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Management of Engineering Projects for the Modernization of Hydrocarbon Transportation Infrastructure

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Abstract— *The article presents an analysis of contemporary approaches to the management of engineering projects aimed at the modernization of hydrocarbon transportation infrastructure. The study consistently examines the challenges faced by participants in modernization projects: the growing importance of cybersecurity under conditions of digitalization of production processes, the need to reduce the carbon footprint and to integrate decarbonization measures into the infrastructure development strategy, as well as conflicts between long-term sustainable development goals and short-term economic constraints. International practices in asset integrity management and the implementation of digital twins are analyzed, enabling predictive monitoring of equipment condition, optimization of operating modes, and enhancement of the justification of managerial decisions regarding capital investment and maintenance. The purpose of the study is to develop an integrated model for managing modernization projects, oriented toward improving their effectiveness, technological and operational safety, as well as long-term sustainability. In the concluding part, conclusions are formulated regarding the applicability of the proposed hybrid model in the context of Russian oil and gas companies, the prerequisites and limitations for its large-scale implementation are discussed, and directions for further research and possible fine-tuning of the model for various types of infrastructure projects are outlined. The results of the study are of interest to project managers, engineers, technical specialists, and researchers involved in the planning, implementation, and support of modernization projects in the oil and gas industry.*

Keywords— *Project management, infrastructure modernization, hydrocarbon transportation, oil and gas industry, industrial safety, digitalization, digital twin, risk management, hybrid management models, stakeholder management.*

I. INTRODUCTION

The infrastructure for hydrocarbon transportation – trunk oil and gas pipelines and associated facilities – currently represents a key system-forming component of both global and national energy security. A significant part of this infrastructure was created in previous technological eras and today is close to or beyond the regulatory service life. Accordingly, the industry faces not the task of local capital repairs but the need for comprehensive, deeply technological modernization [7, 10]. An additional complicating factor is the convergence of a number of external challenges: the consistent tightening of environmental requirements and the development of the regulatory agenda of decarbonization [8, 9], the intensification of geopolitical turbulence, as well as the exponential growth of cyberthreats targeting critical energy infrastructure facilities [5, 6].

The traditional linear approach to the management of engineering projects, based on a rigid cascade logic (Waterfall), demonstrates limited adaptability and insufficient risk controllability under conditions of high uncertainty, accelerated technological renewal, and digital transformation [1]. At the same time, modernization projects in the oil and gas sector by definition cannot rely exclusively on agile methodologies (Agile), since industrial safety regimes, process standardization, and regulatory requirements establish strict boundaries for permissible changes and procedures [2]. A managerial gap arises between the need for flexibility and the requirement for rigid regulation, which determines the need for new hybrid models. The relevance of the present study is determined by the attempt to substantiate theoretically and practically the synthesis of classical engineering approaches with modern digital project management tools in order to address this complex task.

The aim of the article is to develop a hybrid adaptive control model for managing engineering projects for the modernization of hydrocarbon transportation infrastructure that ensures a rational balance between safety requirements, economic effectiveness, and a sufficient rate of technological innovation deployment.

To achieve this aim, the following research objectives are formulated:

– To carry out a system analysis of the results of contemporary studies in order to identify key trends, problem areas, and best practices in the management of oil and gas infrastructure modernization projects.

– To identify the main barriers and success factors in the implementation of digital technologies (digital twins, IoT, AI) and the strengthening of industrial safety contours in modernization projects, drawing on the author's practical experience.

– To develop and present the author's hybrid adaptive control model (HACM) integrating risk management, digital transformation, and stakeholder engagement processes.

The scientific novelty of the study lies in the attempt to combine theoretical concepts of project management (hybridization of PMBOK and Agile approaches) with applied aspects of project implementation under Russian conditions (using as an example the author's practical experience in SiburTyumenGas JSC). In contrast to most works that focus predominantly either on the issues of digitalization of the oil and gas sector [4] or on aspects of industrial safety [2], the proposed model considers digital solutions and safety as interrelated elements of a single integrated management system within a modernization project.

The author's hypothesis is as follows: the use of standardized cascade approaches (Waterfall) is the best solution at the stages of design and commissioning, where strict normative and regulatory requirements prevail. At the same time, at the stages of implementation and monitoring, the inclusion of elements of agile methodologies (Agile/Scrum) in the management framework for the digital components of the project (for example, the development and implementation of software for a digital twin [4]) in combination with proactive safety management [2] makes it possible to significantly shorten calendar timelines, reduce resource losses, and increase the overall adaptability of the project to inevitable changes in the external and internal environment.

II. Materials and Methods

In preparing the study, the methodological basis was a systems approach, which made it possible to interpret the management of modernization projects as a complex, multi-level system in which technical, managerial, digital, and regulatory subsystems function in interconnection and are in a state of constant interaction.

The main methodological procedure consisted of comparative analysis and subsequent synthesis of foreign scientific literature. To ensure high relevance of the empirical base, a targeted search for English-language publications issued in the period from 2021 to 2025 was organized, which made it possible to take into account the latest trends and research results in the field under consideration.

The search for relevant information was structured in stages. At the initial stage, a set of key search queries was formed: "hydrocarbon transportation infrastructure" modernization project management, "oil and gas pipeline" upgrade project management, risk management in "pipeline modernization", digitalization in "hydrocarbon transport", asset integrity management "oil and gas" modernization, safety management "oil and gas" engineering projects, digital twin for "pipeline integrity" and cybersecurity in "oil and gas" pipeline.

The information search was carried out using leading scientometric databases and academic search systems: Google Scholar, Scopus, Web of Science, as well as specialized resources IEEE Xplore and ScienceDirect. In addition, materials from key industry conferences and analytical reports of authoritative industry and research organizations were analyzed.

The inclusion criteria for sources were substantive relevance to the subject of the study, year of publication, language, and document type. Sources of a predominantly commercial (advertising) nature, as well as publications with unproven or low scientific significance, were excluded.

III. Results

A systematized review of foreign publications in recent years [1] made it possible not only to inventory existing approaches but also to identify a number of stable trends in the management of projects for the modernization of hydrocarbon transportation infrastructure. The identified patterns are directly related to the practical challenges that the author encountered in the course of professional activities at SiburTyumenGas JSC.

Firstly, a shift is observed from a predominantly reactive operation practice (maintenance upon equipment failure) to the concept of proactive asset integrity management (AIM) [3]. Modern modernization programs are focused not on the episodic replacement of worn-out pipeline sections but on the formation of smart infrastructure capable of anticipating failure. The key instrument in this context is digital twin technologies [4, 8], which make it possible, in a mode as close as possible to real time, to model the condition of assets, forecast the evolution of defects, and build optimized maintenance strategies. This logic is fully consistent with the tasks of minimizing product losses that the author addressed in the course of implementing production projects.

Secondly, the role of digitalization and associated cybersecurity issues is increasing. What until recently was perceived as an auxiliary tool is becoming the core of modernization projects [5]. The integration of SCADA systems with corporate IT platforms, the large-scale deployment of the industrial Internet of Things (IoT) for continuous monitoring, and the use of artificial intelligence methods for processing and interpreting large arrays of data [4] are gradually becoming an industry standard. At the same time, the vulnerability of critical infrastructure to cyberattacks is increasing, as foreign researchers systematically indicate [5, 6]. As a result, the principle of Zero Trust [5] is de facto embedded in the architecture of modernization projects, implying a different level of interaction between operating units and IT services. In the author's professional practice, this aspect was an integral part of supervising digitalization projects.

Thirdly, the approach to industrial safety (HSE — Health, Safety, Environment) is undergoing a noticeable transformation. It ceases to function as an isolated block and is considered a cross-cutting process integrated into all phases of the project life cycle, from conceptual justification to commissioning [2]. Empirical studies demonstrate a statistically significant relationship between the maturity of the safety culture in an enterprise and the success of complex engineering initiatives [2]. In the author's professional activities, issues of industrial and process safety, as well as the development and regular updating of technical documentation (regulations, instructions, etc.), constituted a key part of the functional responsibilities. This confirms the thesis that the management of safety and documentation cannot be fully transferred to contracting organizations and requires continuous competent control on the part of the client.

Fourthly, the project management methodology itself is being transformed. Analytical reviews [1] show the limited applicability of the cascade Waterfall model to highly complex modernization projects. In practice, a hybrid format prevails, within which the basic stages (design, procurement, construction) are strictly regulated, whereas adaptive Agile-oriented approaches are used for the IT component, primarily for software development related to the digital twin and associated services [1].

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Fifthly, stakeholder management acts as a critical success factor. Modernization projects inevitably affect a wide range of participants: production personnel, supervisory and regulatory authorities, design organizations, contractors, and subcontractors [10]. The author's practical experience in coordinating interaction with these groups in the implementation of production tasks shows that the absence of a clearly formalized communication matrix and a unified information contour (created, in particular, through digital platforms) becomes the main source of organizational disruptions, delays, and errors.

Consequently, the results obtained from the analysis of the literature make it possible to conclude that a modern modernization project is not only an engineering task but also a comprehensive socio-technical task in which it is necessary to manage, simultaneously and in a coordinated manner, the technological infrastructure, risks and safety culture, data and digital services, as well as the engagement and interaction of people.

IV. Discussion

The analysis of the literature presented in the Results section made it possible to identify a set of key elements of a successful modernization project: proactive asset management [3], deeply integrated digitalization [4], end-to-end safety management [2], and the use of hybrid approaches to project management [1]. At the same time, most research works focus on each of these components separately, virtually not considering them as a single managerial construct. The author's professional experience shows that the main difficulty lies precisely in the targeted, methodologically sound integration of these elements into a unified management system.

Based on the synthesis of the analyzed sources [1, 3, 5] and the author's practical observations, the concept of a Hybrid Adaptive Control Model (HACM) for projects on the modernization of hydrocarbon transportation infrastructure is formed.

The substantive core of the model consists in constructing a two-level management architecture:

– The macro-level (strategic) is implemented in the logic of a modified cascade Waterfall model, since the key stages of the project (Initiation, Design, Procurement, Construction, Commissioning) are rigidly regulated by industry and regulatory requirements [10]. This ensures predictability, controllability of deadlines, and compliance with the formal criteria of supervisory authorities.

– The micro-level (operational) functions according to the principles of agile methodologies (Agile/Scrum) and is represented by three cross-cutting, continuously operating streams (work streams): Safety, Digitalization, and Stakeholders. These streams run through all stages of the macro-level, ensuring continuous attention to the critical aspects of the project and the possibility of promptly adapting to changing conditions.

Such a configuration makes it possible, on the one hand, to maintain strict control over the physical execution of works (which is fundamentally important for oil and gas facilities) and, on the other hand, to provide the necessary flexibility in managing IT components, digital services, and responding to dynamic requirements in the field of safety and stakeholder expectations.

For illustrative purposes, Figure 1 below presents the general structure of the Hybrid Adaptive Control Model (HACM).

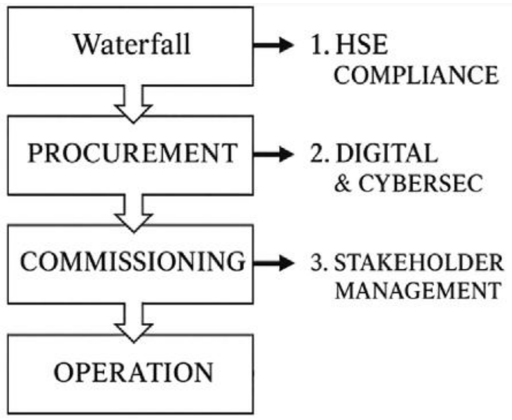

Fig. 1. General structure of the Hybrid Adaptive Control Model (HACM) [1, 3, 5, 10].

The proposed model directly addresses the challenges identified in the Results section and confirmed by the author's practical activities. Thus, the responsibility for the development and updating of technical documentation is organically embedded into the Safety Stream and is implemented in an iterative format at each stage of the macro level, rather than being limited solely to the Design stage. This ensures both the relevance and internal consistency of the documentation and a higher level of risk controllability at all stages of the project.

A comparison of GAMU with the traditional approach is presented in Table I.

TABLE I. Comparison of the Traditional (Waterfall) and Hybrid Adaptive Control Model (HACM) management models [1, 2, 4].

Parameter	Traditional model (Waterfall)	Hybrid Adaptive Control Model (HACM)
Change manageme nt	Reactive, via formalized change requests (Change Request). High resistance.	Proactive. Changes in digital components and in safety processes are managed in a flexible manner (within sprints).
Digitalizati on	Considered as a separate subproject or deliverable. Implemented at the final stage.	Integrated end-to-end process (Digitalization Stream). The digital twin is developed in parallel with the physical project.
Safety (HSE)	Compliance control at the key project gates.	Continuous iterative process (Safety Stream). The safety culture is embedded in all teams.
Interaction	Formalized, hierarchical. Communication between contractors and IT is impeded.	Network-based. A single digital platform for all stakeholders. Direct interaction between technical services and software developers.

Let us consider in more detail the operational streams of the model, drawing on the practical experience of the author.

Digitalization and Cybersecurity Stream. The implementation of digital solutions [4] in the context of hydrocarbon transportation infrastructure in practice is not limited to a one-time installation of software or the deployment of an individual module. Under the conditions of SiburTyumenGas JSC, digitalization projects constituted a continuous process of refinement, configuration, and adaptation to changing production requirements and the regulatory environment. Within the GAMU Digitalization Stream (see Fig. 2), work is carried out in the format of 2–4-week sprints, which ensures a controllable iterative character of changes. A cross-functional team that includes process engineers, process control system specialists, and IT developers (including from contractor organizations) consistently builds and develops the digital twin of the infrastructure [8], integrating into it data from IIoT sensors and conducting testing of predictive analytics algorithms. In parallel, the team responsible for cybersecurity [5] performs verification of each new component and interface for vulnerabilities, thereby ensuring that the expansion of the digital platform's functionality is not accompanied by an increase in cyber risks.

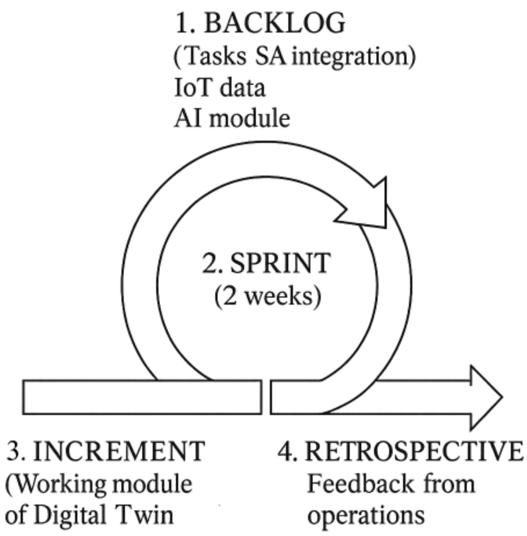

Fig. 2. Diagram of the operational Digitalization Stream [4, 5, 8].

Stakeholder Management Stream. The practical experience of the author shows that the most significant time losses and organizational disruptions arise not within individual functional blocks, but precisely at the interfaces between zones of responsibility: between technical services, occupational safety divisions, contractor organizations, and design institutes. Within the framework of the GAMU, it is proposed to institutionalize this contour by creating a Unified Project Management Center (Project Management Office, PMO), which performs not only coordination and administrative functions, but also acts as an active management link for communications. Such a PMO relies on a unified digital platform, including one based on the software used to manage the digital twin [4], and ensures that all key stakeholders operate within a common information environment, with consistent versions of data, coordinated decisions, and transparent documentation of areas of responsibility.

To verify the effectiveness of the model under development, it is necessary to form a balanced system of key performance indicators (KPI). However, the traditional triad of KPIs — project schedule, project budget, and quality of results [1] — proves to be methodologically incomplete, since it does not provide an adequate reflection of target benchmarks in the areas of safety and digital transformation.

Below, Table II presents the proposed KPIs for modernization projects under the GAMU model.

TABLE II. Proposed KPIs for modernization projects according to the GAMU model [2, 5, 6].

Category	Key Performance Indicator (KPI)	Data source / Measurement method
Efficiency	TCI (Total Cost of Inspection): Total cost of inspections (reduction due to predictive analytics).	Financial accounting / Digital Twin data
Safety	LTIFR (Lost Time Injury Frequency Rate): Frequency rate of injuries with lost work time.	Occupational health and safety and industrial safety logs.
Safety	Number of HSE non-conformities: Number of non-conformities with industrial safety requirements identified by supervisory authorities [10].	Inspection reports, internal audits.
Digitalization	Data Availability Rate: Percentage of time that data from IoT sensors is available in the Digital Twin.	IT system monitoring.
Digitalization	Cyber-Incident Response Time: Average response time to a cybersecurity incident.	Information security department logs.
Sustainability	Reduction in product loss: Reduction in the level of product losses.	Commercial accounting data.

The Hybrid Adaptive Control Model (HACM) developed by the author represents an original conceptual framework that integrates best international management practices [1, 4, 5] with empirically validated approaches developed under Russian conditions. The fundamental distinction between GAMU and traditional methodological solutions lies in the rejection of the Waterfall or Agile dichotomy in favor of their systemic complementarity. The model assumes the construction of a two-level management architecture, within which the rigid regulation of the cascade approach at the macro level (driven by the need for strict compliance with regulatory requirements [10]) is balanced by the high adaptability of three cross-cutting operational streams — Safety, Digitalization, and Stakeholders — at the micro level. Such structuring makes it possible to consider the modernization project as a holistic sociotechnical management object, ensuring the sustainable alignment of innovation-driven development with safety requirements [2] and with resource and managerial efficiency parameters.

V. Conclusion

In the course of the conducted research, the stated objective was achieved: a Hybrid Adaptive Control Model (HACM) was developed for engineering projects aimed at modernizing hydrocarbon transportation infrastructure, oriented toward

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maintaining a sustainable balance between safety requirements, performance indicators, and the pace of digital innovation deployment.

To achieve this objective, the following tasks were accomplished:

– A systematic analysis of contemporary foreign scientific literature was carried out. The results of the analysis made it possible to identify a number of key trends: the shift from reactive to proactive approaches in asset management, the deepening integration of digitalization (including the use of digital twins) and cybersecurity, as well as the growing hybridization of project management methodologies.

– Key barriers were identified on the basis of the author's practical experience at SiburTyumenGas JSC. It was shown that the determining constraints are driven less by technological factors than by managerial ones: the high complexity of coordinating numerous stakeholders (contracting organizations, design institutes, supervisory authorities) and the misalignment between the rapid cycles of IT solution deployment and the slower, strictly regulated cycles in the field of industrial safety.

– The author's Hybrid Adaptive Control Model (HACM) was developed and presented. The model institutionalizes the division of management into the strategic level (Waterfall) and the operational level (Agile). The element of scientific novelty lies in the introduction of three cross-cutting streams (Safety, Digitalization, Stakeholders) permeating all phases of the project. This provides the possibility of iterative management of digital components and safety culture without violating the strict requirements imposed on the physical execution of works and compliance with formalized norms.

The author's hypothesis has been confirmed: cascade management is a necessary condition for regulatory compliance at the stages of facility design and commissioning, whereas the application of agile approaches within the operational streams is critically important for successful digitalization and proactive safety management during the project implementation stage.

The implementation of the proposed model and its associated KPI system will enable oil and gas companies to increase the transparency of modernization processes, minimize the risk of schedule slippage, reduce product losses, and ensure compliance with tightening requirements in the field of industrial and cybersecurity.

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