_k	0.4	0.6	0.7	0.8	0.4	0.5	0.9
C_k	948	1115	1749	2699	743	863	3744

7 Conclusion

The problem of allocating investment resources between the pipeline construction projects is being solved. This problem is to increase the probability of completion of projects in the target dates for initial volumes of resources. To solve the problem, a step-by-step algorithm is proposed. Based on the technological sequence of the pipeline construction, an appropriate network schedule was formed. The volume of investments for each section of the pipeline is calculated.

Given the initial volumes of investment resources of the megaproject in the amount of 11.861 bn rubles. The optimal allocation of resources between the pipeline sections is determined, provided that they are completed within the target dates. The schedule of work execution and the dynamics of investment distribution have been constructed.

The obtained results show the effective of the proposed method to calculate the resource allocation between subprojects and realistic completion time for specified project implementation deadlines. The suggested method can be recommended for use by project managers in order to allocate resources and prevent possible abandonment of project completion deadlines.

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