Mining Industry Risk Assessment Methods

Subjects: Energy & Fuel Technology
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Recently, there has been a growing interest in the mining industry in issues related to risk assessment and management, which is confirmed by a significant number of publications and reports devoted to these problems. However, theoretical and application studies have indicated that risk in mining should be analyzed not only in the human factor aspect but also in strategic (environmental impact) and operational ones. However, there is a lack of research on systematic literature reviews and surveys of studies that would focus on these identified risk aspects simultaneously. Therefore, the purpose of this article is to develop a literature review in the area of analysis, assessment, and risk management in the mining sector, published in the last decade and based on the concept of a human engineering system. Following this, a systematic search was performed with the use of Primo multi-search tool following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The main inclusion criteria were: (a) not older than 10 years, (b) article written in English, (c) publication type (scientific article, book, book chapter), (d) published in chosen electronic collections (Springer, Taylor and Francis, Elsevier, Science Direct, JSTOR). This resulted in the selection of the 94 most relevant papers in the area. First, a general bibliometric analysis was conducted. Later, the selected papers in this review were categorized into four groups and the critical review was developed. One of the main advantages of this study is that the results are obtained from different scientific sources/databases thanks to using a multi-search tool. Moreover, the authors identified the main research gaps in the area of the implementation of risk management in the mining industry.

This article is focused on a literature review in order to provide a valuable resource for understanding the latest developments in risk management and assessment in the mining sector. The conducted research will be useful for many people, including risk managers, mining engineers, and researchers, who are interested in risk management/engineering issues. The authors believe that the conducted literature review will introduce the readers to the major up-to-date theory and practice in risk management/assessment problems in the mining sector. The presented study gives the possibility to identify the thematic structure related to risk assessment/management for the analyzed industry sector. In addition, it shows which topics from the studied scientific area are the most investigated in a given country/region. At the same time, the conducted analysis gave an opportunity to develop future research directions in the areas identified as research and knowledge gaps.

1. Introduction

Mining has always constituted one of the most dangerous industries. This is confirmed by data published in Eurostat, OECD (Organisation for Economic Co-operation and Development), or by national organizations, such as, in Poland, the State Mining Authority. The reports presented by these organizations indicate the main risk groups and the effects of their occurrence in mining plants. Prepared reports on accidents in mining indicate their causes and circumstances of occurrence. Thanks to this, it is possible to develop standards relating to actions taken to improve health and safety at work in mining, public safety, and environmental protection [1].

Moreover, the importance attributed to the risks associated with mining operations is determined not only by the fact that it is one of the most dangerous sectors of the economy but also by the scale of mining operations. Figure 1 shows total mining productions by continents in tons.
Figure 1. Total mining productions by continents in 2018 in tons (developed on the basis of data available in the World Mining Data database. (World Mining Data provides an indispensable basis for commodity forecasts and activities in minerals policy at national and European level; it contains production of mineral commodities listed in detail by continents, country groups, development status, per capita income, economic blocks, political stability of producing countries, largest producers and others. The data are available online: https://www.world-mining-data.info/ (accessed on 13 July 2020).

Such an intensive mining process, which results in a huge scale of production, generates many risks related to both the operations and resources used, but also to the interaction between the mining system (mines) and the environment. This makes research on risk analysis, assessment and management for this sector particularly important, especially regarding ecological, social and economic aspects. Therefore, the demand for research in this area and new publications, especially for the most productive areas, such as Asia and North America, should continue to grow.

Because mines are a complex human engineering system, they are exposed to multi-faceted risk. Often, the result of this risk occurrence is the loss of life and health of people. It is important to note that these effects may apply not only to employees of mines, but also to the environment—i.e., for example, residents of areas adjacent to the mine. For this reason, the mining sector has been focusing for several years on the need to implement and develop various risk assessment and management concepts. This risk should be analyzed not only in the professional aspect (human factor) but also in strategic (environmental impact) and operational aspects (safety of machines and devices, correctness of the implemented mining process). Research conducted in Polish mining enterprises for several years confirmed that the attention of managers has been focused primarily on the specific risk that comes from within the mining company and is associated with the occurrence of natural and technical hazards, the effects of which are particularly severe for human health and life [2].

The emphasis on implementing the concept of risk management in mine operations is also reflected in the laws, regulations, and standards appearing in subsequent years that relate to risk assessment and management. An analysis of the currently applicable standards in this area has allowed us to distinguish 19 documents dedicated to the mining sector. It is worth noting that these standards can also be classified in accordance with the above-mentioned division of the analyzed risk into general and human-, machine-, and environment-focused standards. The division of the analyzed standards and directives is presented in Figure 2. Part of the presented standards are on a global scale, while others are related to the region of the European Union, but the figure also shows documents that are valid only in Poland. A detailed description of the standards is given in Appendix A, Table A1.
Figure 2. Classification of the main risk-related standards for the mining sector (where: (W)—global scope of application, (E)—standards applicable in Europe, (P)—standards applicable in Poland).

The increasing importance of risk management in mining processes is also indicated by commercial reports prepared for the purpose of managing the mining sector. One such report is the *Mining Risk Review*, which is published by Willis Towers Watson. This report appeared for the first time in 2014, and since 2016 it has been published periodically every year. Each report deals with a different topic related to risk, but they all focus on emerging challenges for the mining sector and the threats therein. The list of topics covered in the years 2016—2019 is presented in Table 1. The second periodical risk report that deserves attention is the *Risk and Opportunities for Mining* that has been appearing for two years, published by KPMG International [3,4]. These reports present the results of research on the state of mining industry—risks and opportunities, key trends, and managers’ expectations for their organizations.

Table 1. The subjects of reports *Mining Risk Review*.

<table>
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<tr>
<th>Year</th>
<th>Title</th>
<th>Goal</th>
<th>Main Topics</th>
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<tbody>
<tr>
<td>2016</td>
<td>Mining Risk Review 2016. Dealing with uncertainty [5]</td>
<td>Highlighting key developments within the industry and focusing on risk management issues</td>
<td>Private equity capital; social license to Operate; advances in 3D printing; maintaining tailings dam; geotechnical, people and environmental risk</td>
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<tr>
<td>2017</td>
<td>Mining Risk Review 2017. The future of mining is now [6]</td>
<td>Determination of four key challenges that mining industry must address in new, innovative ways and focusing on risk mitigation and transfer issues</td>
<td>Geopolitics; stakeholder relations; digitization; people</td>
</tr>
</tbody>
</table>
Determining six key messages that are critical in ensuring that the industry remains on track

Mining risk is no longer an option; greater attention for managing project delivery; avoiding a regulatory headache; geopolitical tensions as a significant threat to the industry; Global insurance market capacity as a threat for thermal coal risks; possible change in insurance market dynamics

Addressing the uncertainties of mining risk and mining risk transfer

Digitization; bottlenecks; geopolitical risk; social economic development

The growing interest within the mining industry in issues related to risk assessment and management is also reflected in conducted scientific research. Therefore, in recent years, there have been more and more publications devoted to these issues. As a consequence, a large number of articles in a given area results in the appearance of review articles aimed at gathering, structuring and classifying knowledge about published scientific results. Analysis of publications from the last decade regarding literature reviews in the area of risk in the mining sector has allowed us to distinguish 20 articles. As well as standards, these articles can be thematically qualified into four groups: general, human factor, machine, and environment. The largest number of review articles concern research on the environmental impact of the mining sector [9–16]. Comparable attention was paid by researchers to conduct reviews on the risks related to the human factor. For this area, six review papers have appeared in the last decade. Analyses of human factor research have focused primarily on issues related to human health and safety (including accidents) [17–20] and work organization and team management [21,22]. There is a visible lack of review articles in the area of risks associated with mining machinery. The analyses carried out allowed us to identify only two reviews of literature devoted to machinery while taking into account the human factor issues [23,24]. The remaining four review articles were classified as general as they did not concern any of the groups distinguished above and were more general in nature [25–28]. Therefore, the aim of the article is to develop a literature review in the area of analysis, assessment and risk management in the mining sector, including (1) biometric analysis of publications from the period 2010–2020 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and (2) thematic analysis of the scope of analyzed publications, aimed at grouping research according to the adopted classification (human-machine-environment). Following this, the main contributions of this paper include:

- a summary of the research developed in the mining sector in the last decade in the area of risk assessment, risk management, risk analysis, and risk decision,
- conducting the qualification procedure in accordance with the adopted distribution criteria based on the concept of functioning of human engineering systems in the mining sector,
- identification of research gaps in the area of implementation of risk management concepts in the mining sector.

In conclusion, the outline of this review paper is as follows: In Section 2, we explain the method used to select and scan relevant journal articles on the topic of risk in the mining industry, which conforms to the PRISMA guidelines. This section also describes the strategy used for literature search process performance and criteria that were applied to assess the relevance of analyzed documents. Section 3 describes the main results of the conducted bibliometric analysis. Section 4 is focused on the presentation of results of thematic analysis aimed at grouping research according to the defined classification. Later, in Section 5, the literature research and knowledge gaps are identified. Finally, Section 6 ends with concluding remarks and recommendations for future studies.

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Keywords
risk assessment; mining industry; hazard event; disruptions

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