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RISK MANAGEMENT OF LARGE-SCALE MINING PROJECTS: THEORETICAL FOUNDATIONS AND A BIBLIOMETRIC LITERATURE REVIEW

Abstract

The relevance of this study stems from the growing importance of large-scale mining projects in Kazakhstan's economy and the increasing complexity of their geological, technological, environmental, financial, organisational, and country risks. This requires a systematic synthesis of global and domestic knowledge on risk management.

The paper aims to systematise the theoretical and methodological foundations of risk management in large-scale mining projects and identify gaps in the scientific literature specific to Kazakhstan. The methodology combines a structured literature review with elements of bibliometric analysis. Publications indexed in Scopus, Web of Science, Google Scholar, and CyberLeninka from 1921 to 2026 were examined, with a substantive focus on 1996–2026. Following relevance screening, a corpus of 40 sources was analysed by publication period and thematic cluster and subjected to qualitative narrative synthesis.

The review shows that risk-management theory is well developed, from Knight's distinction between risk and uncertainty to ISO 31000, ISO/IEC 31010, PMBOK, and COSO ERM. Mining-project risks are also represented through an established four-dimensional classification covering geological, technological, economic-managerial, and environmental risks. This study systematises this classification for Kazakhstan rather than presenting it as original.

The bibliometric analysis indicates growth in publications during 2023–2026, which account for 11 of the 40 sources. Recent research focuses primarily on digitalisation, including the Internet of Things, digital twins, predictive analytics, and blockchain. However, Kazakhstan's literature remains fragmented, predominantly general economic in nature, and lacks dedicated empirical studies based on major domestic mining enterprises. To address this gap, the paper proposes a conceptual model and three working hypotheses for subsequent empirical research. The findings provide a theoretical foundation for future studies of risk management in Kazakhstan's large-scale mining projects.

Keywords: risk management, mining industry, large-scale projects, bibliometric analysis, digitalization, country risk

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УПРАВЛЕНИЕ РИСКАМИ КРУПНОМАСШТАБНЫХ ГОРНОДОБЫВАЮЩИХ ПРОЕКТОВ: ТЕОРЕТИЧЕСКИЕ ОСНОВЫ И БИБЛИОМЕТРИЧЕСКИЙ ОБЗОР ЛИТЕРАТУРЫ

Аннотация

Актуальность исследования обусловлена возрастающей ролью крупных горнодобывающих проектов в экономике Казахстана и усложнением связанных с ними геологических, технологических, экологических, финансовых, организационных и страновых рисков. Это требует систематизации международных и отечественных научных знаний в области управления рисками.

Цель исследования заключается в систематизации теоретико-методологических основ управления рисками крупных горнодобывающих проектов и выявлении пробелов в научной литературе применительно к Казахстану. Методология основана на структурированном обзоре литературы с элементами библиометрического анализа. Рассмотрены публикации, представленные в базах Scopus, Web of Science, Google Scholar и CyberLeninka за 1921–2026 годы, с основным акцентом на период 1996–2026 годов. После отбора по релевантности корпус из 40 источников был проанализирован по периодам публикации и тематическим кластерам с последующим качественным нарративным синтезом.

Обзор показал, что теория управления рисками достаточно развита — от разграничения риска и неопределённости Ф. Найтом до стандартов ISO 31000, ISO/IEC 31010, PMBOK и концепции COSO ERM. Риски горнодобывающих проектов представлены устоявшейся четырёхмерной классификацией, включающей геологические, технологические, экономико-управленческие и экологические риски. В исследовании данная классификация систематизирована применительно к Казахстану и не рассматривается как авторская.

Библиометрический анализ выявил рост количества публикаций в 2023–2026 годах: на этот период приходится 11 из 40 источников. Современные исследования сосредоточены преимущественно на цифровизации управления рисками с использованием Интернета вещей, цифровых двойников, прогнозной аналитики и блокчейна. Вместе с тем казахстанская литература остаётся фрагментарной, носит преимущественно общеэкономический характер и практически не содержит специальных эмпирических исследований на базе крупных отечественных горнодобывающих предприятий. Для устранения выявленного пробела предложены концептуальная модель и три рабочие гипотезы дальнейшего эмпирического исследования.

Ключевые слова: управление рисками, горнодобывающая промышленность, крупномасштабные проекты, библиометрический анализ, цифровизация, страновой риск.

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ІРІ ТАУ-КЕН ЖОБАЛАРЫНДАҒЫ ТӘУЕКЕЛДЕРДІ БАСҚАРУ: ТЕОРИЯЛЫҚ НЕГІЗДЕР ЖӘНЕ ӘДЕБИЕТКЕ БИБЛИОМЕТРИЯЛЫҚ ШОЛУ

Аңдатпа

Зерттеудің өзектілігі Қазақстан экономикасындағы ірі тау-кен жобаларының маңызының артуымен және оларға тән геологиялық, технологиялық, экологиялық, қаржылық, ұйымдас-тырушылық және елдік тәуекелдердің күрделенуімен айқындалады. Бұл тәуекелдерді басқару жөніндегі халықаралық және отандық ғылыми білімді жүйелі түрде жинақтауды талап етеді.

Зерттеудің мақсаты – ірі тау-кен жобаларындағы тәуекелдерді басқарудың теориялық-әдіснамалық негіздерін жүйелеу және Қазақстанға қатысты ғылыми әдебиеттегі зерттеу олқылықтарын анықтау. Әдіснама библиометриялық талдау элементтері бар құрылымдалған әдеби шолуға негізделді. Scopus, Web of Science, Google Scholar және CyberLeninka базаларында 1921–2026 жылдары жарияланған еңбектер қарастырылып, негізгі назар 1996–2026 жылдар аралығына аударылды. Релеванттылық бойынша іріктеуден кейін 40 дереккөз жариялану кезеңдері мен тақырыптық кластерлер бойынша талданып, сапалық нарративтік синтез жүргізілді.

Шолу Найттың тәуекел мен белгісіздік арасындағы айырмашылығынан бастап ISO 31000, ISO/IEC 31010, PMBOK және COSO ERM стандарттары мен тұжырымдамаларына дейінгі тәуекелдерді басқару теориясының жеткілікті дамығанын көрсетті. Тау-кен жобаларының тәуекелдері геологиялық, технологиялық, экономикалық-басқарушылық және экологиялық тәуекелдерді қамтитын қалыптасқан төрт өлшемді жіктеу арқылы жүйеленді. Бұл жіктеу зерттеуде авторлық жаңалық ретінде емес, Қазақстан жағдайына бейімделген теориялық негіз ретінде ұсынылады.

Библиометриялық талдау 2023–2026 жылдары жарияланымдар санының өскенін көрсетті: осы кезеңге 40 дереккөздің 11-і тиесілі. Соңғы зерттеулерде заттар интернеті, цифрлық егіздер, болжамдық аналитика және блокчейн негізіндегі тәуекелдерді цифрлық басқаруға басымдық берілген. Қазақстандық әдебиет фрагменттік сипатта қалып, ірі отандық тау-кен кәсіпорындарына негізделген арнайы эмпирикалық зерттеулер жеткіліксіз. Анықталған олқылық негізінде кейінгі эмпирикалық зерттеуге арналған тұжырымдамалық модель мен үш жұмыс гипотезасы ұсынылды.

Түйін сөздер: тәуекелдерді басқару, тау-кен өнеркәсібі, ірі жобалар, библиометриялық талдау, цифрландыру, елдік тәуекел.

Introduction

The development of deposits by open-pit and underground methods, the construction of mining and processing plants and the commissioning of new processing capacities remain among the key drivers of industrial production, export revenues and employment in the economy of Kazakhstan. These projects are characterised by high capital intensity, multi-year investment cycles, irreducible geological uncertainty, and increased sensitivity to swings in global commodity markets. Thus, the management of related risks is not an additional activity, but a system-forming management function.

The spectrum of risks affecting such projects has broadened considerably over the past decade: in addition to traditional geological, technological and environmental risks, cyber risks have emerged, originating from the digitalisation of production processes, as well as country and political risks, which are particularly relevant for projects implemented in jurisdictions with developing institutional environments.

The theory of risk management has been developed over the past century — from F. Knight's classic distinction between risk and uncertainty (Knight, 1921) to the modern international standards ISO 31000 (International Organization for Standardization [ISO], 2018) and ISO/IEC 31010 (International Organization for Standardization [ISO] & International Electrotechnical Commission [IEC], 2019), the PMBOK® body of knowledge (Project Management Institute [PMI], 2017), and the COSO ERM framework — and provides a mature methodological foundation applicable across a wide range of industries. However, the integration of this theoretical apparatus with the industry-specific features of mining projects on one hand, and with the institutional, geological and climatic context of individual emerging market countries on the other, remains the subject of an actively developing, yet still fragmented, academic debate. Special attention has recently been paid to the impact of digital technologies (Internet of Things, digital twins, predictive analytics, big data and blockchain) on mining companies' risk-management models and practices.

The article aims to systematise the theoretical and methodological bases of risk management in large-scale mining projects, and through a structured review of the literature, which contains elements of bibliometric analysis, to identify a gap in the existing body of scientific knowledge as applied to Kazakhstan. The proposed approach supplements the substantive analysis with a descriptive bibliometric profile of the selected publications – their distribution by publication period and thematic area, unlike a traditional narrative literature review limited to a sequential account of individual sources. This allows a more objective trace of the development of research interest and a more precise identification of the present gap. The combination of systematic review and bibliometric analysis is a well-established format in the current international practice. Similar methodological approaches have been applied, in particular, in a bibliometric study of the relationship between sustainable development and risk management based on 1,233 publications in Scopus; in a systematic review and bibliometric analysis of enterprise-wide integrated risk-management research; and in a recent review of barriers to digitalisation in the mining industry carried out under the PRISMA protocol with bibliometric elements and based on 41 publications in Web of Science and Scopus.

To this end, the following objectives were taken into account:

- 1) To present and apply a methodology for structured selection and bibliometric characterisation of relevant publications;
- 2) To organise the conceptual and theoretical basis of risk management and carry out a comparative analysis of the main international standards and frameworks;
- 3) To identify the industry-specific risks of large-scale mining projects and to systematise the classification of such risks established in the international literature as applied to the conditions of Kazakhstan;
- 4) To analyse modern models and digital technologies of risk management in the mining industry;
- 5) To assess the country and political risks of mining projects in developing countries;
- 6) To explain the institutional context of Kazakhstan and point to the empirical gap;
- 7) To develop a conceptual model for further empirical research.

Materials and methods

The research was carried out as a systematic literature review with elements of bibliometric analysis. The format is methodologically somewhere between a traditional narrative review and a formal systematic review following the PRISMA protocol that involves exhaustive data extraction from bibliographic databases using specialised software. Such a format was defined by the specifics of the research task: the article is theoretical and based on review, and does not contain a quantitative

meta-analysis of effects. At the same time, systematising a rapidly growing and thematically diverse body of publications requires elements of descriptive bibliometric statistics in addition to qualitative narrative analysis.

Scopus, Web of Science and Google Scholar were used to search for publications, and CyberLeninka and eLibrary.ru were used additionally for Kazakhstani and Russian-language sources. The search was conducted from 1921, when F. Knight's seminal work was published until 2026, with a substantive focus on publications between 1996 and 2026. The search strategy was a combination of keywords in English and their Russian-language equivalents: ("risk management" OR "enterprise risk management") AND ("mining" OR "mining industry" OR "mining project") AND (ISO 31000 OR PMBOK OR COSO OR digitalisation OR Kazakhstan OR "developing countries" OR "emerging markets"). Russian terms for risk management, mining, digitalisation and Kazakhstan were also searched for. The criteria for including a source in the final corpus were as follows:

a) substantive relevance to risk theory, international risk-management standards, industry-specific risks of mining projects, digital risk-management technologies, or country/political risks of developing economies;

b) the peer review or institutional standing of the source (an international standard, a report of an international organization or an official government website);

c) for domestic sources, the relevance to risk management, industrial safety or digitalisation of the Kazakhstan mining industry.

Publications that were not directly substantively relevant to these areas, and sources that were duplicative of one another in content, were excluded from analysis.

Source selection proceeded in two stages. At the first stage, the titles and abstracts of the publications retrieved from the databases listed above were screened for their thematic relevance to the topic of the study. At the second stage, publications that passed the initial screening were assessed in full text against inclusion criteria (a)–(c) above; at this same stage, sources that duplicated one another in content were identified and removed. Publications that failed to meet the inclusion criteria, or that duplicated sources already included, were excluded from the final corpus.

Therefore, the final corpus consisted of 40 sources: international standards and bodies of knowledge, peer-reviewed articles in international journals, monographs and educational publications, analytical reports of international organisations and consulting firms, official materials from government bodies and industry regulations of the Republic of Kazakhstan. The selected corpus was analysed through descriptive bibliometric analysis in two dimensions:

1) distribution of sources by publication period, which makes it possible to trace changes in research interest over time;

2) distribution of sources into six substantive thematic clusters revealed by qualitative coding of each publication: "international standards and general risk theory", "industry-specific mining risks", "digital risk-management technologies", "country and political risks of developing economies", "Kazakhstan's institutional context", and "review and bibliometric methodology". The boundaries of the thematic clusters were defined deductively, on the basis of the study's objectives (see items 2–6 above), and refined inductively as the content of the sources was reviewed. Each source was assigned to a single cluster corresponding to its main (dominant) substantive contribution; publications addressing several themes at once were assigned to the cluster that most fully reflected their central research problem. Coding of sources was carried out by one of the authors on the basis of a full-text reading of each publication, with a sample of results cross-checked by a second author. Characteristics of the leading sources in the selected corpus were also identified.

Based on the theoretical foundations and the structured literature-search methodology set out above, the following conceptual model for further empirical research is proposed (Figure 3); it will be examined against the results of the bibliometric analysis in the following section. The model rests on the premise that the maturity of a large-scale mining project's risk-management system is shaped

jointly by Kazakhstan's institutional, geological and climatic context and by the degree of digitalisation of risk management, with digitalisation simultaneously giving rise to a new risk category — cybersecurity of the industrial Internet of Things; in turn, the maturity of the risk-management system determines project performance and sustainability, and this relationship is moderated by country and political risk specific to Kazakhstan's institutional context. Within this model, the following working hypotheses are advanced:

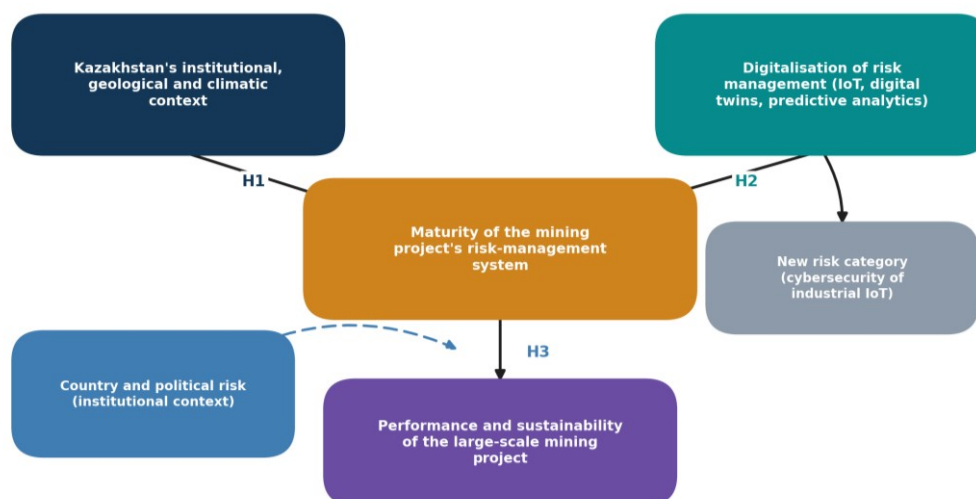


Figure 3 – Conceptual model for further empirical research (compiled by the authors)

H1. Kazakhstan's institutional, geological and climatic context requires substantive adaptation of international risk-management standards (ISO 31000, PMBOK, COSO ERM); consequently, the maturity level of risk-management systems at large domestic mining enterprises differs significantly from the level implicitly assumed by the direct (unadapted) application of these standards.

H2. The adoption of digital risk-management technologies (Internet of Things, digital twins, predictive analytics) is positively associated with the maturity of a mining project's risk-management system, and is simultaneously accompanied by the emergence of a new risk category — cybersecurity of the industrial Internet of Things — that requires separate treatment within the corporate risk register.

H3. Country and political risk specific to Kazakhstan's institutional context significantly moderates the relationship between the maturity of the risk-management system and the performance (sustainability) of a large-scale mining project.

Testing hypotheses H1–H3 is the subject of the subsequent empirical stage of the research and falls outside the scope of the present structured literature review.

Results and discussion

The distribution of selected sources by publication period demonstrates a clear, but not strictly monotonic, increase in the research interest in mining-project risk management over the last fifteen years (Figure 1). The last corpus had six sources published before 2016 and eight published in 2016–2019, while the period 2023–2026 contributed 11 publications, the highest number of all periods. This indicates an increasing academic interest in the setting of the fast-paced digital transformation of the mining industry and the increasing geopolitical uncertainty in commodity markets.

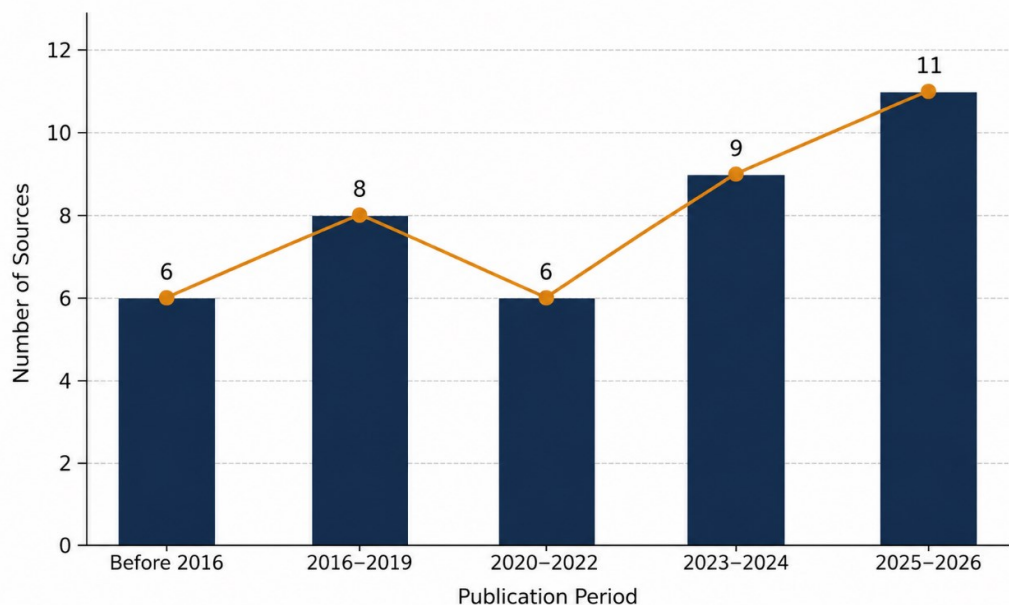


Figure 1 – Distribution of selected sources by publication period

Note: compiled by the authors

Thematic structure of the selected corpus (Figure 2) shows that the two most widely represented clusters are “international standards and general risk theory” (10 sources) and “Kazakhstan’s institutional context” (10 sources). This corresponds to the dual aims of the review, which are to systematise general theory and to identify a country-specific gap. The clusters “digital risk-management technologies” and “country and political risks of developing economies” contain six sources each, which indicates that these are some growing areas of study, but not comprehensively researched yet. The cluster of “industry-specific mining risks” is formed by key works on classification and systematic reviews of risk-assessment methods in the industry and contains five sources.

The methodological cluster combines examples of bibliometric reviews used to justify the design of this study and contains three sources.

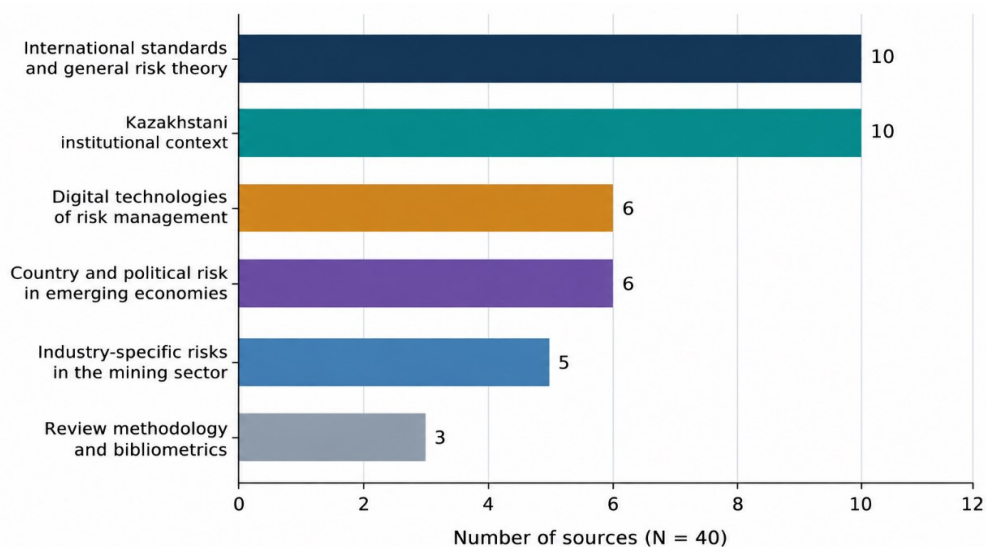


Figure 2 – Thematic structure of the selected publication corpus

Note: compiled by the authors

Analysis of the distribution of sources by publication outlet shows that the selected research articles were most frequently published in MDPI's Applied Sciences and Resources Policy while the ISO series of international standards is represented by two documents: ISO 31000 and ISO/IEC 31010. The other 31 sources each have only one publication and appear in a variety of outlets. Such dispersion of publishing activity across a wide range of journals, reports, and institutional sources, rather than concentration within a narrow set of specialised publications, is typical of a rapidly growing interdisciplinary field.

In the mining industry, the theoretical basis of risk management takes on a number of important industry-specific characteristics, due to the capital intensive and long-term nature of projects – from the geological exploration through to mine closure – irreducible geological uncertainty, the dependence of project economics on volatile global commodity prices, heightened industrial and environmental safety requirements, and significant impacts on local communities and the environment. Among the first comprehensive hierarchical classifications of risks in a new mining project are those which group identified risks into broad categories and indicate that although risk-management tools are widely used, a significant number of major mining projects fail precisely because some risk categories are underestimated or overlooked (Badri et al., 2012). In a later systematic review of risk-assessment methods in mining this classification is further developed by identifying four broad dimensions: human-factor risks, equipment and technical-system risks, general (managerial and economic) risks and environmental risks. It also demonstrates that the industry norms and regulatory documents are mostly structured around the same division (Tubis et al., 2020).

In the last decade, classical risk-management models, which typically involve periodic expert reassessment of the risk register (usually annually or quarterly), have been increasingly supplemented by dynamic, data-driven approaches. This is a bigger paradigm shift from reactive risk management to proactive and predictive management. The Internet of Things enables continuous data collection from sensors installed on geotechnical structures (open-pit walls, tailings facilities), on mining transport equipment, and in underground ventilation systems. This enables the switch from periodic visual inspection to continuous real-time monitoring of slope stability and equipment condition. Among the most promising directions for such monitoring, the literature considers the creation of adaptive IoT platforms to predict the structural and environmental risks of tailings facilities. Digital-twin technologies create a virtual model of a physical asset, which is updated in real time with streaming sensor data. They are used by leading mining companies to simulate abnormal situations and predict failures of equipment and infrastructure without affecting physically the real asset, as confirmed by a systematic review of predictive maintenance, digital twin and intelligent asset management in mining (Rojas et al., 2025).

Blockchain is considered as a means to improve data integrity and traceability in mineral supply chains and thus to mitigate risks of information falsification as well as opaque interactions between participants along the production chain. Artificial intelligence and machine-learning approaches improve the capabilities of risk management with predictive analytics, anomaly detection systems, and automation of risk assessment processes. A systematic review of artificial intelligence algorithms and IoT platforms for predicting anomalies and failures in industrial equipment confirms that these solutions improve the speed and evidential basis of management decisions in high-risk production environments. At the same time, the expansion of digital infrastructure introduces new categories of risk. The growing number of connected industrial devices increases the attack surface of critical infrastructure. Therefore, cybersecurity for the Industrial Internet of Things should be included in the scope of enterprise risk management as an independent risk category, and not to be treated solely as a technical issue for the IT department (Mekala et al., 2023). A separate body of work on country and political risks of investment in extractive industries in developing markets should be paid attention. Analytical materials of international insurance and consulting companies show that political instability in a number of mining jurisdictions continues to create significant uncertainty for mining

companies and their financial partners and stimulates the development of specialised political and credit risk insurance instruments. Research into political-risk management by multinational enterprises involved in infrastructure and resource projects in a variety of developing markets explicitly labels this as a “under-researched” problem and calls for further research into political-risk management mechanisms in international projects. One example is the Global Emerging Markets Risk Database (GEMs Risk Database), which is an empirically based country-specific approach to risk assessment. This consortium of development institutions and multilateral development banks combines data on the realised credit risk of projects in low- and middle-income countries and finds that this risk does not always match traditional sovereign-rating assessments. The findings underscore the need for empirically-based methods of riskassessment rather than methods transferred universally from developed economies (Global Emerging Markets Risk Database [GEMs] Consortium, 2025).

Research on critical mineral and metal supply chains in emerging markets confirms the robustness of the four-part classification of industry risk across levels of analysis from an individual project to a national industry, and extends it to the supply-chain level, confirming the persistence of the issue at the industry level. A study of risk-management practices in mining projects in Kwale County, Kenya (Muthui et al., 2024) confirms the relevance of the identified patterns in an African context. In contrast, a study on the relationship between risk-management practices and sustainability and performance of construction projects in Brazil, India and South Africa shows that the relationship is still under studied in developing economies, where institutional uncertainty and limited infrastructure make the achievement of project sustainability objectives much more complex. This conclusion, though based on the construction industry, is broadly applicable to the mining sector of the emerging-market countries including Kazakhstan, where research in this field is now almost non-existent.

A diagnostic report by the World Bank Group on Kazakhstan's mining sector identifies a twofold problem. On the one hand, the country holds a substantial resource base, with about 8,000 registered deposits of solid minerals and hydrocarbons in the national register; on the other hand, it faces the depletion of easily recoverable reserves amid insufficient investment in geological exploration, while the economy as a whole remains highly dependent on extractive industries with limited diversification. The report, however, provides a macroeconomic and institutional diagnosis of the sector and does not offer a systematic methodology for identifying, assessing and mitigating risks at the level of an individual large-scale mining project.

In Kazakhstan, research on risk management as an independent field is still scarce and is mainly of a general-economic nature rather than industry-specific. R.K. Kazyieva and M.A. Kusainova (Kazyieva & Kusainova, 2016), in their study of risk-management practice in Kazakhstan using the example of franchising relationships, conclude that risk management at Kazakhstani enterprises “has not yet received proper development”, and that existing internal-control systems are often unable to provide a complete picture of the scale of risks or prevent their materialisation (Balabanov, 1996). The educational and methodological publication by G.S. Myakenkaya and A.M. Seitzkazyieva provides a theoretical and practical basis for managing project risks in Kazakhstani higher education, although it does not treat mining projects as a separate object of research (Myakenkaya & Seitzkazyieva, 2015). Another strand of domestic research addresses methods of industrial-risk assessment: S.S. Kudryavtsev and co-authors, in a paper titled “The Development of a Risk Management System in the Field of Industrial Safety in the Republic of Kazakhstan” published in an international peer-reviewed journal, confirm the existence of an established methodological culture of industrial-risk assessment in Kazakhstan (Kudryavtsev et al., 2018), while T.S. Kadyrzhanova examines international trends in occupational safety and health as applied to domestic conditions and emphasises the importance of adapting international experience rather than simply copying foreign solutions (Kadyrzhanova, 2024). This methodological culture, however, remains tied to individual production factors (industrial safety, occupational health) and has not yet been extended to an integrated risk-management system for the mining project as a whole.

Practical introduction of digital technologies of risk management in the Republic of Kazakhstan is still at the pilot stage. The phased digitalisation of separate segments of the production chain, without the need for a simultaneous radical transformation of the entire enterprise, allows for the implementation of projects such as the "smart quarry", "smart factory", "digital mine". Recent publications in scientific journals indicate that the digitalisation of mining companies in Kazakhstan is at an early but rapidly developing stage. A review of the current state and prospects for the digitalisation of mining enterprises notes the uneven distribution of technology adoption by large and medium-sized companies. A study of innovation and digitalisation in the mining industry of Kazakhstan records at the same time productivity growth rates of about 15% at individual enterprises with the introduction of digital solutions, despite the presence of institutional and investment barriers. The need for digitalisation in the industry is related to harsh climatic conditions in the mining areas, increased industrial-safety requirements and the lack of highly qualified personnel, according to the official materials of the relevant government agency (Ministry of Industry and Construction of the Republic of Kazakhstan, 2024). The structured literature review, supplemented with the components of bibliometric analysis, allows us to reveal the following gap in the existing scientific knowledge. Although there is a well-developed general risk management theory (ISO 31000, PMBOK, COSO ERM), and the international research on mining project risk management is growing, there is no comprehensive study in the domestic and international literature that integrates the identification, assessment and mitigation methods of large-scale mining project risks considering the specific institutional, geological, climatic and technological context of the Republic of Kazakhstan and the potential of modern digital technologies.

To plug the identified gap, a shift in focus from descriptive literature analysis to a testable research model is needed, consistent with the conceptual model and working hypotheses (H1–H3) already presented in the Materials and Research Methods section above (Figure 3).

Conclusion

The structured literature review with bibliometric analysis elements allows us to support several conclusions: First, the theoretical framework of risk management is mature. From F. Knight's classic distinction between risk and uncertainty, to the international standards ISO 31000 and ISO/IEC 31010, the body of knowledge on PMBOK and the COSO ERM framework, a stable and internally consistent methodological framework has emerged that is applicable to a wide array of industries and management levels, from an individual project to a corporate board of directors.

Second, the international literature has comprehensively evaluated the industry-specific risks of large-scale mining projects. They are capable of being systematised in a four-part classification of geological, technological, economic-managerial and environmental risks, complemented by quantitative tools for the evaluation of the investment performance under uncertainty and a qualitative matrix of probability and impact in the early stages of a project. It should be emphasised that this classification is systematised and adapted here to the institutional, geological and climatic context of Kazakhstan, and is not presented in this article as an original development of the authors.

Third, the bibliometric analysis of the selected corpus of 40 sources revealed a stable increase in research interest in recent years, with 11 out of the 40 sources published in 2023-2026. This interest focuses on the digital transformation of risk management – the Internet of Things, digital twins, Artificial Intelligence-based predictive analytics, and blockchain. At the same time, these technologies create new types of risk, especially risks of cybersecurity of the Industrial Internet of Things.

Fourth, country and political risks of mining projects in developing economies is a rapidly expanding research area. This research is however, mainly concentrated in Sub-Saharan Africa and Latin America in a geographical sense. The institutional, geological and climatic context of Central Asia and in particular of Kazakhstan is highly fragmented in the literature.

Fifth, the Kazakhstani academic literature on risk management is mainly limited to the general-economic studies and studies on industrial safety and occupational health. There is no systematic study in the literature on the integration of international risk-management methodology, specifics of large-scale mining projects, and potential of digital technologies in the Kazakhstani context.

The scientific novelty of this article does not lie in developing a new classification of mining-project risks: the four-part classification used in the article (geological, technological, economic-managerial, environmental risks) was already established in the international literature. The novelty lies instead in: (1) applying a combination of structured bibliometric analysis and qualitative content analysis to systematise the theoretical and methodological foundations of mining-project risk management; (2) systematising and adapting this classification, together with international risk-management standards (ISO 31000, PMBOK, COSO ERM), to the institutional, geological and climatic context of Kazakhstan; (3) precisely localising the empirical gap in the Kazakhstani academic literature on the topic; and (4) developing the authors' own conceptual model for further empirical research, with three original working hypotheses (H1–H3). The practical significance of the work is that the systematised theoretical frameworks and the proposed conceptual model are a direct methodological basis for further empirical research at a large mining enterprise in Kazakhstan. The research will include a qualitative diagnosis of the maturity of the existing risk-management system and quantitative testing of the hypotheses formulated by means of structural modelling. Future research should extend the bibliometric analysis by using dedicated software tools such as VOSviewer and Bibliometrix to create formalised maps of co-authorship and keyword co-occurrence over a broader range of publications, and empirically test the proposed conceptual model.

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ANALYSIS OF DIGITAL INNOVATIONS AND THEIR FINANCIAL IMPACT ON CHINESE AND KAZAKH AGRICULTURAL ENTERPRISES

Abstract

In the context of the rapid development of digital technologies in the economy, the introduction of innovative solutions in the agricultural sector is of particular importance. Digital innovations have a significant impact on the production efficiency and financial results of agricultural enterprises.

The relevance of the study is due to the need to assess the impact of digital technologies on the financial efficiency of agricultural enterprises, as well as insufficient study of the experience of introducing digital innovations in agriculture in China and Kazakhstan.

The purpose of the study is to analyze digital innovations and their impact on agricultural enterprises in the two countries. The paper uses methods of comparative and economic-statistical analysis based on the analysis of statistical data, scientific publications and analytical materials that reflect the level of development of digital technologies in agriculture and their impact on the performance of enterprises. The study showed that the use of precision farming technologies, digital production management platforms, data analysis systems, to increased yields, lower production costs, and increased profitability of agricultural enterprises.

A comparison of the situation in China and Kazakhstan showed that China has achieved a higher level of digitalization in the agricultural sector due to the development of digital infrastructure and active government support. In Kazakhstan, the processes of digitalization are at the stage of active development.

The practical significance of the research lies in the fact that its results can be used to develop strategies for digitalization of the agricultural sector, improve government policy in the field of agriculture and introduce innovative technologies in agricultural enterprises.

Key words: digital innovations, agriculture, digitalization of agriculture, financial efficiency, agribusiness enterprises, China, Kazakhstan.