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ALGORITHM FOR DEVELOPING AN ORGANIZATIONAL AND TECHNOLOGICAL MODEL WITH RISK ASSESSMENT FOR TIMELY CONSTRUCTION COMPLETION

ANNOTATION

The organizational and technological construction model serves as a conceptual foundation for structuring the construction process during its implementation phase. The effectiveness of adopted organizational and technological solutions significantly impacts the quality and timely completion of construction projects. This paper proposes an algorithm for developing a model that includes both quantitative and qualitative risk assessment aimed at ensuring timely project delivery. The research hypothesis suggests that enhancing the reliability of the construction process requires the application of a predictive approach when designing organizational and technological solutions. The methodology is based on systems analysis, a multifactor approach, and analytical modeling of construction processes. The outcome of the study is the development of a predictive probabilistic mathematical model that accounts for the influence of random factors and enables quantitative risk assessment that may affect construction timelines. The model considers potential deviations from the critical path and allows forecasting the probability of timely project completion. The proposed algorithm enhances the organizational and technological reliability of the construction process and enables more efficient resource allocation under uncertainty.

Key words: *organizational and technological solutions, construction management, predictive modeling, risk factors, systematic approach.*

Introduction. Almost every sequence of organizational and technological processes in construction, whether simple, complex, unique, or technically sophisticated, is influenced by numerous technological and organizational factors. Some of these factors may negatively impact the execution of construction procedures. The occurrence of adverse factors or their combinations leads to deviations from the planned quality characteristics of the construction output. This, in turn, reduces the level of organizational and technological reliability, stability, and overall efficiency of the construction process.

In traditional construction planning, deterministic models are used extensively. These models rely on fixed input values for time, resources, and sequence of operations, assuming that the environment is stable and predictable. However, in practice, construction projects are affected by uncertainty at every stage—from design to commissioning. These uncertainties stem from fluctuating weather conditions, variable labor productivity, material delivery delays, equipment failures, changes in client requirements, and external socio-economic influences. As a result, deterministic models often fail to capture the dynamic nature of real-world construction environments.

A construction process, by its nature, is characterized by a multitude of interdependent activities, each having its own duration, prerequisites, resource constraints, and risks. Therefore, any delay or disruption in one activity can propagate through the project schedule, leading to cumulative effects on the project duration, cost, and quality. The critical path method (CPM), which is commonly used for scheduling, assumes fixed durations and lacks flexibility to accommodate uncertainties. This underlines the need for a more robust framework that incorporates risk and uncertainty into construction planning and control mechanisms [1,2].

To address this issue, the development of a probabilistic organizational and technological model is proposed. Such a model considers variability in task durations, resource availability, and environmental conditions. Instead of providing a single estimate for project completion, the probabilistic model generates a range of outcomes, offering a more realistic forecast of project performance. Monte Carlo simulation is one of the widely used tools for implementing probabilistic models in construction. By running thousands of iterations with randomly selected input parameters within defined probability distributions, project managers can assess the likelihood of meeting deadlines and identify activities with the greatest risk exposure [3,4].

Materials and methods of research. The integration of probabilistic models allows for a comprehensive risk analysis of construction operations. It facilitates the identification of critical risks, quantification of their impact, and development of mitigation strategies. For instance, if excavation work is prone to delays due to weather conditions, the model can simulate different weather scenarios and assess how each impacts the start of subsequent activities like foundation laying or structural assembly [5].

Another important aspect of probabilistic modeling is its role in resource optimization. Construction resources—labor, equipment, and materials—are often limited and subject to availability issues. Traditional planning methods allocate resources based on fixed assumptions, which may lead to over-allocation or underutilization. Probabilistic models allow planners to test different resource allocation strategies under various risk scenarios, leading to more efficient and flexible project execution plans [6,7].

Furthermore, organizational decision-making benefits greatly from probabilistic planning. Project managers, contractors, and stakeholders can use probabilistic forecasts to make informed decisions about project milestones, buffer times, contingency plans, and contract clauses. It enables dynamic scheduling and continuous performance monitoring throughout the construction lifecycle. As uncertainties unfold, the schedule can be updated to reflect actual performance and re-forecasted using new input data [8].

A critical element in enhancing organizational and technological stability is the development of performance indicators that reflect both deterministic and probabilistic characteristics. These indicators may include:

- Reliability index: the probability of completing the project within a given deadline;
- Stability coefficient: a metric showing how sensitive the project duration is to variations in key parameters;
- Technological cohesion score: an indicator of how well construction activities are coordinated and integrated;
- Risk exposure level: a measure of the cumulative impact of identified risks on project performance.

Incorporating such indicators into project dashboards can significantly improve real-time control and project transparency. It aligns with the principles of Lean Construction, where value delivery and waste minimization are emphasized [9,10].

Another promising direction in enhancing the effectiveness of probabilistic modeling is the use of Building Information Modeling (BIM) integrated with risk analytics. BIM-based platforms enable the visualization of construction sequences and risk zones in a 3D or 4D environment, offering a better understanding of where and how delays can occur. Through simulation and scenario analysis, decision-makers can evaluate alternative construction strategies and select the one with the optimal balance between speed, cost, and risk [11].

The integration of digital tools such as BIM, GIS, drones, and IoT devices with probabilistic models further enhances the capacity to monitor construction processes in real time. Sensors installed on construction sites can provide data on weather, temperature, material conditions, or equipment status. This real-time data can be fed into the probabilistic model, enabling adaptive scheduling and early warning systems for potential delays or failures [12].

Case studies and applications of probabilistic models in construction have shown significant improvements in project predictability and resource use. For example, in large-scale infrastructure projects, the use of probabilistic scheduling reduced project delays by 10–15%, while improving budget adherence by 8–12%. In complex residential projects, risk-based planning allowed for better coordination between subcontractors and reduced rework caused by overlapping schedules [13,14].

Despite these advantages, several challenges exist in the wide-scale adoption of probabilistic models. These include:

- Lack of data for accurate probability distribution estimation;
- Resistance from practitioners accustomed to deterministic methods;
- The complexity of modeling and interpretation of results;

- Need for specialized software and skilled personnel.

To overcome these barriers, it is necessary to provide training for construction managers, promote research in the field of stochastic modeling, and encourage the adoption of digital technologies in construction practices. National and international standards should begin to reflect the importance of risk-based planning and provide methodological guidance for its implementation.

In conclusion, the move from deterministic to probabilistic models in construction planning marks a paradigm shifts toward more resilient and adaptive construction management. It acknowledges the inherent uncertainty in the construction environment and provides tools to manage it effectively. By embedding risk awareness into every stage of construction—from design through execution and commissioning—stakeholders can enhance project reliability, reduce cost overruns, and improve client satisfaction [15].

Thus, probabilistic organizational and technological modeling is not only a theoretical necessity but a practical imperative for modern construction. It serves as the foundation for risk-oriented project management, technological reliability, and strategic decision-making in a volatile, uncertain, and complex industry [16,17].

Figure 1 illustrates the structural framework of a study focused on proactive (predictive) risk analysis. It highlights the impact of adverse factors on the construction process and potential deviations from the planned functional quality indicators of construction projects and production.

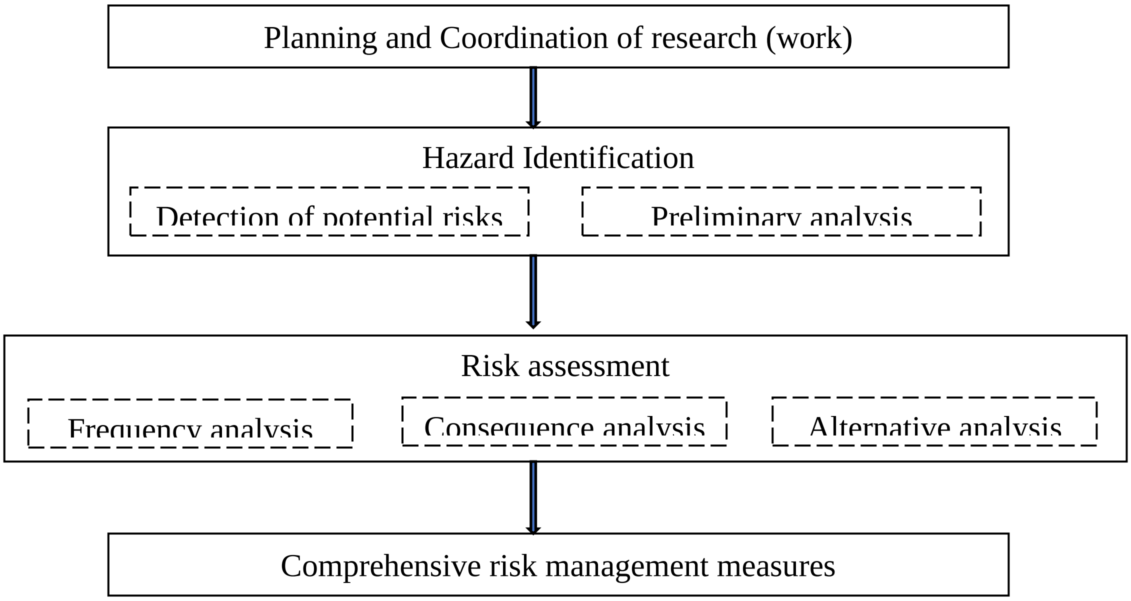

Figure 1 - Structural framework for predictive risk assessment in construction production and evaluation of construction quality

The quantitative assessment of risks in construction production is determined by the following key indicators [18]:

– maximum allowable risk value [R]:

$$[R] = [P] \cdot F; \tag{1}$$

– calculated risk value R:

$$R = P \cdot F \tag{2}$$

here: F — the calculated magnitude of consequences resulting from the impact of adverse factors (risks) in construction production;

P — the calculated probability of the occurrence of adverse factors (risks) in construction production;

[P] — the permissible probability of adverse factors (risks) occurring in construction production.

Condition for the compliance of the calculated risk with its maximum allowable value:

$$R < [R]. \tag{3}$$

It is evident that a positive forecast for meeting condition (3) highlights the need to develop a comprehensive risk management strategy in the following key areas [4]:

– reducing or eliminating the causes and prerequisites that lead to adverse consequences in construction production.

– establishing reserves of material and intangible resources necessary to mitigate and compensate for the effects of adverse factors in construction.

The lack of a methodological framework for forecasting the occurrence of adverse factors in construction production and allocating the necessary resources to minimize their impact is one of the primary reasons for the insufficient effectiveness of organizational and technological solutions in construction.

The quality and efficiency of construction project solutions (organizational and technological) are evaluated using a system of qualitative and quantitative indicators known as technical and economic parameters (TEP). An optimal organizational and technological design should ensure that TEP values comply with established regulatory requirements for construction products [19].

The results and their discussion. For instance, Table 1 presents the technical and economic parameters (TEP) for organizational and technological solutions used in the construction of a low-rise residential building.

Table 1 – Key technical and economic parameters (TEP) of organizational and technological solutions for low-rise residential construction

№	Indicator Name	Indicator characteristic	Unit of measurement	Value
1	Total Construction Duration ($П_w$)	By the critical path:	days	153
2	Duration of the Main Construction phase	According to the organizational and technological model: $П_{main.w.} = П_{total.w.} - П_{prep.w.}$ $П_{main.w.} = 153 - 9 = 144$	days	144
3	Total labor intensity (T_{total})	According to the organizational and technological model:	Man-days	1701
4	Labor intensity per 1m^3 of building, man-days/m^3,(T_w/1 m^3)	$T_w/1\ м^3 = T_w/V_з$ $T_w/1\ m^3 = 1701/2267.47 = 0.751$	Man-days/1 m^3	0.751
5	Maximum number of workers simultaneously per shift	According to the organizational and technological model: $N_{max} = 19$	man	19
6	Coefficient of workforce movement irregularity	$N_{aver.} = T_w/П_w = 1701/144 = 11.812$ $N_{irreg.} = N_{max} / N_{aver.} = 19/11.812 =$ $=1.609$	-	1.653
7	Coefficient of construction process overlap	According to the organizational and technological model: $K_{overlap} = П_{pr.norm.}/ П_{pr.w.}$ $K_{pr.} = 364/144 = 2.459$	-	2.459

The analysis of the composition of technical and economic parameters (TEP) of organizational and technological solutions (see Table 1) reveals that the existing regulatory indicators do not include characteristics reflecting the organizational and technological reliability of construction. This indicates that any project-based organizational and technological decisions do not account for the influence of random factors, thereby creating potential risks associated with adverse impacts.

Table 2 presents the results of an analysis (forecast) of risks associated with negative factors in construction, which may contribute to an increase in the overall construction duration (critical path) of the given project.

The analysis of the calculated data presented in Table 2 indicates that the probability of completing construction on time (with a critical path of 153 days) is 50% if potential adverse factors are not considered.

Therefore, improving organizational and technological reliability is only possible by developing an algorithm for calculating construction duration that accounts for the impact of adverse factors and by creation a corresponding probabilistic organizational and technological model [20].

The development of a predictive probabilistic organizational and technological model for construction includes the following key stages:

1. Creating an initial model in a deterministic format, fully complying with the requirements of existing regulatory and technical documents.
2. Defining and assessing quantitative values of random (probabilistic) parameters, which supplement the initial deterministic model.
3. Quantitative evaluation (forecast) of the probability of timely project completion, considering identified adverse factors.
4. Developing recommendations for accounting for potential adverse factors in the organization of construction processes.

Table 2 – Calculated Parameters of Probability for On-Time Construction Completion $P(t_{cr} < T_{cr})$

Percentage of critical path duration exceedance in the construction model	Critical path duration, t_{cr}	Critical path duration, T_{cr}	Dispersion indicator, $\sqrt{\sigma^2}$	Probability of critical path duration, $P(t_{cr} < T_{cr})$
0 %	153.0	153.0	0.000	0.5000 (50.0 %)
1 %	153.0	154.50 (*154.53*)	1.500	0.8413 (84.13 %)
2 %	153.0	156.00 (*156.06*)	2.041	0.9292 (92.92 %)
3 %	153.0	157.50 (*157.59*)	2.500	0.9641 (96.41 %)
4 %	153.0	159.19 (*159.12*)	3.005	0.9799 (97.99 %)
5 %	153.0	160.67 (*160.65*)	3.504	0.9857 (98.57 %)
6 %	153.0	162.17 (*162.18*)	4.003	0.9890 (98.90 %)
7 %	153.0	163.67 (*163.71*)	4.503	0.9911 (99.11 %)
8 %	153.0	165.17 (*165.24*)	5.003	0.9925 (99.25 %)
9 %	153.0	166.67 (*166.77*)	5.503	0.9935 (99.35 %)
10 %	153.0	168.33 (*168.30*)	6.009	0.9946 (99.46 %)

Conclusions. The result of the research was the development of a predictive probabilistic mathematical model that takes into account the influence of random factors and allows quantifying the risks that may affect the construction period. The model takes into account possible deviations from the critical path and allows you to predict the probability of timely completion of the project.

1. An organizational and technological model of construction, developed in a deterministic format according to modern regulatory and technical requirements, does not provide sufficient stability and reliability in the construction process.
2. To accurately assess and forecast the impact of adverse factors on construction duration, it is essential to develop and implement a probabilistic organizational and technological model.
3. The integration of probabilistic modeling allows for the identification and quantification of risks that may affect the critical path, enabling proactive measures to mitigate delays.
4. A predictive probabilistic approach improves the adaptability of construction planning under conditions of uncertainty and enhances decision-making at all stages of project execution.
5. The proposed model contributes to the organizational and technological reliability of the construction process by providing a framework for dynamic risk assessment and scenario analysis.
6. Implementation of the model supports optimal resource allocation and scheduling strategies, increasing the likelihood of completing construction projects on time and within budget.

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ТҮЙІН

Құрылыстың ұйымдастырушылық-технологиялық моделі оны жүзеге асыру кезеңінде құрылыс процесін құрылымдаудың тұжырымдамалық негізі ретінде қызмет етеді. Қабылданған ұйымдастырушылық және технологиялық шешімдердің тиімділігі құрылыс жобаларының сапалы және уақтылы аяқталуына айтарлықтай әсер етеді. Бұл жұмыста жобаның уақтылы орындалуын қамтамасыз етуге бағытталған тәуекелдерді сандық және сапалық бағалауды қамтитын модельді әзірлеу алгоритмі ұсынылған. Зерттеу гипотезасы құрылыс процесінің сенімділігін арттыру ұйымдастырушылық және технологиялық шешімдерді жобалау кезінде болжамды тәсілді қолдануды қажет ететіндігін көрсетеді. Әдістеме жүйелік талдауға, көп факторлы тәсілге, құрылыс процестерін аналитикалық модельдеуге негізделген. Зерттеу нәтижесі кездейсоқ факторлардың әсерін ескеретін және құрылыс мерзімдеріне әсер етуі мүмкін тәуекелдерді сандық бағалауға мүмкіндік беретін болжамды ықтималдық математикалық моделін жасау болып табылады. Модель сыни жолдан ықтимал ауытқуларды қарастырады және жобаның уақтылы аяқталу ықтималдығын болжауға мүмкіндік береді. Ұсынылған алгоритм құрылыс процесінің ұйымдастырушылық және технологиялық сенімділігін арттырады және белгісіздік жағдайында ресурстарды тиімдірек бөлуге мүмкіндік береді.

РЕЗЮМЕ

Организационно-технологическая модель строительства служит концептуальной основой для структурирования процесса строительства на этапе его реализации. Эффективность принятых организационных и технологических решений существенно влияет на качество и своевременность завершения строительных проектов. В данной статье предлагается алгоритм разработки модели, включающей как количественную, так и качественную оценку рисков, направленную на обеспечение своевременной реализации проекта. Гипотеза исследования предполагает, что повышение надежности процесса строительства требует применения прогностического подхода при разработке организационных и технологических решений. Методология основана на системном анализе, многофакторном подходе и аналитическом моделировании процессов строительства. Результатом исследования стала разработка прогностической вероятностной математической модели, учитывающей влияние случайных факторов и позволяющей количественно оценить риски, которые могут повлиять на сроки строительства. Модель учитывает возможные отклонения от критического пути и позволяет прогнозировать вероятность своевременного завершения проекта. Предложенный алгоритм повышает организационную и технологическую надежность процесса строительства и позволяет более эффективно распределять ресурсы в условиях неопределенности.