Assessment of Options for Substantiating an Infrastructure Project Implementation Plan in the Presence of Associated Risks

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Abstract. The study describes the approach to drawing up and evaluating project implementation plans in the presence of associated risks. Two alternative approaches to planning are considered and evaluated: network modeling and integer programming. It is assumed that the project risk is associated with a positive or negative event or a combination of them that may occur with some probability during the implementation of the project. Different scenarios are developed depending on the conditions under which risk events occur. The risk value for each scenario is estimated based on the expected values of the project’s financial characteristics. Scenario tests are performed for each approach. The described procedure is checked using an illustrative example of an infrastructure project which consists in laying a section of a gas pipeline on the seabed. A software package for project planning was developed taking into account the associated risks based on a scenario approach using the Python.

1. Introduction: relevance of the study
Investment projects in real sectors of the economy are of key importance in the socio-economic development of any country. A special role is played by infrastructure projects in various areas and spheres of activity, in particular, in information, transport and energy, as stated in the Decree of the President of the Russian Federation “On the national goals and strategic objectives of the development of the Russian Federation for the period up to 2024” (2018). The implementation of such projects is associated with the influence of a number of uncertain factors which often leads to such negative events as exceeding the deadlines for their implementation, misalignment of their goals, inconsistency of work, activities and set of projects, etc. In practice it is necessary to know the exact assessment of the negative impact of risks, but also to be able to organize project activities to the most rational way to avoid them, reducing its possible negative impact. In this regard, it is extremely important to develop software and mathematical tools to quickly formulate and adapt project implementation plans taking into account time and resource constraints.

2. Review of scientific publication and research
There are two main approaches for making project plans: heuristic discrete optimization and metaheuristic algorithms; optimization of the composition and structure of project work using mathematical programming methods.

Traditionally, various optimization algorithms for resource allocation based on network modeling are used for project planning [1]. At the beginning of the procedure, it is necessary to calculate prelim-
inary plan, obtained without taking into account the resource requirements. The project works have a priority, which is evaluated on the basis of the importance of the project, the urgency of its completion, the size of the total time reserve for the work, their complexity, the amount of necessary resources. The duration, beginning and end of works may change depending on the priorities.

However, heuristic algorithms are often not suitable for obtaining complex integrated estimates of ranges of program parameters and their stability. In this regard, a number of works of domestic and foreign researchers was devoted to the development of planning support methods based on mathematical apparatus, and in particular, integer programming [2], [3], [4], [5]. In the general case, the question of the appointment of resources for a certain time, for the implementation of the relevant work, is considered. Problems of this type can be solved using various dynamic programming [6], the branch and bound algorithm.

The risk of the project is an uncertain event, which in case of occurrence has a positive or negative impact on at least one of the goals of the project [7] and is expressed as a combination of the probability of occurrence and damage from a risk event [8]. There are different ways to assess risks within the model depending on the planning method.

In stochastic network modeling, usually the variation component is the duration of the project, as well as the likelihood of some events (interpreted as risky events) [9], [10], [11]. According to the network model of the project, it is possible to analyze the logical relationships between the sequence of work among themselves and their relationship with various risk events. The occurrence of these events depends on the presence or absence of any signs that can be formalized in the form of probabilistic models [12], [13].

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The stochastic programming method for solving optimization problems is a recognized approach for the analysis of uncertainty [15, 16]. Stochastic programming is used to solve the following problems:

1) Optimization of some probabilistic measure (expected value).
2) Assessment of the impact of uncertainty on the optimal plan.
3) Optimization with random constraint (based on the assumption that the distribution of uncertain variables is stable, for example, the normal distribution, \( \chi^2 \) - distribution).

3. Formation of a model

There is data on the sequence of works forming the project, their planned time and resource costs. In order to ensure the successful execution of the project no later than the specified period, a calendar and resource plan for the project implementation must be built and evaluated.

As part of the study, a software package was developed to support project planning taking into account associated risks based on a scenario approach. The scenarios assume the implementation of various risk events at different stages of the project. At this stage of development, it is assumed that the probability distribution of risk events is known in advance. The risk assessment characteristic is the basic indicator of project profitability – NPV [17]. The value of risk \( R \) is defined as the difference between the NPV of the project under the baseline scenario (excluding associated risks) and the expected NPV.

The algorithm of the complex includes the following steps:

1) preparation of the initial project implementation plan and identification of possible risks;
2) calculation of the initial calendar and resource plan of the project (baseline);
3) supplement the project plan with identified possible risk events for various scenarios: taking into account at what stage they may occur and what their consequences and probabilities are, as well as, if necessary, measures for their processing;
4) experimentation on the model: when using network modeling, a series of Monte Carlo tests are performed to average the impact of added risk events on the result; when using mathematical programming, a stochastic programming problem is created with the probability of occurrence of risk events;

5) expected NPV values for the project plans are estimated and the risk value is calculated based on the received plans.

During the first stage, two approaches to planning were implemented: traditional (network planning) and an approach based on integer programming.

In an integer programming (IP) problem it is necessary to find the values of binary integer variables $x_i^j(t)$, $y_i^j(t)$ that indicate the start and end points of each work. Variable $x_i^j(t) = 1$ if the $i$-th work started at the $t$-th moment of time, and variable $y_i^j(t) = 1$ if the $i$-th work ended at the $t$-th moment of time. We assume that the prescribed duration of the project is known.

The following groups of restrictions must be taken into account in the task:

1. Resource constraints: 1) financial constraints: specialization of projects and programs with state participation is financing can be carried out from various sources (state budget, state corporations, etc); a financing plan for each source should be known; 2) constraints on scarce resources: their volume is initially determined; after completion of work, it can be reused.

2. Constraints on the sequence of work: for each $i$-th work, we can get a set of works directly preceding it. For each $t$-th moment of time, until all the work from this set is completed, the $i$-th work will not be started, i.e. $x_i^j(t) = 0$;

3. Constraint on the duration of work: the difference between the end of the $i$-th work and its start should not be less than the duration of the $i$-th work $l_i$;

4. Constraints on the start and end times of work: the start of each $i$-th work must not be later than $T - l_i$;

5. Constraints for performing and completing all work. Each work can start and end exactly once.

These conditions are necessary for making an adequate project plan. With the help of the various options for formalizing the objective function it is possible to project plans tailored for various situations. In particular, the target function can characterize: minimizing the total project execution time; minimizing pauses (downtime) between jobs; minimizing the number of jobs with zero time reserves; minimizing the expenditure of scarce resources per unit of time (uniform resource consumption), etc.

The following classification of risk events is used:

1) “Catastrophic” risk event leads to the closure of the project.

2) “Ordinary” risk event is not related to the progress of the project. The occurrence of this event is determined by external independent factors.

3) “Ordinary” risk event related to the progress of the project.

The algorithms were implemented using the Python, and the Pyomo module [18] and the Couenne solver were used for the mathematical programming problem. This is an open source software product designed for solving integer problems based on the branch and bound algorithm [19]. The PySP module (Pyomo Stochastic Programming) was used to solve the stochastic programming problem [20].

4. Calculation results
An illustrative example of an infrastructure project was used to show both approaches. This is a project for laying a section of a gas pipeline on the seabed. The list of project activities and design plans are shown in table 1 (“S” is a “start”, “F” is a “finish”). The durations of all works are indicated by integer values in months (“Plan duration”), the prescribed duration of the project is 16 months. Some works use a scarce renewable resource — the use of specialized equipment of the same type (“Resource”, amount = 7 units). Profit received after successful completion of the project - 43 cu, discount rate - 10%.

We will draw up a project schedule using the two described approaches: the network modeling method (column “NM”) and integer programming (“IP”). Depending on the type of objective function,
3 variants of the plan were built: “IP(1)” - minimization of the total project execution time; “IP (2)” - minimization of pauses between jobs; “IP(3)” - minimizing the cost of scarce resources per unit time.

Suppose that only two risk events were identified for this project: 1) “Breaking partnerships with one of the participating countries of the project” - the catastrophic risk event (CRE), it leads to the termination or the freezing of the project; 2) “During the monitoring of the seabed an unexploded shell from the Second World War was discovered” - the risky event depends on the work 1-4 (ORE). So we consider three main scenarios, in addition to the baseline: S(ORE) - only ORE happened, S(CRE) - only CRE happened, S(ORE & CRE) - both ORE and CRE happened. To assess the risk, the plans for each scenario were evaluated by indicators: expected duration (eDuration) and expected NPV (eNPV).

The calculations are shown in Table 2. For each scenario, the risk value R(S) is: R(S) = NPV\textsubscript{base} - eNPV\textsubscript{S}.

| Works                        | Plan duration | Re source | IP(1) | IP(2) | IP(3) |
|------------------------------|---------------|-----------|-------|-------|-------|
| 1-2. Study of the seabed     | 1             | 4         | 3     | 4     | 1     | 2     | 8     | 9     | 8     | 9     |
| 1-3. Research ecologist. setting | 2             | 3         | 4     | 5     | 1     | 2     | 1     | 2     | 1     | 2     |
| 1-4. Zone seabed monitoring  | 0             | 5         | 1     | 3     | 3     | 5     | 2     | 4     | 4     | 6     |
| 1-5. Availability of materials | 1             | 0         | 1     | 1     | 1     | 1     | 1     | 1     | 1     | 1     |
| 2-6. Aggregation of results  | 1             | 3         | 4     | 5     | 2     | 3     | 9     | 10    | 9     | 10    |
| 3-6. Aggregation of results  | 1             | 3         | 5     | 6     | 2     | 3     | 4     | 5     | 2     | 3     |
| 4-6. Aggregation of results  | 1             | 3         | 3     | 4     | 5     | 6     | 9     | 10    | 6     | 7     |
| 5-7. Delivery necessary materials | 1             | 0         | 1     | 2     | 1     | 2     | 1     | 2     | 1     | 2     |
| 6-7. Formation of an laying route | 1             | 3         | 6     | 7     | 6     | 7     | 10    | 11    | 10    | 11    |
| 7-8. Block preparation for welding | 1             | 0         | 7     | 8     | 7     | 8     | 11    | 12    | 11    | 12    |
| 7-10. Preparation of equipment | 1             | 0         | 7     | 8     | 7     | 8     | 13    | 14    | 13    | 14    |
| 8-9. Welding with the previous | 1             | 0         | 8     | 9     | 8     | 9     | 12    | 13    | 12    | 13    |
| 9-10. Weld point isolation   | 1             | 0         | 9     | 10    | 9     | 1     | 0     | 13    | 14    | 13    | 14    |
| 10-11. Laying the section    | 1             | 0         | 10    | 11    | 1     | 1     | 0     | 14    | 15    | 14    | 15    |
| 11-12. Connection            | 1             | 0         | 11    | 12    | 1     | 1     | 2     | 15    | 16    | 15    | 16    |

| Project duration variance    | 0.0           | 0.36      | 0.25  | 2     |       |

Table 1. Comparison project implementation plans.

Table 2. Scenario test results.

| Scenarios | Parameter | NM | IP(1) | IP(2) | IP(3) |
|-----------|-----------|----|-------|-------|-------|
| Baseline  | Duration  | 12 | 12    | 16    | 16    |
|           | NPV       | 11.7| 11.86 | 10.92 | 10.7  |
| S(ORE)    | eDuration | 12.11| 12.1  | 16    | 16    |
|           | eNPV      | 11.47| 11.7  | 10.75 | 10.6  |
|           | R(S)      | **0.23**| **0.18**| **0.17**| **0.12** |
| S(CRE)    | eDuration | -  | -     | -     | -     |
|           | eNPV      | 9.97| 10.61 | 9.87  | 9.82  |
|           | R(S)      | **1.73**| **1.25**| **1.05**| **0.98** |
The “NM” plan can be considered more stable, the variance of the timing for the “IP” is higher. Note that integer problems of large dimensions are quite difficult to solve and require significant computer time resources. One of the drawbacks of such a statement of the problem is the geometrically increasing dimension of the problem with an increase in the scope of the project, and even more so when considering various implementation scenarios. However, this toolkit allows you to get more informed and adaptive implementation plans, in contrast to traditional network algorithms.

The calculation options for the “IP(2)” and the “IP(3)” in the current setting do not imply time optimization, that is, the implementation of the work is not concentrated. However, the expected duration of the project in the S(ORE) scenario is the same as in the deterministic version, that is, the project completion date will not change.

Planning approaches “IP(1)”, “IP(2)”, “IP(3)” can be considered as adaptation to external conditions and implementation of risk management strategies.

In the considered implementation scenarios, the eNPV order is close, which confirms the correctness of the calculation logic. The difference in values arises due to changes in the moments of the end of work. For all scenarios, the condition is fulfilled: \( \text{R(ORE & CRE)} \geq \text{R(ORE) + R(CRE)} \), with the joint occurrence of risk events, the overall risk increases.

The values of the base NPV for various options for calculating plans depends on the sequence of work and the overall project implementation period. Options NM and “IP(1)” are characterized by the highest NPV base values, and for each scenario, R(S) by “IP(1)” is lower than by “NM”. Therefore, in terms of profitability, the “IP(1)” plan is less risky.

5. Conclusion
The study examined two alternative approaches to project implementation planning. Their assessment and implementation of the project risk assessment procedure was based on a control example. Calendar planning based on mathematical programming is more effective for enlarged plans, since it requires a mathematically based optimality of the resulting solution and the problem dimension is not so high due to low detail by period (months, quarters, years). Operational planning requires more detail and a lower degree of validity of the solution, which significantly increases the complexity of solving the problem of mathematical programming, which means that it is preferable to use network modeling algorithms.

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Acknowledgments
The Russian Foundation for Basic Research supported this work (project № 19-310-90022).