Volume XXI, Issue (1) (2025) 129-141

International May Conference on Strategic Management

DOI: 10.5937/IMCSM25129S *Original Research*

SUSTAINABILITY PROBLEM SOLVING IN THE MINING INDUSTRY: RISK ASSESSMENT APPROACH

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Abstract: This paper applies risk assessment methods for determining the risks in the mining industry based on social, environmental and economic aspects of sustainability. The objectives of this work are to examine specific indicators for the mining industry related to a given state of sustainability and to identify the risks and their quantification. The risk identification is the first step in the process of risk assessment. Hierarchical Holographic Modelling (HHM) is the initial phase of mathematical theory for creating new models in terms to indicate and illustrate new types of risks and their further treatment. Hierarchical Holographic Modelling is applied to identify sources of risks for the mining industry by considering sustainability indicators. The method Risk Filtering, Ranking and Management (RFRM) is used in this study as a technique for filtering, ranking and creating new ideas for risk management. The holistic approach in this study enables a systematic and comprehensive review of risk sources and probable emerging risks. The results of this work show determined potential sources of risks and quantified the scenarios of risks as based information for risk management. The use of graphical representation, quantified and qualified data provides the basis for further research.

Keywords: risk assessment, sustainability, hierarchical holographic modeling, decision making.

1. INTRODUCTION

The role of the mining sector in the global economy and the world's gross domestic products (GDP) has grown rapidly over the last decade, and a low growth rate will be insufficient to foster sustained economic development (World Bank, 2025). Many countries consider that the mining industry has become a focal point in the overall economic picture (Jahanmiri et al., 2021).

On the one hand the mining industry has a significant role in the world's GDP, but on the other hand, it poses challenges from a sustainability point of view. The enormous growth in

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the value of mining materials, along with the recognition of risks and the consideration of sustainability principles are reasons for increased research in this sector.

The methods Hierarchical Holographic Modelling (HHM) and Risk Filtering, Ranking and Management (RFRM) are used in this study as analytical and more usable frameworks for risk modelling, assessment and management. These methods were created by Yacov Haimes, Stan Kaplan and James Lambert (2002).

HHM is a holistic philosophy/methodology aimed at capturing and representing the inherent diverse risks of systems and their attributes - multiple aspects, perspectives, and hierarchies (Haimes, 2008). The holographic approach means seeing the system from various aspects and analysing the system from different perspectives. The hierarchical means approach involves analysing the different layers of the system.

This paper presents examples of the risks in the mining sector associated achieving a state of sustainability in social, environmental and economic aspects. The main objectives of this work are to determine specific indicators for the mining sector used in different areas of sustainability, as well as to identify and quantify risks.

2. LITERATURE REVIEW

Risk-based decision making and risk-based approach in decision making are terms frequently used to indicate that some systematic process dealing with uncertainties is being used to formulate policy options and assess their various distributional impacts and ramifications (Haimes, 2008). Rausand (2013) stressed that risk-based decision making is "a process that uses quantification of risks, costs, and benefits to evaluate and compare decision options competing for limited resources".

Kaplan (1997) defined risk as the complete set of triplets risk scenario, likelihood of scenario and resulting consequences. Also, it is possible to assess the set of scenarios which should be complete. "The risk assessment process is a set of logical, systemic, and well-defined activities that provide the decision maker with a sound identification, measurement, quantification, and evaluation of the risk associated with certain natural phenomena or man-made activities" (Haimes, 2008). The same author defined Total Risk Management (TRM) as a systematic, statistically based, holistic process that uses quantitative risk assessment and management. The positive outcomes in the theory of the risk management process are considered, but in practice mitigating losses is more in focus (Evans et al., 2007).

Sustainability indicators show the impact and importance of economic, environmental, and social performance in the decision-making process. The assessments and decisions of stakeholders are influenced by organizations' economic, environmental, and social aspects (Global Reporting Initiative, 2015). "The purpose of sustainability indicators for industry is to help measure a company's economic, environmental and social performance and to provide information on how it contributes to sustainable development" (Azapagic, 2004; Azapagic & Perdan, 2000).

"The social dimension of sustainability concerns the impacts the organization has on the social systems within which it operates" (Global Reporting Initiative, 2015). Environmental indicators are important, because they reflect the impact of care on the living and not - living world, including land, air, water and ecosystems. The economic dimension of sustainability is concerned with the impact of economic conditions on the participants in the system. The economic aspect is important because it follows the flow of capital between the different stakeholders, as well as the impacts on society as a whole and on the natural environment.

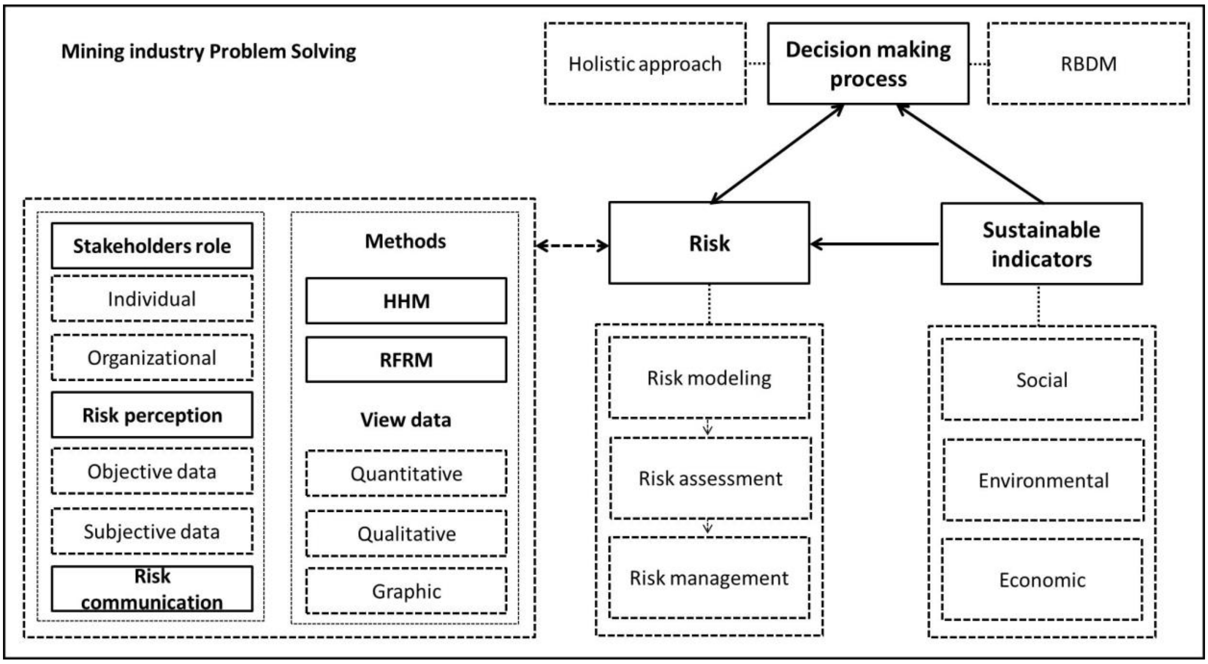


Figure 1. Holistic approach Risk-based decision making (RBDM) in the mining industry based on sustainable indicators (RBDM – Risk Based Decision Making, HHM – Hierarchical Holographic Modelling, RFRM – Risk Filtering, Ranking and Management)

The holistic approach (Figure 1) in this study examines overall sources where risks may appear and develops risk scenarios. The systems approach may be defined as a logical and disciplined process of problem solving (Kerzner, 2013). According to Haimes (1992), one of the operational principles of a holistic approach to sustainable development is the consideration of multiple decision makers and constituencies. The most difficult part related to this principle is comprehensiveness and practicability / operationality (Haimes, 1992). Evans, Brereton and Joy (2007) studied about the connection between risk management and sustainability in the mining sector. The authors pointed out that risk assessment represents a potentially useful methodology to involve operations with the wider range of issues involved.

Hierarchical Holographic Modelling (HHM) is applied in this research to identify and view sources of risks. Some of the authors used HHM as an approach in risk identification to show which companies "need to adopt various risk management principles to visualize a full picture of the organizational risk level" (Ting et al., 2009). HHM and RBDM are considered by the authors to be desirable methodologies for making predictions on maritime traffic risks (Zhang et al., 2022). Giannakis and Papadopulos (2016) revealed in their research that risk treatment strategies are proposed for sustainability-related risks. The authors Pan, Ihlenfeld and Voulvoulis (2010) used the HHM method for identifying chemical risks from mining operations. They stressed that a risk-based methodology for identification, filtering and ranking risks can be used as initial information for risk management. "It also provides a practical decision making tool for mine acquisition and helps to communicate risk to all members of mining operation teams" (Pan et al., 2010).

The final result of using Risk Filtering, Ranking and Management (RFRM) is the creation of new ideas for risk management based on qualitative, quantitative and graphic views and data.

3. DATA AND METHODOLOGY

In this paper are combined methods of risk assessment and sustainability indicators as key factors for identifying sources of risk. The explanation of these methods follows.

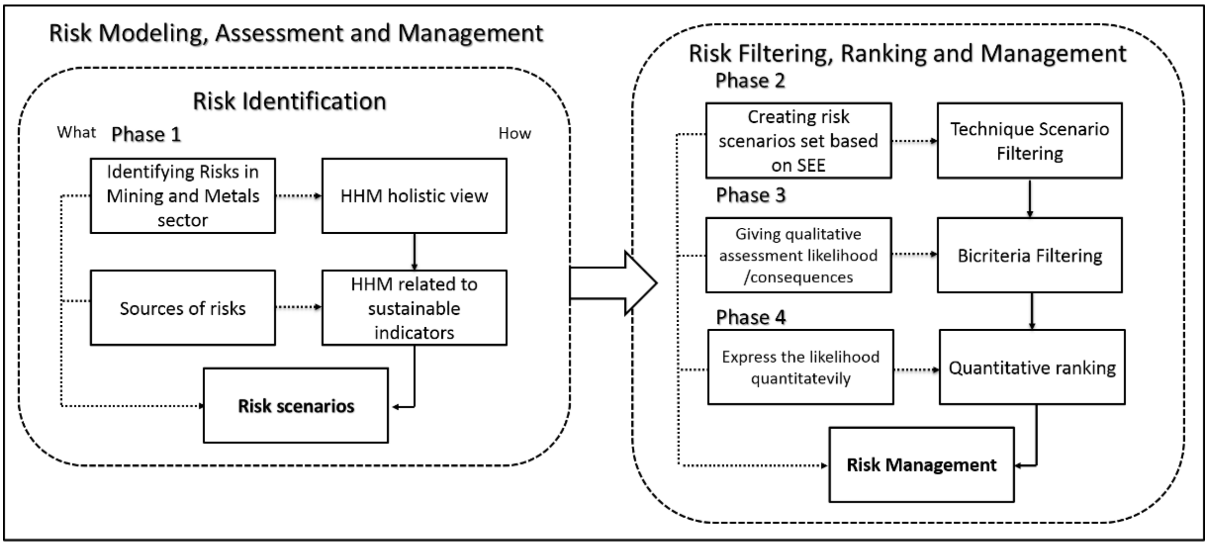


Figure 2. The phases of risk identification and quantification according to Haimes approach (Haimes, 2008)

Phase 1. Risk identification. Risk identification is the first step in the process of risk assessment. In the Figure 2 a framework for Risk Modeling, Assessment and Management used in this research according to the Haimes approach (Haimes, 2008) is shown. The first phase is Risk identification which includes two HHM figures (Figure 3 and Figure 4). The first HHM figure presents a holistic view of potential places of risk and the second one presents a selected certain number of areas where possible emerging risks exist. The HHM Diagram presents the main topics / categories and subtopics / subcategories as each represents an area of potential risk scenarios. Results from this phase determine potential places for risk scenarios.

Phase 2. Scenario filtering. The next step involves creating a set of risk scenarios from the HHM model, based on the given state of sustainability. This phase is the first phase of Risk Filtering, Ranking and Management (RFRM) as a technique for filtering, ranking and generating new ideas for risk management. The RFRM technique combines qualitative and quantitative data for ranking risk scenarios. In this phase it is necessary to create a set of scenarios based on research questions and objectives and filter the subtopics using the scenario filtering technique. Identification of scenarios is based on expert thinking, managers from different levels or investor interest.

Table 1. Qualitative Measures of Likelihood

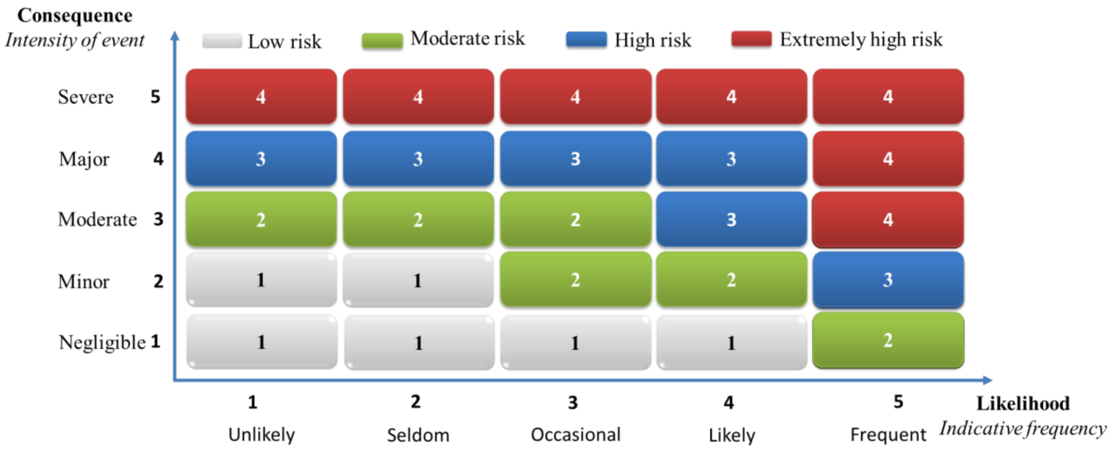
Level	Description	Frequency
5	Frequent	Expected risk scenario
4	Likely	Risk scenario more likely than not emerge
3	Occasional	Risk scenario may or may not emerge
2	Seldom	Risk scenario less likely than not to emerge
1	Unlikely	Risk scenario not expected to emerge

Phase 3. Bicriteria filtering. In phase three, it is necessary to give qualitative assessment of the likelihood and consequences of filtered subtopics using bicriteria filtering. Each scenario is evaluated in relation to the criteria of severity of impact and frequency of likelihood. Reducing the number of risk scenarios is done based on the preferences of decision makers. The levels for qualitative measures of likelihood are shown in Table 1. The levels of qualitative measures of consequence are shown in Table 2. In the same tables, quantitative levels of frequency and intensity of risks are also presented. This data is the basis for the next phase and for creating the risk matrix.

Table 2. Qualitative Measures of Impact

The level of intensity	Score	Description
Severe	5	Unacceptable risk, 100 % loss of jobs, resources of materials is at the non-appropriate level, profit loss.
Major	4	Unacceptable risk. Major loss of jobs, major lack of resources of materials, major profit loss.
Moderate	3	Moderate loss of jobs. Moderate lack of resources. Moderate profit loss.
Minor	2	Tolerable risk / Minor loss of jobs. Minor lack of resources. Minor profit loss.
Negligible	1	Risk acceptable under review. / No loss of jobs. No treatment for lack of resources. No profit loss.

Phase 4. Quantitative ranking. The quantitative ranking is used here as a technique for giving qualitative characteristics and expressing the likelihood of risk scenarios quantitatively. The categories for qualitative measures of likelihood are: Frequent, Likely, Occasional, Seldom and Unlikely, with quantitative values of 5, 4, 3, 2, and 1, respectively. The categories for qualitative measures of impact are: Severe, Major, Moderate, Minor and Negligible, with quantitative values of 5, 4, 3, 2, and 1, respectively. Explanation of colors and numbers: 1, Grey - Low risk, 2, Green - Moderate risk, 3, Blue - High risk, 4, Red - Extremely high risk (Graphic 1).



Graphic 1. Risk Matrix - Likelihood vs. Consequence

Using the HHM method it is possible to decompose the system, build clear a understandable view, and depict connections between categories and potential sources of risks. In the research of complex systems such as industry, this method enables systematic and comprehensive review of sources of risks and emerging appearing risks.

The RFRM method provides decision makers with filtering, ranking and quantification of risk scenarios. The combination of qualitative and quantitative aspects is important as a way of taking holistic approach. The crucial significance lies in preferences of decision-makers. Decision-makers provide a subjective assessment in the process of creating and selecting risk scenarios using available techniques and analyses. All steps of the RFRM as a result, provide important suggestions and basis for calculations in risk management.

The importance of indicators has several aspects. Indicators are a tool for the implementation and further development of the decision matrix. It is very important that there are available data measured indicators. The use of sustainability indicators provides the opportunity to use quantified data in the next phase and further research.

Before starting the risk identification process it is necessary to determine who the participants or stakeholders are and their role in the decision-making process. The importance of each stakeholder has significant implications for the further flow of the risk analyses. The condition for including indicators in the analysis is that they are closely related to some of the participants in the decision-making process in the mining industry. By recognizing the indicators it is possible to measure the behaviour of the system, and also based on the measured indicators and the determined rules between them, it is possible to determine measures for the future state of system. In this case, recognized risks are given the highest probabilities of risk scenarios.

These methods are suitable for risk analyses and view the situations from different and multidisciplinary aspects. The use of a combined graphic view and quantified and qualified data emphasizes the importance of a holistic approach which is applied in this research. Finally, the results from risk modeling and assessment are important information for risk management decision makers.

4. RESULTS AND DISCUSSION

Applicability of the described Risk Assessment methods is presented through the following example in mining. The source of primary data was literature (Global Reporting

Initiative, 2015; United Nations, 2007; Popovic et al., 2014; Azapagic, 2004). and on finally stage expert opinion samples. There were several iterations explained below.

Phase 1. Risk identification. Figure 3 shows a Hierarchical Holographic Modeling example framework for risk identification which is decomposed from multiple perspectives, by considering sustainability indicators determined in the papers (Global Reporting Initiative, 2015; United Nations, 2007; Popovic et al., 2014; Azapagic, 2004).

Firstly, there were 9 categories and a total of 42 subtopics, extended to 74. The defined categories are Social, Operational / Functional, Phases, Environmental, Geographical / Location, Institutional / Organizational, Economic, Infrastructure and Temporal. Related to the given type of sustainability specific indicators within the social category include employment, health and safety, education, equally, employee welfare, innovation and competitiveness, human rights, community funding and support, corruption and fair business and operations (Popovic et al., 2014). The defined specific indicators within environmental indicators are pollution, use of natural resources, climate change, nuisance, eco-tourism and biodiversity (Global Reporting Initiative, 2015; United Nations, 2007). Within the economic part of sustainability, specific indicators include economic performance, trade, material consumption and energy use (Global Reporting Initiative, 2015; Azapagic, 2004). Based on the aim of the research associated with the three types of sustainable development, the focus of the next phase of research is 8 subtopics, determined as potential areas of sources of risk (Figure 4). Figures 5, 6 and 7 show the social, environmental and economic main categories and their subcategories, respectively.

Description of subcategories:

- Employment - Employment benefits and characteristics include staff turnover, dismissal of employees, working hours, full-time and part-time employees and years of service (Popovic et al., 2014),
- Education – includes training, education and personal skills as well as training and educational level (Popovic et al., 2014),
- Innovation and competitiveness – Innovations, new products, and scientific publications (Popovic et al., 2014),
- Pollution – Solid waste (Global Reporting Initiative, 2015; United Nations, 2007),
- Use of natural resources - Primary resources extracted and reserved of resources (Azapagic, 2004),
- Economic performance – Investment, per capita GDP and value added (Global Reporting Initiative, 2015; Azapagic, 2004),

Phase 2. Scenario filtering. Techniques for creating scenarios are applied in this phase. From Phase 1, the following potential fields of risk are filtered:

- Employment - loss of jobs, number of dismissals of employees,
- Education - lack of qualified people,
- Innovation - lack of new technological processes,
- Solid waste - low level of recycling materials,
- Primary resources extracted - high level of extracted raw materials,
- Reserves of resources - lack of raw materials,
- Investment - lack of investment,
- Value added - risk of low profit,
- Price volatility - risk of price changes.

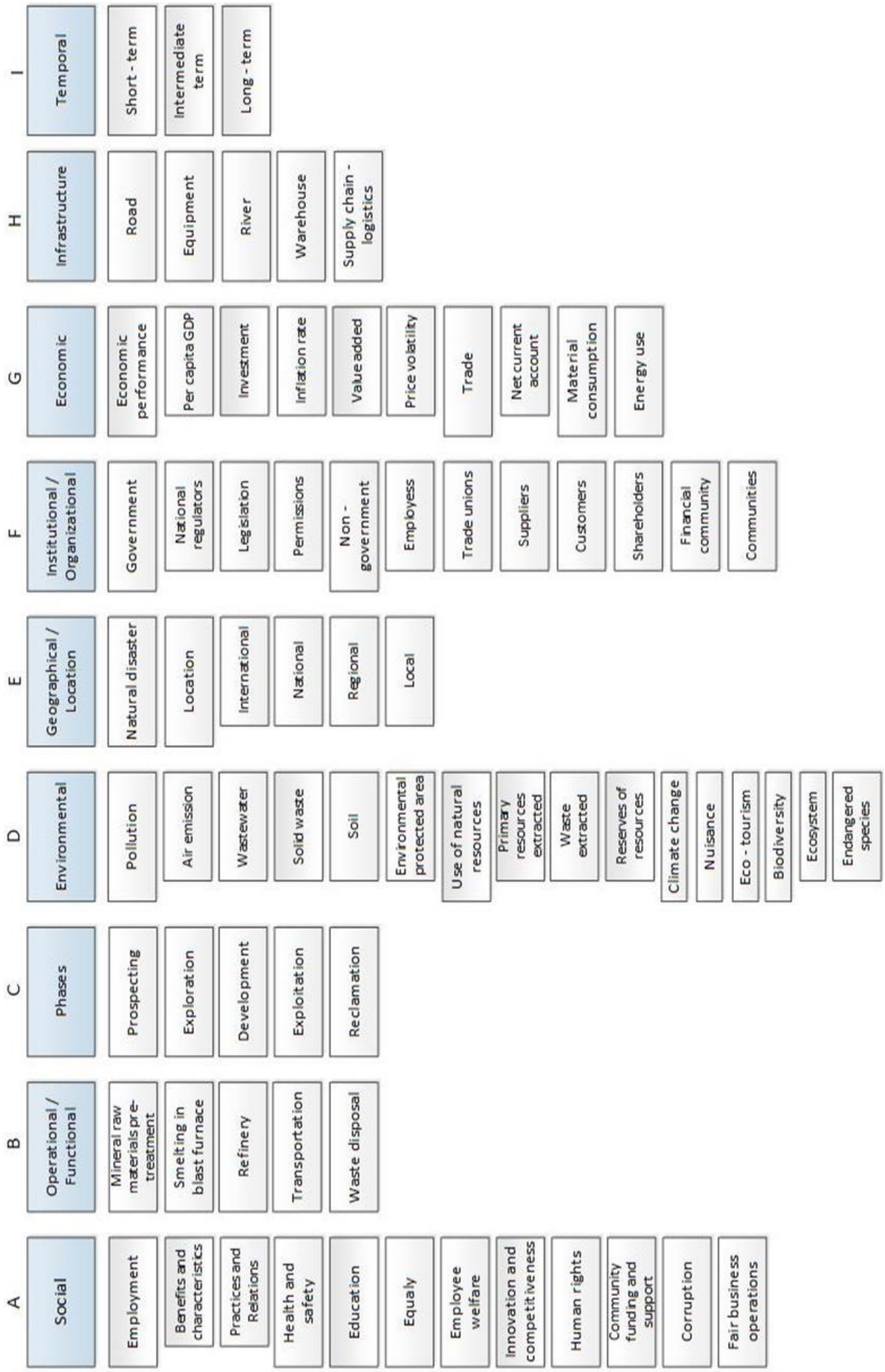


Figure 3. HHM example framework for risk identification based on sustainability indicators: social (Popovic et al., 2014), environmental and economic (Global Reporting Initiative, 2015; United Nations, 2007; Azapagic, 2004).

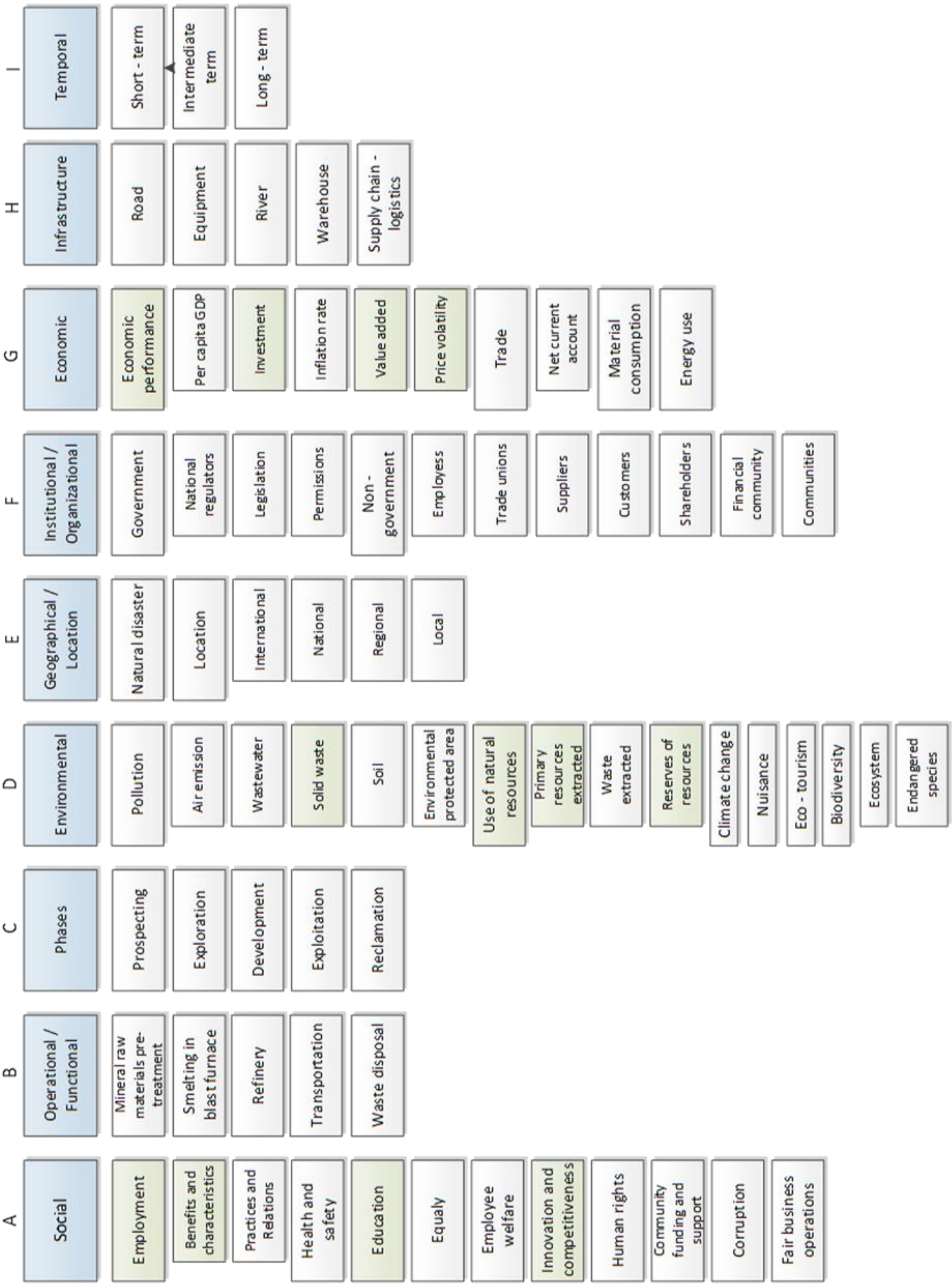


Figure 4. HHM - determined 8 potential areas of sources of risks based on sustainability indicators: social (Popovic et al., 2014), environmental and economic(Global Reporting Initiative, 2015; United Nations, 2007; Azapagic, 2004).

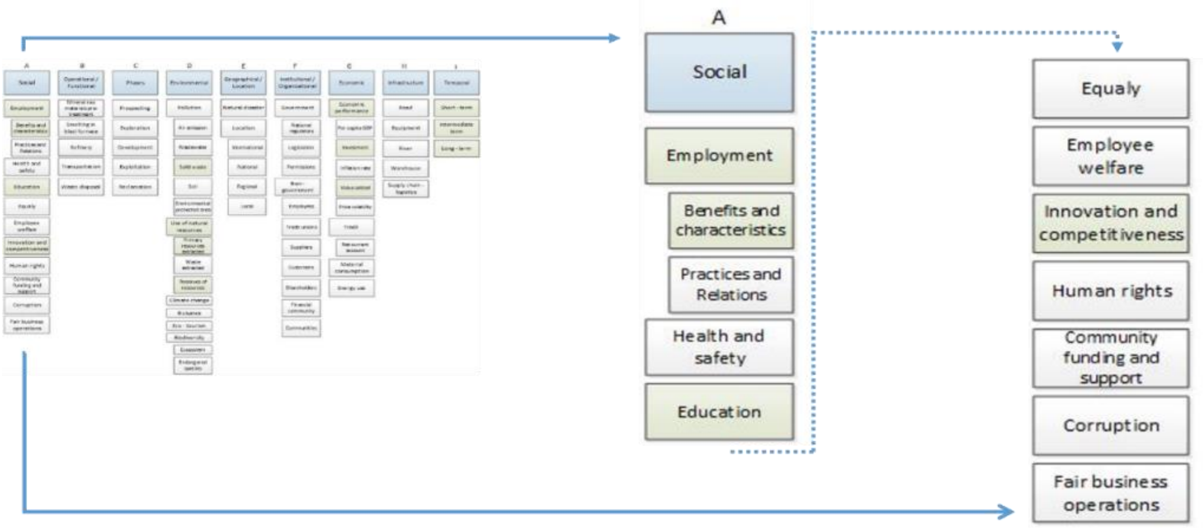


Figure 5. HHM example framework for risk identification in the social category

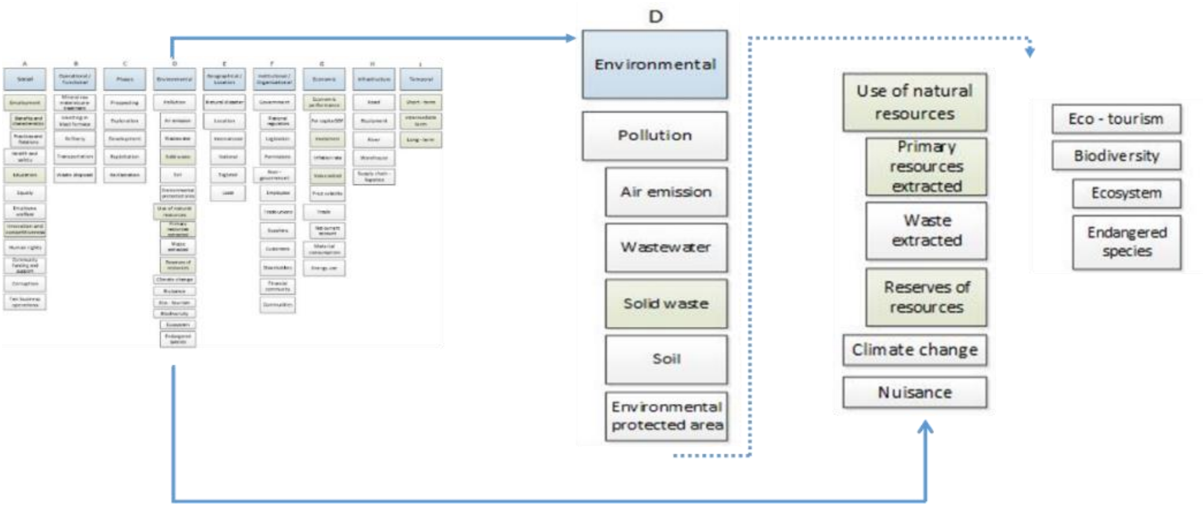


Figure 6. HHM example framework for risk identification in the environmental category

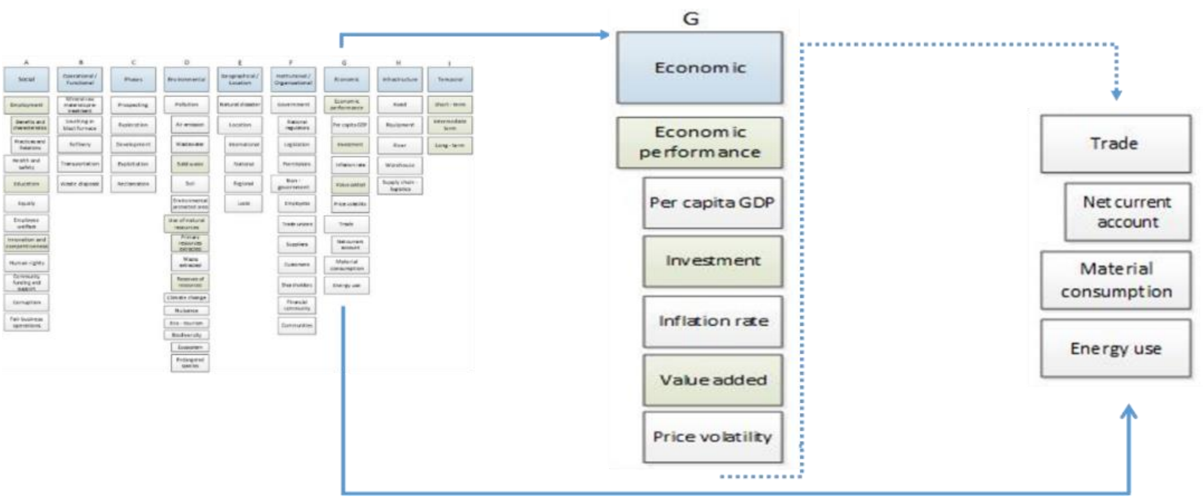


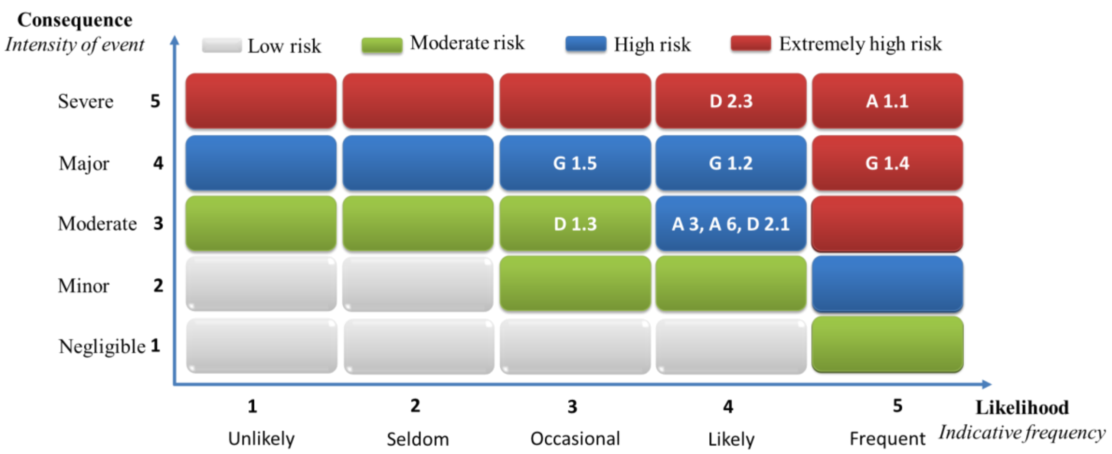
Figure 7. HHM example framework for risk identification in the economic category

Phase 3. Bicriteria filtering. In this phase, Bicriteria filtering is used as the second step in Risk Filtering, Ranking, and Management (RFRM) explained in the methodology approach. Preferences of decision makers and an intuitive approach are the basis for reducing the number of scenarios. Finally, Table 4 shows risk scenarios of probable risks using qualitative measures of likelihood. The labels A1.1, A3, A6, D1.3, D2.1, D2.3, G1.2, G1.4, G1.5 are derived from HHM diagrams (Figures 5, 6, 7).

Table 4. Risk Scenarios of Probable Risks

Topic	Subtopic	Risk scenario	Likelihood	Consequence
A 1.1 Social	Employment	loss of jobs	5	5
A 3 Social	Education	lack of qualified people	4	3
A 6 Social	Innovation	lack of new technological processes	4	3
D 1.3 Environmental	Solid waste	low level of recycling materials	3	3
D 2.1 Environmental	Primary resources extracted	high level of extracted raw materials	4	3
D 2.3 Environmental	Reserves of resources	lack of raw materials	4	5
G 1.2 Economic	Investment	lack of investment	4	4
G 1.4 Economic	Value added	risk of low profit	5	4
G 1.5 Economic	Price volatility	risk of price changes	3	4

Phase 4. Quantitative ranking. In this phase, a given quantitative value is assigned to the likelihood of risk scenarios. In Graphic 2, examples of measures of likelihood are shown. The most probable risk scenarios based on the given state of sustainability are loss of jobs, lack of raw materials and the risk of low profit.



Graphic 2. Risk Matrix Example - Likelihood vs Consequence

5. CONCLUSION

Using the HHM model for risk identification in the mining industry considering sustainability indicators in Figure 2, 9 categories and a total of 42 subtopics, extended to 74, are shown. In the next stage of this phase, 8 subtopics are determined as potential sources of risks. The following phases of risk filtering, ranking and management show identified risk scenarios in the social aspect of sustainability employment, education and innovation. The identified risks here are loss of jobs, the number of dismissals of employees, lack of qualified people and lack of new technological processes. In the environmental aspect of sustainability the main topics identified include solid waste, primary resources extracted and reserves of resources. The following risk scenarios are identified: low levels of recycling materials, high levels of extracted raw materials and lack of raw materials. Finally, the economic aspect of sustainability includes topics such as investment, value added and price volatility. Risk scenarios identified include lack of investment, risk of low profit and risk of price changes.

In this example a combination of graphic, quantitative and qualitative analyses is presented. The analyses show the most probable risks lack of raw materials, loss of jobs and risk of low profit.

Involving sustainability indicators in order to determine the potential sources of risks in the mining industry is an emerging approach in research related to this field. The huge importance of natural resources and their enormous impact on the world's GDP provide motivation to examine the state of this area in this way. This paper presents an example of the risks in the mining industry based on the given three types of sustainability.

The findings of this research provide valuable insights for the next phase of risk management and serve as a basis for developing a decision matrix as a crucial tool for decision makers. Utilizing and examining the methodology in this research is just the first step in the decision making process related to risk management, which is the most important process in discovering and managing new situations that could arise. Additionally, in the second phase, the research focuses on several sources of risk, not all of them. In further research it is possible to develop a combined method of risk management and provide solutions to the questions of what is an acceptable level of risk and how to achieve balance among the three types of sustainability related to the condition of minimum risks in all aspects.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to Professor Dr. Andrzej Kraslawski from Lappeenranta University of Technology in Finland.

REFERENCES

Azapagic, A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. Journal of cleaner production, 12(6), 639-662. doi: 10.1016/S0959-6526(03)00075-1.

Azapagic, A. & Perdan, S. (2000) 'Indicators of Sustainable Development : Guidelines and Methodologies', Process Safety and Environmental Protection, 78(4), pp. 243–261. doi: 10.1205/095758200530763.

Evans, R., Brereton, D., & Joy, J. (2007). Risk assessment as a tool to explore sustainable development issues: lessons from the Australian coal industry. International Journal of Risk Assessment and Management, 7(5), 607-619.

Giannakis, M., & Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. International journal of production economics, 171, 455-470.

Global Reporting Initiative (2015) G4 Sustainability Reporting Guidelines, Global Reporting Initiative. Available at: https://www.globalreporting.org/standards/g4/Pages/default.aspx.

Haimes, Y. (1992) 'Sustainable development: a holistic approach to natural resource management', IEEE Transactions on Systems, Man, and Cybernetics, 22(3), pp. 413–417. doi: 10.1109/21.155942.

Haimes, Y. Y. (2008) 'Risk Modeling, Assessment, and Management', Risk Modeling, Assessment, and Management, Third Edition, pp. 1–1012. doi: 10.1002/9780470422489.

Haimes, Y. Y., Kaplan, S., & Lambert, J. H. (2002). Risk filtering, ranking, and management framework using hierarchical holographic modeling. Risk Analysis, 22(2), 383-397.

Jahanmiri, S., Asadizadeh, M., Alipour, A., Nowak, S., & Sherizadeh, T. (2021). Predicting the contribution of mining sector to the gross domestic product (GDP) index utilizing heuristic approaches. Applied Artificial Intelligence, 35(15), 1990-2012.

Kaplan, S. (1997). The words of risk analysis. Risk analysis, 17(4), 407-417.

Kerzner, H. H. R. (2013) Project management: a systems approach to planning, scheduling, and controlling, New York. doi: 10.1016/0377-2217(82)90164-3.

Pan, J., Oates, C. J., Ihlenfeld, C., Plant, J. A., & Voulvoulis, N. (2010). Screening and prioritisation of chemical risks from metal mining operations, identifying exposure media of concern. Environmental monitoring and assessment, 163, 555-571. doi: 10.1007/s10661-009-0858-0.

Popovic, T., Kraslawski, A., Heiduschke, R., & Repke, J. U. (2014). Indicators of social sustainability for wastewater treatment processes. In Computer Aided Chemical Engineering (Vol. 34, pp. 723-728). Elsevier. doi: 10.1016/B978-0-444-63433-7.50105-X.

Rausand, M. (2013). Risk assessment: theory, methods, and applications (Vol. 115). John Wiley & Sons.

Ting, J. S. L., Kwok, S. K. & Tsang, A. H. C. (2009) 'Hybrid Risk Management Methodology: A Case Study', International Journal of Engineering Business Management, 1, p. 3. doi: 10.5772/6783.

United Nations (2007). Indicators of Sustainable Development : Guidelines and Methodologies, New York, (October), pp. 1–90. doi: 10.1016/j.cirpj.2010.03.002.

World Bank. (2025). Global Economic Prospects, January 2025. © World Bank. http://hdl.handle.net/10986/42452 License: CC BY 3.0 IGO.

Zhang, W., Zhang, Y., & Qiao, W. (2022). Risk scenario evaluation for intelligent ships by mapping hierarchical holographic modelling into risk filtering, ranking and management. Sustainability, 14(4), 2103.