# TECHNOLOGY AND ORGANIZATION OF CONSTRUCTION
# ТЕХНОЛОГИЯ И ОРГАНИЗАЦИЯ СТРОИТЕЛЬСТВА

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## Analysis of Control of Construction Timing Taking into Account the Early Warning System of Missed Deadlines

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**Abstract**

***Introduction.*** The study is dedicated to evaluating the existing methods for monitoring the construction time of residential buildings and substantiating the advantages of the early warning system (EWS). Traditional tools such as schedules and monitoring are insufficiently effective due to their reactivity and inability to identify risks ahead of time. The aim is to demonstrate the transition from reactive management to proactive predicting likely problems [1]. Modernization of traditional methods by integrating digital tools, introducing predictive analytics and using hybrid management methodologies transforms time control from simple tracking into proactive projection becoming an important competitive edge, allowing the construction industry to effectively deal with challenges and achieve goals with a maximum accuracy.

***Materials and Methods.*** The object of the study is a construction time management system that includes planning, monitoring, and response methods. The major drawbacks of the traditional approach are delayed identification of problems as these methods mainly record problems as they emerge. Assessments are biased and holistic information environment is lacking.

***Research Results.*** As part of the study, the author is expected to design a unique system of EWS indicators adapted to the realities of the Russian construction conditions, a methodology for integrating predicative analytics into the BIM environment, as well as an economic and mathematical model for calculating the effect of EWS implementation. These solutions will reduce the number of missed deadlines by 20–30%, automatically detect risks a week or a week and a half before they emerge, and achieve up to a 95% accuracy in predicting project completion.

***Discussion and Conclusion.*** The proposed measures have a high practical value as they contribute to reducing developers' financial and reputational costs, implementing legislative norms and increasing amount of trust among those involved in the market. Integration of modern technologies, use of predictive models and flexible management approaches transform timing control from passive monitoring into active prevention of possible disruptions. It is assumed that the implemented method will provide a reduction in the number of cases of missed deadline by 20–30%, and will allow early detection of possible threats prior to the impact of negative consequences improving the quality of project time frame assessment.

**Keywords:** construction timing control, project management, missed deadlines, early warning, calendar and network planning, Earned Value Management, BIM predictive analytics

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*Оригинальное эмпирическое исследование*

# Анализ контроля сроков строительства с учетом методов раннего предупреждения срыва сроков

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**Аннотация**

***Введение.*** Исследование посвящено оценке существующих методик контроля сроков возведения жилых зданий и обоснованию преимуществ подхода раннего предупреждения (EWS). Традиционные инструменты, такие как календарные планы и мониторинг, недостаточно эффективны ввиду своей реактивности и неспособности заранее выявить риски.

Целью является демонстрация перехода от реактивного управления к проактивному, предвосхищающему потенциальные проблемы [1]. Модернизация традиционных методов путем интеграции цифровых инструментов, внедрения предикативной аналитики и использования гибридных методологий управления трансформирует контроль сроков из простого отслеживания в проактивное предвидение, что становится важнейшим конкурентным преимуществом, позволяя строительной отрасли эффективно преодолевать вызовы и достигать поставленных целей с максимальной точностью.

***Материалы и методы***. Объект изучения — система управления сроками строительства, включающая методы планирования, мониторинга и реагирования. Основные недостатки традиционного подхода заключаются в запоздалом выявлении проблем, эти методы преимущественно фиксируют проблемы по факту их возникновения, субъективизме оценки и отсутствии целостной информационной среды.

***Результаты исследования.*** В рамках работы ожидается создание авторской системы EWS-индикаторов, адаптированных под реалии условий российского строительства, методики интеграции предикативной аналитики в BIM-среду, а также экономико-математической модели для расчета эффекта от внедрения EWS. Данные решения позволят снизить количество срывов сроков на 20–30 %, автоматически обнаруживать риски за неделю–полторы до их наступления и достичь точности прогнозирования сроков сдачи до 95 %.

***Обсуждение и заключение***. Предложенные меры имеют высокую прикладную ценность: сокращают финансовые и репутационные издержки застройщиков, способствуют выполнению законодательных норм и повышают доверие участников рынка. Интеграция современных технологий, использование предиктивных моделей и гибких управленческих подходов превращают контроль сроков из пассивного наблюдения в активное предупреждение возможных нарушений. Предполагается, что внедренный метод обеспечит снижение количества случаев нарушения дедлайнов на 20–30 %, и позволит заблаговременное обнаружение возможных угроз до наступления негативных последствий, что улучшит качество оценки временных рамок исполнения проектов.

**Ключевые слова*:*** контроль сроков строительства, управление проектами, срыв сроков, раннее предупреждение, календарно-сетевое планирование, Earned Value Management, BIM. предиктивная аналитика

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**Introduction.** Construction delays do not merely result in additional financial costs, but they actually undermine customers' trust, affect contractors' reputation, entail legal disputes and might eventually cause a project to terminate altogether.

The aim of the study is to develop a practice-oriented algorithm for preventive control of missed deadlines in construction based on integrating the early warning system.

The development tasks are as follows:

1. Critical analysis of current timing control systems.

2. Structuring the EWS (Early Warning System) for the construction industry, identifying the key risk indicators.

**Materials and Methods.** The object of the study is a system aimed at monitoring construction timing of residential facilities in its current state, including:

– planning procedures (calendar schedules, CPM analysis, resource allocation);

– progress monitoring methods (reporting, data collection tools);

– deviation response mechanisms;

– interaction of project participants (customer, contractor, subcontractors).

Traditional control methods such as calendar planning, Gantt charts (Fig. 1), use of the critical path method (CPM) (Fig. 2), recording and stage-by-stage inspections have certainly been the foundation for systematic planning and tracking progress[1] and have dominated the industry over decades.

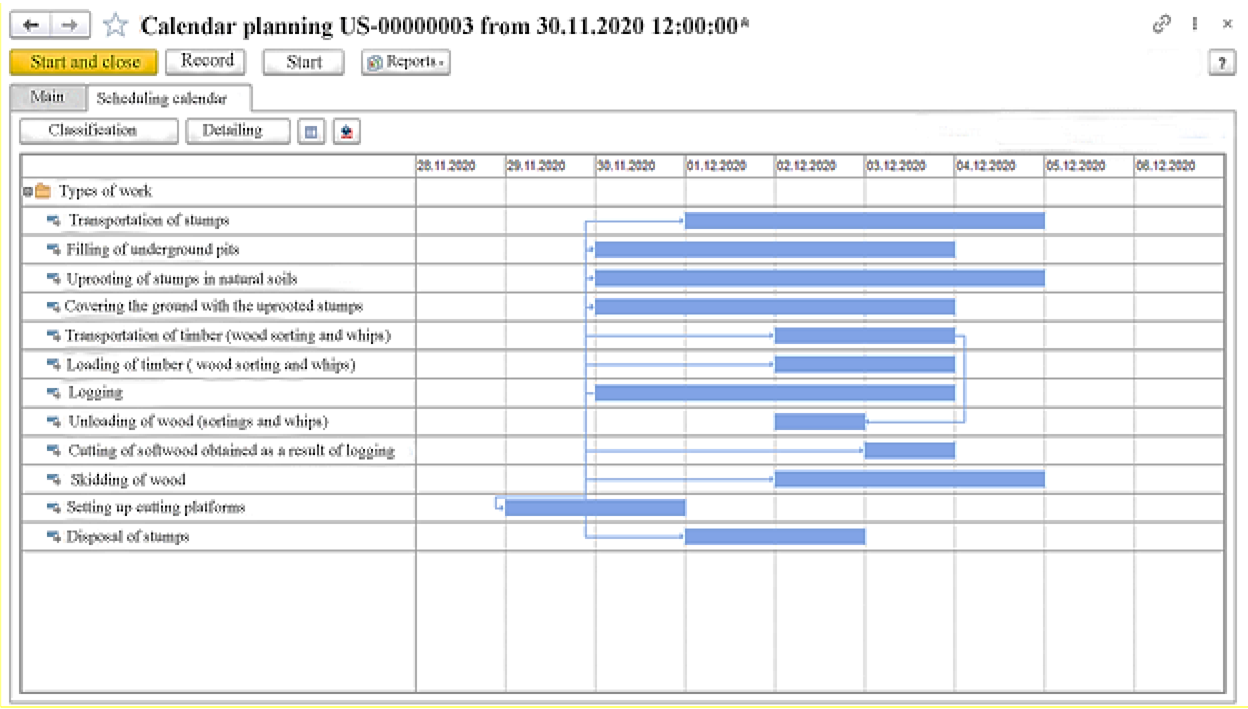


Fig. 1. Example of a Gantt chart

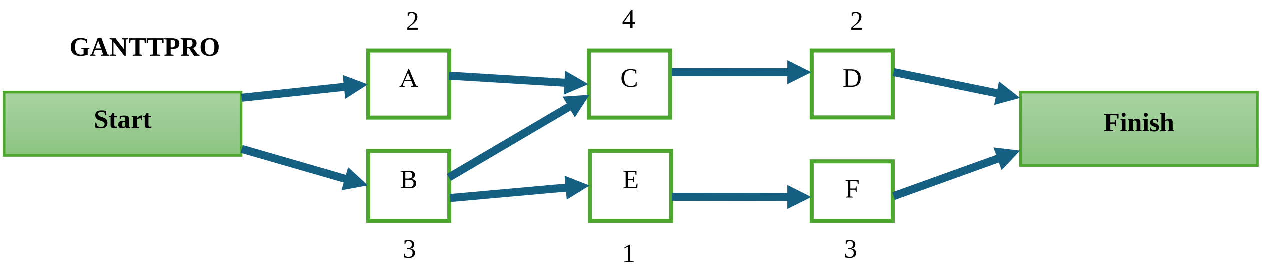


Fig. 2. Critical path method in construction management based on a network graph

Let us analyze the major traditional approaches to timing control [2]:

1. *Calendar (mostly linear) planning*:

The essence of the method, its main mechanism: development of step-by-step plans with fixed dates for the start and end of work.

Main tools: Gantt charts, network graphs (PERT).

Application methods: typical for any projects with preliminarily predictable construction stages, e.g., foundation → frame → finishing→ quality control (particularly hidden work) → commissioning.

*2. Journal recording and reporting:*

The main mechanism is recording of completed works in paper or electronic journals, e.g., in the "Work Production Journal".

[1] Bovteev SV *Methods and Forms of Organizing Construction Production: a Study Guide.* Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering; 2022. 221 p.

Application methods by means of data recording: incoming daily reports from foremen on the time spent, amount of work completed over a period of time, and problems that occur in the process.

*3. Stage-by-stage inspections* [3]:

The essence of stage-by-stage inspections is quality control at the key construction stages in order to prevent defects and ensure that the project adheres to the standards.

*Ways and forms of control* (see Fig. 3):

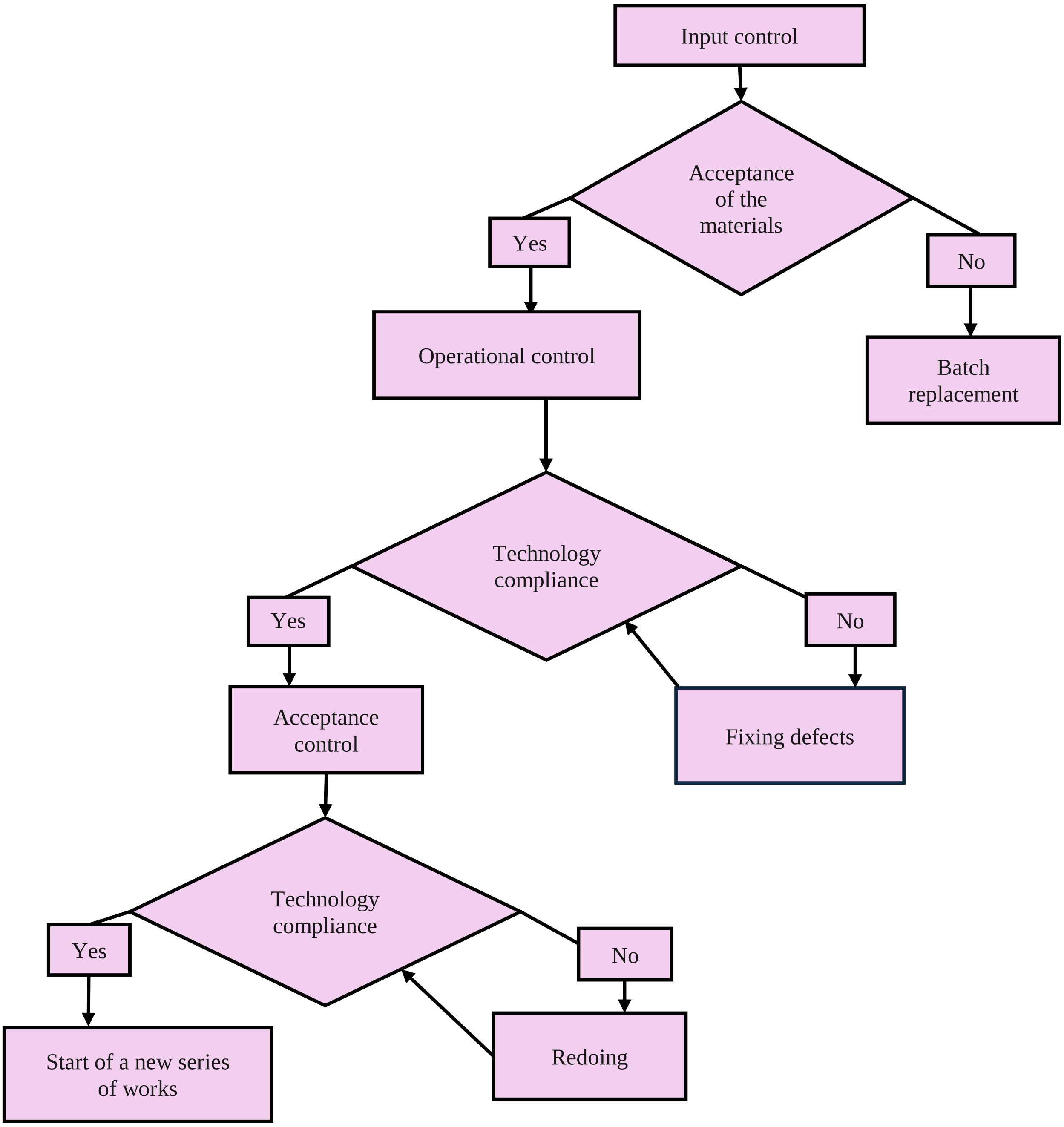


Fig. 3. Current scheme of stage-by-stage inspections

– *input control*: inspection of materials and equipment, including machinery and mechanisms, prior to the start of a work phase: certificates, passports, compliance with the GOST, possible defects ranging from packaging to more significant ones. E.g., at the construction site of the Lakhta-2 residential complex in St. Petersburg, a batch of fittings was rejected due to a diameter discrepancy of 12 mm instead of 14 mm according to the project;

– *operational control*: monitoring of technological processes through the course of work (technology, geometry, temperature during concreting) can be very highly efficient provided that modern technical tools are properly utilized. E.g., during the construction of monolithic ramps from the Bolshoy Smolensky Bridge across the Neva River, temperature sensors detected concrete overheating up to + 40 °C instead of + 25 °C, and the work was stopped for cooling to be held. The use of Concrete DNA sensors with a strength prediction for 72 hours in advance contributed to the high-quality performance with zero defects and a time reduction of 18 days;

– *acceptance control*: as the final stage prior to the start of the next series of work, checking compliance with the drawings, strength of materials, documentation, signing acts after the stage completion (e.g., "Certificate of Inspection of Hidden Works"), fairly commonly implies the need for defect elimination. E.g., in the Etalon residential complex in Yuzhny Butovo in Moscow (2021), the acceptance of the frame of the last object was delayed due to some cracks detected in the columns by means of ultrasound, which called for reinforcement of the column structures.

A critical analysis of current timing control systems enables one to identify the main strengths and weaknesses of traditional methods (Table 1).

Table 1

Comparative analysis of the methods and their flaws

| Method | Strengths | Weaknesses | Example of consequences / assessment of economic losses |
|---|---|---|---|
| Calendar graphs | Visual, easy to use | Rigidity, Operational adjustments are not possible | A 3-month delay in a residential complex completion (Moscow) |
| Journal recording | Legal significance | Subjectivity, falsification | Budget overruns:<br>– Residential complex "Severnaya Dolina", St. Petersburg: cracks in the walls were identified following the commissioning, i.e., demoulding with insufficient concrete strength due to lack of thermometers;<br>– Residential complex "Etalon", Moscow, 2021: adding water to the concrete - mixer drivers diluted the mix to facilitate the unloading. |
| Stage-by-stage inspections | Compliance with the standards (SP 48.13330) | Narrow focus, overlooking defects | Slab collapse in Kirovsky shopping center — spot ultrasonic inspection overlooked the voids in the concrete |

The key results are specified in Table 2.

It can thus be concluded that the efficiency of the traditional methods is constrained by some hidden disadvantages, the main one is that they are more commonly employed in order to identify missed deadlines rather than prevent them [4].

To put it in another way, most traditional approaches are inherently reactive that turn active after the timing problem has become obvious.

The need to move from reactive to proactive construction time management has become the fundamental aim of the study.

The modern approach calls for early warning methods to be introduced that are capable of identifying potential threats to deadlines long before they become critical. This enables the project management team to develop and implement corrective actions in a timely manner keeping negative impacts to a minimum [5]. The key to effective early warning is integrated use of data, technology, and well-established communication processes. The major ways of enhancing the verification stages include digitalization, monitoring sensors, blockchain, and indispensable construction control records.

Table 2

Specifying the key focus. Impact of delays [4]

| Criterion | Study object/<br>Problem statement/Consequences | Subject matter<br>in decision making |
|---|---|---|
| Essence | The timing control system is flawed – a low level of accuracy – unreliable source data<br>Human factor: control subjectivity (visual assessment of the formwork); reporting falsification (overestimation of the volume of work by 15–20%).<br>Technical limitations: narrow focus control allows hidden defects (plate collapses in Kirovsky shopping center in 2020, Hollywood shopping center in December 2021). | Transformation with the EWS methods |
| Problem focus | The problems of the current system:<br>– *reactivity:* deviations from the schedule are detected late, oftentimes only in the weekly reporting;<br>– *delays:* impossibility of surgical intervention causes delays to accumulate;<br>– *financial losses:* error correction takes up to 30% of the project budget. | Proactivity, predicting risks at early stages |
| Tools | Weakness of the traditional system:<br>– disparate databases (graphs, journal records, geodata is stored separately);<br>– manual input of information slows down the process; The result: delays in approvals, loss of documents, discrepancies between plans and facts for up to 7–10 days. | Digital technologies (BIM, AI), automated KPIs, prediction algorithms.<br>„Stroykontrol“ blockchain platform |
| Study aim | Diagnostics of the deficiencies in the current system | Developing an integrated EWS control model for residential buildings |

Methods for predicting schedule deviation risk[2] [6] are to include:

1. Early detection and digital management of possible risk factors by analyzing a timing performance monitoring system.
2. An integrated approach with delay warning monitoring, including a delay analysis strategy.
3. Prevention of missed deadlines in construction based on analytical approaches in time parameter management.

One of the fundamental methods of early warning is the Earned Value Management (EVM) system. EVM integrates cost, schedule, and work volume data, providing valuable metrics such as cost value (CV) and scope value (SV) [7]. A negative SV value indicates running behind the schedule, and the SPI index reflects the efficiency of the project in relation to the schedule. Monitoring these metrics helps one toidentify a problem in a timely manner, predict its impact, and take action before there are some irreversible delays occurring. The analysis of SPI dynamics allows for an accurate assessment of the work progress and prediction of the completion dates. Apart from EVM, detailed risk analysis and management have a major role to play [8]. Early identification of risks and their systematic assessment at the early stages of a project (e.g., risks associated with materials supply, lack of qualified professionals, changes in weather conditions, obtaining permits), allow preventive measures to be developed. The formation of a risk register with the calculation of a likelihood and impact lays a foundation for foreseeing threats. Scenario analysis and modeling (Monte Carlo method) help to more accurately predict timelines and plan time resources.

Integration of BIM and network planning (4D BIM) provides a visual representation of construction progress, allowing for future conflict resolution and proactive problem solving (Fig. 3). The use of IT (Internet of Things) sensors on equipment and in key areas of a construction site ensures real-time data collection on work progress, equipment performance and resource location [9].

[2] Oleinik PP, Brodsky VI, Kuzmina TK, Cherednichenko ND Theory, *Methods and Forms of Organizing Construction Production: a coursebook in the study area 08.04.01 Construction. Part 1.* Moscow: National University of Science and Technology MISiS — Moscow State University of Civil Engineering; 2019. pp. 174–244.

Fig. 4. Example of using BIM technology

Artificial intelligence and machine learning analyzing huge amounts of data (Fig. 4) from past projects, current metrics, and external factors (weather, economic indicators), are capable of identifying hidden patterns and predict likely delays with a high degree of accuracy offering optimal corrective actions to be taken [10]. Project management systems (PMS) with automatic alerts and dashboards (Fig. 5) displaying the key indicators in real time also significantly improve the early warning efficiency.


Fig. 5. Example of a dashboard

In this case, all incoming user requests are arranged in sequence and are visible. Based on the priority, a request or incoming information is ranked, tasks are assigned to the relevant services and a schedule for their completion is generated, the algorithm then reduces the integrated tasks. Effective communication helps to address early warning problems. The open exchange of data on current tasks, difficulties encountered, and resources needed helps to respond to deviations in a timely manner [11]. Regular meetings of all of the project participants ensure prompt discussion of progress and emerging difficulties. It is also critical to implement clear change management procedures: clear design of changes (design, scope of work, materials) and analysis of their impact on timing and cost reduce schedule disruption risks. Uncontrolled changes are one of the major causes of missing deadlines.

Constant monitoring of the critical path [12] identified at the planning stage is vital for early warning. Dynamic path updates are regularly recalculated and analyzed to account for actual execution rates. A change in the critical path or new critical tasks signal potential timing issues. The assessment of time reserves (float) allows one to identify potentially dangerous stages, where even minor delays might affect the overall completion time.

**Research Results.**

Structuring the EWS methodology for the construction industry:

1. Identifying the *key risk indicators:*

– consumption rate of temporary buffers;

– labor productivity dynamics (deviation of > 15 % from the standard);

– delays in delivering the critical materials.

2. Development of a *predictive analytics algorithm* based on historical data (ML-models).

*Managerial innovations:*

– a system of triggers for rapid response;

– adaptation of risk management processes to a preventive model.

*A trigger example:* when the IT sensors detect an 18 % drop in the installation speed of ferroconcrete structures, the system automatically:

– recalculates the timing of the critical path;

– initiates the order of additional equipment;

– notifies the general contractor of a stage delay risk.

It was proposed that the technological architecture of a system is structured taking into account the optimization of the critical path [15].

Table 3

Tool integration

| Technology | Functional |
|---|---|
| BIM 4D/5D | Graph visualization + automatic progress update |
| IT-sensors | Monitoring the pace of work (e.g., the volume of concrete laid per shift) |
| Cloud-platforms | Data aggregation → warning generation (SMS/e-mail) |

***Process model of risk management***

1. Introducing a *three-level trigger system* (Fig.6):

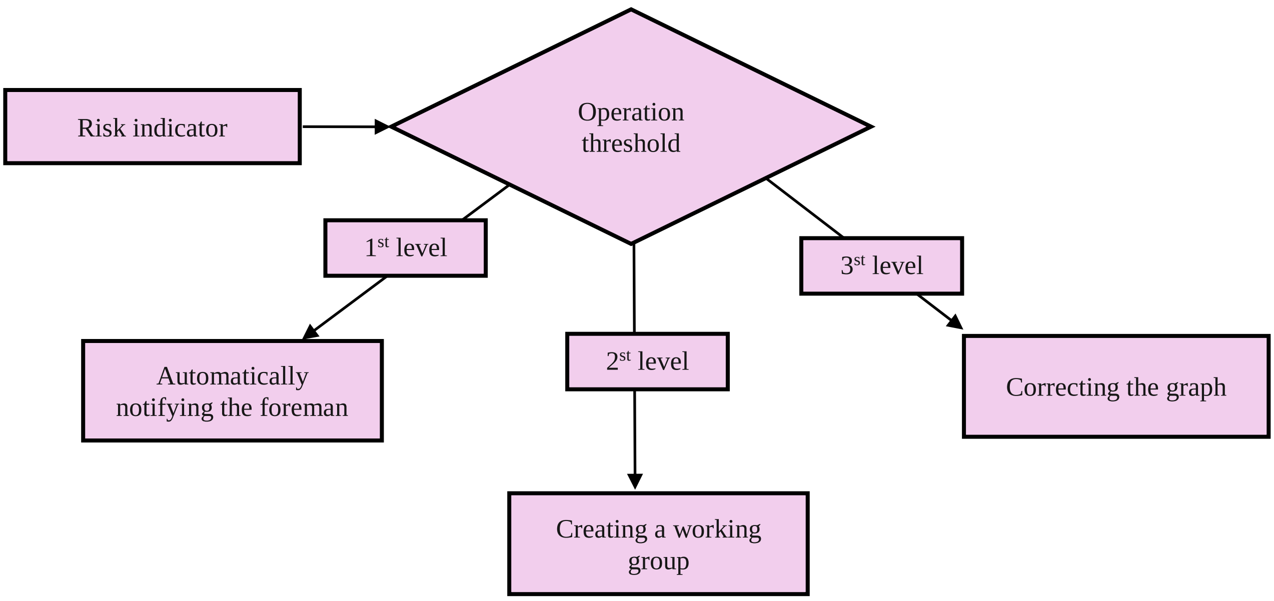


Fig. 6. Algorithm for implementing a three-level system

2. *Operational response regulations* (time period: 1–24 hours).

3. *Case study of the model testing.*

Pilot implementation of EWS at the residential complex "Lakhta-2" (2022–2024 data).

Parameters: 24 floors, 356 apartments, construction time — 28 months.

Results:

– a delay reduction of 27 %;

– 11 mln roubles saved due to downtime reduction.

4. *Designing the recommendations:*

– for developers: EWS implementation algorithm (stages, budget, ROI);

– for regulators: proposals for updating the SNiP/GOST accounting for preventive control.

The subject focuses on designing *an algorithm for proactive timing management* that:

– *Reduces the frequency of delays.* The algorithm continuously monitors the key indicators of the project. Deviations (a 15 % drop in productivity, delayed deliveries) trigger an early warning. An early reaction prevents negativity accumulation and reduces the costs of correcting the schedule.

– *Integrates EWS*-indicators into routine processes. The central element of the algorithm is the Early Warning System (EWS). The indicators reflect changes in the project and warn of impending problems. An example: the consumption rate of the critical path reserve. A rapid depletion of reserves signals impending deadlines and calls for urgent action. EWS integration provides access to up-to-date information and real-time decision support.

– *Formalizes the response.* In order to ensure a prompt and uniform response to identified risks, the algorithm provides for the formalization of the response. This means that for each potential scenario deviation or when certain threshold values of the EWS indicators have been reached, specific corrective measures are identified ahead of time. E.g., setting a trigger: "if the time reserve is reduced by 50% → initiate a review of the logistics." This approach reduces decision-making time, eliminates subjectivity, and ensures instant implementation of pre-approved response protocols.

In order to get some understanding of the algorithm mechanics, let us consider the following scenario: introduction of IT sensors designed to continuously monitor the rate of concrete hardening on monolithic structures. The collected data, including temperature, humidity, and other environmental parameters, are subjected to machine learning (ML analysis). Based on historical data and current indicators, the ML model is capable of predicting a potential delay in completing monolithic work, e.g., 10 days prior to this delay becoming obvious and causing disruption. Upon receiving such a projection, the system initiates automatic or manual adjustments to the overall construction schedule, which might include reallocating the resources, changing the sequence of related works, or activating alternative plans to compensate for the delay identified. This example is indicative of how the algorithm transitions from data collection to data analysis, prediction, and ultimately to proactive control.

***Anticipated Research Novelty.***

1. *The system of EWS*-indicators *we have developed* for the construction industry (adapted to the realities of the Russian Federation). The first specialized Early warning Indicator System (EWS) has been designed for the Russian construction sector. Apart from the consideration of the local factors (climate, legislation, prices, workers' qualifications), a unique methodology for measuring, prioritizing and combining indicators has been set forth.

2. *Method of integrating* of predictive analytics in the BIM environment.

The scientific novelty of the research lies in the design of an original method for algorithmizing a two-way data exchange between predicative models (machine learning, neural networks) and a BIM platform transforming it into a BIM model. The method allows one to predict deviations in terms of time, resources, and costs using historical and current project data. A two-way, automatically updated data exchange between analytical models and BIM transforms the latter from a diagnostic tool that displays the current state of a project into a tool of predicting and optimizing the construction processes.

3. *Economic and mathematical model* of calculating the impact of the EWS implementation.

The novelty of the model is in its capacity to account for both direct financial benefits (e.g., reducing penalties for failure to meet the deadlines, optimizing resource costs, minimizing the risks of budget overruns) and indirect, albeit no less significant advantages (such as increasing a developer's reputational value, reducing legal costs, and increasing the degree of shareholders and investors' trust). The model will include algorithms for calculating return on investment (ROI), net present value (NPV) and the other key performance indicators, as well as enable a scenario analysis and sensitivity assessment to a wide array of parameters providing reliable justification for management decisions.

The practical significance of the study lies in radically improving the reliability and stability of the construction process by means of introducing a proactive timing control system based on the deep integration of early warning systems (EWS). The model reduces developers' financial and reputational risks, improves compliance with the requirements of Federal Law No. 214-FZ from 31.12.2004 "On Participating in the Shared-Equity Construction of Apartment Buildings and Other Real Estate Objects and on Amendments to Certain Legislative Acts of the Russian Federation", increases shareholders and investors' confidence in construction companies – transparency, predictability and timeliness of project implementation considerably reduce the number of potential lawsuits and claims, which creates a favorable investment climate and bolsters a developer's competitive position in the residential construction market.

The model provides:

– a 20–30 % reduction of missed deadlines due to continuous monitoring of the key indicators;

– automatic identification of risks 7–14 days prior, which provides project managers with an invaluable window of opportunity to take timely corrective action, reallocate the resources, or activate alternative plans, minimizing a negative impact;

– an increase in the accuracy of timing prediction of up to 95 %.

As a result, projects are implemented on time, legal claims and administrative sanctions are reduced, and companies' investment attractiveness and competitiveness are boosted.

***Prospects of modernization of traditional methods.*** Digital tool integration:

– *BIM (Building Information Modeling):* One of the key areas is the use of BIM for 4D planning. This technology enables one to dynamically link detailed work schedules with 3D project models, which automatically identifies potential collisions, conflicts and inaccuracies in the sequence of operations as early as at the starting stages of planning. This contributes significantly to a reduction in the risk of errors and alterations on the construction site.

– *IT-sensors:* The widespread adoption of IT sensors ensures continuous monitoring of the key construction parameters in real time. E.g., tracking the pace of concreting, vibration levels, or temperature conditions on the construction site. The successful experience of projects such as the Lakhta-2 residential complex in St. Petersburg is a clear indication of a high efficiency of such systems in increasing control and predictability of work progress.

*Implementation of predictive analytics: early risk warning.* The active use of predictive analytics is the second major aspect of modernization. Modern algorithms based on analysis of extensive historical data and machine learning methods are capable of predicting potential delays and risks with a high level of accuracy. E.g., when a 15% drop in productivity is detected in a segment of work, the system automatically generates an alert, allowing managers to respond swiftly and adjust plans before a problem has become critical.

Hybrid management methodology: Waterfall + Agile: Modernization of management methods also involves development of hybrid methodologies combining elements of the traditional Waterfall and Agile approaches. This involves integrating rigid planning and consistent execution of the key project milestones (typical for Waterfall) with flexible, adaptive sprints for rapid adjustments and response to changes and risks identified (typical for Agile). The advantages of this blend have been practically proved, e.g., during the construction of the bridge over the Neva River, the use of digital twins within the framework of a hybrid methodology allow a 18-day reduction in the total work time indicating the potential for synergy of a wide array of approaches in improving management efficiency of large and complex projects.

**Discussion and Conclusion.** Traditional methods of monitoring construction deadlines suffer from reactivity, subjectivity, and fragmented data. In order to address these flaws, an integrated approach is essential combining digitalization (BIM, AI), management flexibility (Waterfall + Agile) and a shift towards proactive management. The experience of the construction of the Lakhta-2 residential complex is a proof that digital integration provides a 20–30% delay reduction.

The new approach changes the paradigm of time management transforming passive observation into active projection. Integrated risk management, data analytics, technology and communications are called for. The implementation of such methods reduces a likelihood of disruptions, optimizes costs, enhances quality and reputation.

The suggested proactive monitoring algorithm is based on the early warning (EWS) system adapted to the Russian conditions. The system provides EWS indicators, predictive analytics, and effect assessment. The results: a 20–30% reduction in missed deadlines, automatic risk detection in 7–14 days, and prediction accuracy of up to 95%. This approach keeps financial and reputational risks to a minimum, adheres to the requirements of Federal Law No. 214 and enhances market participants' trust. Digital tools and predictive analytics transform time control into strategic projection that warrants sustainability and growth of the construction industry.

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