Methods of risk minimization in investment and construction projects

I V Sukhorukova*, D A Maksimov and G P Fomin

1Plekhanov Russian University of Economics, Stremyanny lane, 36, Moscow, 117997, Russia

Email: suhorukovaira@yandex.ru

Abstract. The paper puts forward a hypothesis about the possible integration of risk assessment methods in order to minimize them in investment and construction projects, for that the problems of risk minimization in the management and implementation of construction projects are considered. A critical review of existing methods of risk analysis is carried out and a method of risk minimization is proposed based on the creation of a “Construction risk Informator” and methods for optimizing the reallocation of resources according to the minimum time criterion, which determines the risk of lost profits. The example of the use of risk minimization methods in the optimization procedure for network models of low-rise building construction is given, and the composition of the application of mathematical methods and models that contribute to increasing the economic effect in this area is described. As a result, effective recommendations were developed in the form of tools for monitoring the dynamics of construction work to prevent risk situations.

1. Introduction
Creating an effective model for managing the implementation of construction projects is one of the main basic problems facing the modern manager. In these conditions, in order to overcome crisis situations and ensure the continuous functioning of the business, the necessary criterion is to develop mechanisms and search for options for the most optimal use of the existing material and production resource base, scientific, technical and organizational and economic capacities. Managing business in a crisis situation is quite a difficult task, as it is necessary to make most management decisions in the shortest possible time. It is necessary to analyze a significant amount of business information when developing optimal behavior, so the price of an error made by the manager increases critically. It is very important for a modern manager to learn not only to solve emerging problems in short time, but it is much more important to warn and prevent their occurrence timely. This can only be done using modern and effective management tools. The most important problem, which is primarily solved by the manager, is the analysis of the effectiveness of the labor activity of the team in carrying out construction work. Implementation of any investment project in the construction sector is associated with various types of risks due to uncertainty conditions. Investment and construction projects are characterized by the uncertainty of the project implementation conditions, which is due to the possibility of negative situations and consequences, the probability of adverse situations and consequences, and the adverse situations and
consequences themselves, which are directly related to damages, economic, social or environmental losses.

It should be noted that modern projects in the investment and construction sector are a very complex system that includes a large number of participants: the customer, general contractor and subcontractor construction and installation organizations; commercial banks and financial bodies and organizations; design and research institutes; suppliers of construction materials, structures, parts and semi-finished products, technological equipment; organizations and bodies that carry out various types of control and supervision of construction; divisions that operate construction equipment, machinery, and vehicles [1-5]. Existing publications illustrate the use of various methods to minimize risks in investment and construction projects, but unilateral decisions have not created convincing outlook for development prospects yet, so it is necessary to continue research in this difficult area.

2. Materials and methods
The modern scientific method of management in construction is a method of modeling future development in investment and construction projects, which allows integrating the advantages of existing methods and models in a successful combination and simultaneously eliminate the disadvantages.

The reasons for the risks are incomplete knowledge of events that may or should occur in the future. In this regard, the types and causes of risks of production and economic activities of a construction company in the market of low-rise housing construction were studied and a continuously replenished accumulator was created – “Construction Risk Information Center”. Various types of classification of construction risks, hierarchical and facet ones, are presented as the main platform for collective discussion with indication of their possible manifestations in construction. All this is graphically linked to the main tasks of organization, planning and management of low-rise construction and construction and installation works; preparation of construction sites; construction of load-bearing structures of buildings; construction of enclosing structures of buildings; arrangement of external engineering networks and equipment; protection of structures and equipment; finishing works; doing ground works; construction of roads, their bases and surfaces; construction and repair of buildings and structures. Network models in the field of modeling and scheduling of discrete technological processes can describe the relationship between work and a certain class of organizational and technological schemes of construction processes.

3. Results
It should be noted that the existing PERT-COST technology assumes the possibility of reducing the time required to complete a set of works by increasing costs. In addition, the PERT-COST technology is a method that allows the manager to minimize the total cost of a project if it is completed within a specified time frame, as well as to minimize the duration of the project in conditions of a limited budget. A typical mistake in the presentation of PERT technology is to assess the risk of project failure solely by the duration of the critical path. So, for example, a set of works must be completed in no more than X weeks, and the variance of the critical path duration is known and the mean square deviation of the critical path duration is equal to \( \sigma \), then we find the probability that the critical path length will be no more than X weeks, and the normal distribution function with mathematical expectation \( a \) and variance \( \sigma^2 \) is used for risk assessment:

\[
F(x, a, \sigma) = \frac{1}{\sqrt{2\pi\sigma}} \int_{-\infty}^{x} \exp \left( -\frac{(t-a)^2}{2\sigma^2} \right) dt.
\]

Calculations in the study show that the probability of failure of complex works within the period is 34.5%, which is of course a lot, but it happens in practice, and it is not determined by the duration of the critical path, and duration of the path is close to critical. Thus, it is shown that when calculating the risk of failure to complete an investment project on time, it is necessary to take into
account the paths that are close to critical. This led to the need to perform a complete optimization of the entire complex of construction works.

Any organizational and technological model should describe the list of construction and installation works, the order of their implementation, the nature of the relations between the works, reflecting the specifics of construction technology, building regulations, and the need for rational use of resources. The challenge is to analyze the network model in order to identify reserves and “weak points”, and then perform optimization. At the same time, it is important to use the advantages and eliminate the disadvantages of various modeling methods and integrate them [6-10]. It should be remembered that the discovered reserves allow managing the complex of work more flexibly by reassigning them from one work to another, more stressful, not arbitrarily, but reasonably according to the chosen optimization methods [11-12].

Thus, we build and analyze the network model in order to identify reserves and “weak points”. At the same time, the tabular method for calculating parameters allows solving this problem, but the graphical method of analysis still provides greater visibility and credibility, which makes it easier to proceed to the optimization process, and the combination of various modeling methods allows combining their advantages. Labor intensity shows the time spent to perform a single operation and is inversely proportional to labor productivity. To justify the business plan, as well as to analyze how effectively the labor force is used and how much labor intensity is affected by a variety of different reasons: the level of qualification of personnel, the degree of technical equipment of production, the complexity of manufacturing, the degree of automation and working conditions, we suggest using existing optimization methods in an integrated version as part of network methods and models on the example of low-rise construction, for which in table 1 a structural and time table of the list of works and resources for the construction of a three-story residential building using the “Construction Risk Information Center” is presented.

| Work content                  | Denotation on $a_i$ | Basic $a_i$ | Cost $b_i$ | Man-hour | Hours $t_i$ |
|-------------------------------|---------------------|-------------|------------|----------|-------------|
| Ground works                  | $a_1$               | -           | $b_1$ 9680 | 390      | 27.62       |
| Construction of foundation    |                     |             |           |          |             |
| - formwork installation       | $a_2$               | $a_1$       | $b_2$ 802150 | 360      | 2479.53     |
| - filling the foundation      | $a_3$               | $a_2$       | $b_3$ 450800 | 440      | 1140.11     |
| Basement utility room         | $a_4$               | $a_1$       | $b_4$ 535600 | 620      | 961.32      |
| Wall construction             |                     |             |           |          |             |
| - exterior walls              | $a_5$               | $a_3a_4$    | $b_5$ 2557000 | 2310     | 1231.79     |
| - interior walls              | $a_6$               | $a_5$       | $b_6$ 1231900 | 2530     | 541.84      |
| Installation of partition walls| $a_7$               | $a_3a_4$    | $b_7$ 3092000 | 4380     | 785.57      |
| Installation of stairs        | $a_8$               | $a_6a_7$    | $b_8$ 100500 | 280      | 399.42      |
| Mounting of platforms         | $a_9$               | $a_8$       | $b_9$ 98500  | 220      | 498.23      |
| Mounting of balcony slabs     | $a_{10}$             | $a_9$       | $b_{10}$ 890500 | 325      | 3049.07     |
| Mounting of floors            | $a_{11}$             | $a_6a_7$    | $b_{11}$ 1905000 | 1100     | 1927.17     |
| Mounting of thermal insulation| $a_{12}$             | $a_{10}a_{11}$ | $b_{12}$ 7510650 | 8000     | 1044.73     |
| Installation of canopies      | $a_{13}$             | $a_{10}a_{11}$ | $b_{13}$ 8500000 | 100      | 9458.80     |
| Mounting of openings          | $a_{14}$             | $a_{13}$    | $b_{14}$ 1708030 | 1550     | 1226.26     |
| Mounting of blind area        | $a_{15}$             | $a_{14}$    | $b_{15}$ 4500000 | 550      | 910.47      |
| Mounting of porches           | $a_{16}$             | $a_{15}$    | $b_{16}$ 7300000 | 400      | 2030.86     |
| Installation of the roof      | $a_{17}$             | $a_{16}$    | $b_{17}$ 1834700 | 4500     | 453.70      |
| Finishing works | $a_{18}$ | $a_{12}a_{17}$ | $b_{18}$ | 3341500 | 10250 | 362.77 |
|----------------|--------|-------------|---------|----------|--------|---------|
| Mounting of water pipes | | | | 0.00 | | |
| - installation of standpipes | $a_{19}$ | $a_{12}a_{17}$ | $b_{19}$ | 320500 | 280 | 1273.76 |
| - the layout in the flats | $a_{20}$ | $a_{19}$ | $b_{20}$ | 10500 | 470 | 24.86 |
| Mounting of the sewage system | | | | | | |
| - installation of standpipes of the sewage system | $a_{21}$ | $a_{20}$ | $b_{21}$ | 560500 | 370 | 1685.74 |
| - the layout in the flats | $a_{22}$ | $a_{21}$ | $b_{22}$ | 250500 | 750 | 371.68 |
| Mounting of heating | | | | | | |
| - pipe layout | $a_{23}$ | $a_{22}$ | $b_{23}$ | 950000 | 810 | 1305.14 |
| - installation of tubes and radiators | $a_{24}$ | $a_{23}$ | $b_{24}$ | 250500 | 1530 | 182.19 |
| Mounting of ventilation | | | | | | |
| - installation of lattices | $a_{25}$ | $a_{24}$ | $b_{25}$ | 260000 | 820 | 352.84 |
| - installation of air ducts | $a_{26}$ | $a_{25}$ | $b_{26}$ | 570500 | 680 | 933.61 |
| Electrical installation | $a_{27}$ | $a_{26}$ | $b_{27}$ | 2236200 | 3400 | 731.90 |
| Lightning protection | | | | | | |
| - installation of tower | $a_{28}$ | $a_{18}a_{27}$ | $b_{28}$ | 850500 | 100 | 9464.36 |
| - installation of connectors | $a_{29}$ | $a_{28}$ | $b_{29}$ | 79500 | 130 | 680.52 |
| Grounding | | | | | | |
| - excavation | $a_{30}$ | $a_{18}a_{27}$ | $b_{30}$ | 60500 | 200 | 336.62 |
| - backfill | $a_{31}$ | $a_{30}$ | $b_{31}$ | 70500 | 90 | 871.69 |
| Mounting of floors | $a_{32}$ | $a_{31}a_{29}$ | $b_{32}$ | 1761000 | 2630 | 745.11 |
| Mounting of doors | $a_{33}$ | $a_{32}$ | $b_{33}$ | 1156200 | 1820 | 706.93 |

We perform optimization based on the time criterion, in accordance with the target function of the following type:

$$T_{KP} = \sum_{i=1}^{n} t_{KP}^i \rightarrow \min.$$  

For the purposes of objectivity, we will analyze the network model, starting with determining the minimum amount of working time for performing a complex of construction works. Therefore, let us trace possible paths from the initial event to the final one. There are thirty-two such paths, of which we will select the longest - the critical path, then we will determine the time reserves for each path relative to it:

$$R(L_i) = T_{KP} - T_i.$$  

Then we build a network graph on a time scale, starting with the work of the critical path to establish the locations of reserves. On this basis, due to the reserves found on non-critical works, the duration of the critical path $T_{KP}$ can be reduced. By transferring some of the resources to critical work, they can reduce the time required to complete the work and thus get new deadlines for the entire complex. The optimal plan for performing construction work will be such a plan, when $T_{KP}$ will be the smallest of all possible. But the mechanism for redistributing funds involves reducing the part of funds for non-critical work $(i,j)$ by a certain amount $x_{ij} < b_{ij}$, defined by special restrictions, which naturally leads to an increase in the time of its execution, then it is fair to write:

$$t'_{ij} = f(x_{ij}) > t_{ij}.$$
At the same time, part of the transferred resources \( x_{ij} = x_{hk} \), invested in critical work \((h, k)\), lead to a decrease in its execution time, which can be described by the following expression:

\[
t_{\text{p,n}}' = f(x_{hk}) > t_{hk}.\]

The duration of the work depends on the amount of resources allocated, obviously, the “time – money” model works, and does not depend on how these resources were invested. Of course, this dependence is nonlinear and is described by the following expression:

\[
t = \lim_{n \to \infty} t_0 \left( 1 \pm c \frac{x}{m} \right)^n = t_0 \exp(cx) = t_0 \exp \left( \frac{c}{p} \right),\]

which indicates on an exponential form of connection, but in practice, when performing calculations, this function is upgraded by an approximate linear expression:

\[
t_{ij}' = t_{ij}(1 \pm x_{ij}) = t_{ij} \pm t_{ij} \frac{x_{ij}}{b_{ij}};\]

Due to the fact that the allocated resources are limited, the condition for their preservation must be met, therefore, the amount of funds withdrawn from the work \((i, j)\) must be equal to the amount of funds transferred to the work \((h, k)\):

\[
\sum_{i}^{M} x_{ij} = \sum_{i}^{N} x_{hk},\]

where \( M \) – the number of jobs that funds were withdrawn from; \( N \) – the number of jobs that funds were transferred to.

In the process of reallocation of funds, they must comply with the restriction on the amount of transferred funds \( x_{ij} \) from work \((i, j)\), which is determined by the availability of a free reserve \( r_{ij}^{\text{CB}} \) in this work according to the formula:

\[
x_{ij} \leq \frac{r_{ij}^{\text{CB}}}{t_{ij}},\]

In accordance with the above models, we optimize and build the optimal network plan for the complex of works for the construction of a low-rise building, then get the location of all works on critical paths that do not have reserves. This provision made it possible to realize the risk of lost profits - savings of an absolute value of \( R=1726 \) hours, which is very significant. Thus, the described network methods and optimization models allow solving problems of optimal distribution and redistribution of limited resources, aimed at minimizing risks for resources of different nature, including the time of completion of the entire complex of construction works.

4. Summary

Thus, modern optimization methods are integrated into a set for solving problems of distribution and redistribution of limited resources, aimed at minimizing the time of completion of the entire complex of works and thereby realizing the risk of lost profits. As a result, we developed effective recommendations for creating a tool called “Construction Risk Information Center”, which provides continuous accumulation of risks to ensure continuous monitoring, as well as visual support of construction operations. In addition, it is very important that all participants in the construction of a residential building are equally informed to monitor the dynamics of the development of construction operations to minimize risks in investment and construction projects.

5. References

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