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Coal Handling Operational Risk Management: Stripped Overburden Transport in Brown Coal Open Pit Mines

Michal VANĚK[1], Gregorio Fidalgo VALVERDE[2], Igor ČERNÝ[3]*
and Vlastimil HUDEČEK[4]

Authors' affiliations and addresses:
[1] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: michal.vanek@vsb.cz

[2] University of Oviedo, School of Mining, Energy and Materials Engineering of Oviedo, Business Management, St. Independencia, 13, 330 04 Oviedo, Spain
e-mail: gfidaldo@uniovi.es

[3] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: igor.cerny@vsb.cz

[4] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Mining Engineering and Safety, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: vlastimil.hudecek@vsb.cz

***Correspondence:**
Michal Vaněk, VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
tel: +420596993336
e-mail: michal.vanek@vsb.cz

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Abstract

This paper deals with the management of coal handling operational risks related to the transport of stripped overburden in giant brown coal pit quarries. It aims to identify and analyze the operational risks of currently applied continuous conveyance and to consider alternative transport, i.e., discontinuous transport. The Ishikawa diagram was used to identify the degree of operational risks affecting the net present value in both transport technologies. The operational risks examined were: human factor, suppliers, legislation, technology, environment, and market. Failure Mode and Effects Analysis was then used to evaluate the operational risks of continuous and discontinuous overburden transport technologies. The data for the analyses were obtained by means of a survey among experts in the field. The analyses show that the most significant operational risks of continuous transport are: lower demand for coal, an increase in the investment costs, conveyance breakdowns, the quality of the transported material, and work attitude. In the discontinuous technology, the identified operational risks were: increases in the cost of fuels, road maintenance and costs of tires, low-qualified labor; and work attitude. The comparison of the two examined technologies shows that discontinuous transport technology involves more operational risks than the continuous one.

Keywords

Coal handling, operational risk, brown coal, Ishikawa diagram, FMEA, stripped overburden transport.

Introduction

Enterprises are exposed to many simultaneously emerging operational risks associated with individual decisions and actions. Despite a number of particularities, mining and processing of mineral resources is a standard business activity. This means that a mining company management aims for profit, increases in the company's market value, and other goals they should outline. According to Shenkir and Walker (2006), in the 21st century, the technology advancements, such as the internet and global competition, brought a number of operational risks to different companies. These include the use of complex financial instruments, deregulations, downsizing, and consumer demands (Shenkir and Walker, 2006).

To reach their goals, managers need to decide on specific steps and measures of both strategic and operational character. Taking the right decision requires experience and relevant information (Kozel, 2017). In the case of investment decisions, managers may not have the courage to make tough decisions. When making decisions and choosing from possible options or alternatives, managers should rely on the results of various analyses. When decisions need to be supported by investment, studies providing information to answer questions on the effectiveness and return on investment are vital.

Despite being standard businesses, companies in the mining industry face many forms of operational risks, such as government policies, environmental incidents, survival circumstances and market threats (Van Thueyet et al., 2007). Similarly to making decisions on the basis of analyses, operational risks should be managed effectively through their analyses, thus affecting the company value.

Although the operational risk is already included in the economic evaluation of an investment, its analysis may foreshadow significant sources of risk and their possible impacts on the investment in question. No doubt, it is valuable for a manager to be aware of the interval in which the values of the selected economic criterion, for example, net present value (NPV), may range. The awareness of operational risks helps responsible managers to focus on measures in order to reduce or eliminate them.

Surface mining systems comprise a number of stripping, mining, back-filling, and auxiliary works and operations, which are implemented in the most diverse geological and deposition conditions. They also use different technologies and equipment. Mining exploitation includes four basic stages, namely, excavation, loading, transportation, and processing (Singh, 2004; Rahimdel and Bagherpour, 2016). This article does not deal with all the stages, focusing only on the transport of the stripped overburden.

The major function of the so-called technological transport is to move the stripped overburden into dumps, heaps or into settling basins, and to transport the useful materials to further processing or directly to the client (Slivka et al., 2002). It comprises the transport equipment and supplementary and auxiliary mechanization, including the means of control. Something characteristic of these transport systems are the conditions under which the transport routes constantly change, alternating loading and unloading points when dealing with steep slopes, various discharge ends and long distances (Singh, 2004), (Mikoláš et al., 2011). A good choice of suitable load transport undoubtedly belongs to the areas that contribute to the general economic success of a mining company.

Although long-distance belt transport is solely used in the Czech giant brown coal pit quarries to transport the stripped overburden, it may be interesting for mine owners that discontinuous transport brings a comparative advantage as opposed to the continuous conveyance. For example, Seidl et al. (2011) state that in contrast to continuous conveyance the use of rubber-tired haulage ensures stability in time and bigger capacity of exploitation, it is mobile in prioritizing the different mining horizons, there is no need to build costly and difficult working floors, and it is more economical as a complementary technology after mining. Despite the threats, such as the costs of services, repairs, fuel, and capital expenditure, rubber-tired haulage appears optimal for the extraction of residual reserves of coal substance (Seidl et al., 2011).

The study by Seidl et al. (2011) also implies that from an economic perspective, both the overburdened transport technologies (continuous and discontinuous) are sustainable. However, the study did not deal with the operational risks that the transport options are related to. As the economic assessment of the technological options is not enough, this article aims to put through operational risk analysis the two transport technologies and to identify whether the alternatives are comparable as for their degree of risk.

Despite the fact that continuous technology has long been used in Czech brown coal open pit mines and discontinuous technology is a considered alternative. It is possible to ask a research question which of the two alternatives is less risky.

Current literature provides mixed empirical evidence and arguments on the relationships between enterprise risk management and company performance. Some studies focus on enterprise risk management in general (Lai and Shad, 2017; Soomro and Lai, 2017; Meidell and Kaarbøe, 2017). Others deal with risks related to investments (Juchniewicz, 2016; Cehlar et al., 2011). Some authors also report research on specific industries, including the mining industry (Toraño et al., 2012; Badri et al., 2013; Tworek et al., 2018; Sabanov et al., 2008; Bijańska, 2016; Chinbat, 2012).

This article focuses on the risks related to the transport of stripped overburden in giant pit quarries in the Czech Republic. The results may be applied by managers of analogous giant pit quarries or in other fields. It compares the operational risks of two technological solutions to transport stripped overburden: continuous transport technology and, as an alternative, discontinuous transport technology, giving the basis for quality decision making. Results show that there may be antagonist relationships between the values characterizing the operational risk and economic efficiency. When deciding on the choice of the technological solution, this makes the decision-making more difficult. Therefore, risks must be identified and assessed using well-selected methods. When evaluating the economic efficiency of an investment project, in particular, it is important to develop an adequate projection of operational risks.

Methods and materials

A risk is defined as the combination of frequency, probability, and consequences of a specific dangerous situation or event, according to the updated standard on risk management (ISO 31000:2018). It can also be defined as a chance that something will happen and that it will have an impact on a facility (Petrovic et al., 2014). Risk, according to the same standard, is presented as the combination of potential events and consequences associated with the probability of its occurrence. The systematic use of information in order to identify the sources and to estimate the risk is defined as the risk analysis (ISO 31000:2018). Risk analysis provides the basis to assess the risk level, the treatment, and the acceptability of a risk (Petrovic et al., 2014).

The point of departure for the operational risk assessment of the transport options in the conditions of a brown coal opencast mine was the ISO 31000:2018. As the standard outlines a generic approach and can be used within different contexts, for example, environmental risks (Krzemień et al., 2016), it was necessary to adjust the approach for the specific issue under solution. This means that the principles and framework of the risk management architecture were not considered, and the risk management was reduced to the process alone. According to the standard, the risk management process has the following parts: (i) communication and consultation, (ii) determination of the context, (iii) risk assessment, and (iv) risk management.

This paper is focused on the risk assessment, which breaks into the following phases: (i) identification of risks, (ii) risk analysis, and (iii) risk rating.

ISO 31000:2018 is only a conceptual framework for risk management. The standard does not render any specific techniques or tools to be applied in the given conditions or situations. Therefore, the IEC/ISO 31010:2009 on risk management and risk assessment techniques should be consulted.

Risk assessment is the main step in risk management. Risk assessment is the overall process of risk identification, risk analysis, and risk evaluation. It should be conducted systematically, iteratively, and collaboratively, drawing on the knowledge and views of stakeholders. It should use the best available information, supplemented by further inquiry as necessary.

Once this procedure has been carried out, risk management instruments and risk controls can be selected. The results of risk assessment, therefore, affect the scope and intensity of protection. According to Nawrocki and Jonek-Kowalska (2016), the "holistic identification of risk sources" is an extremely important element in risk assessment, being related to all areas of the enterprise's business and its environment (Nawrocki and Jonek-Kowalska, 2016).

Risk assessment may be carried out at various depths and details using one or several methods, either simple or more complex ones. The form of risk assessment and its output should comply with the risk criteria developed as parts of context determination (IEC/ISO 31010:2009).

To assess risks, the standard offers 31 tools and techniques to choose from. In this article about continuous and discontinuous transport of the stripped overburden, two major methods were applied: (i) Cause-and-effect analysis for risk identification and (ii) Failure Models and Effects Analysis (FMEA) for risk analysis and evaluation.

Focusing on the transport of the stripped overburden from the point of extraction to the disposal site, either internal or external spoil heap, belt transport is used in case of continuous conveyance, being an inseparable part of the whole mining complex. Concerning this transport, usually, rubber-tired haulage is used. In giant pit quarries with discontinuous conveyance, they usually use trucks with a working load from 12 – 50 t, the so-called dumpers. Apart from dumpers, there are also dozers, tanks, spray dampers, etc.

Risk identification: Cause-and-effect analysis.

Following ISO 31000 (2018), the first step in risk assessment is risk identification, whose purpose is to find, recognize, and describe risks that might help or prevent an organization from achieving its objectives. Relevant, appropriate, and up-to-date information is important in identifying risks. It is a structured method to identify possible causes of undesirable events or problems and used to classify the possible contributing factors into extensive categories. The information is plotted either into a fishbone diagram (Ishikawa diagram), or a tree diagram (IEC/ISO 31010:2009).

The cause-and-effect analysis renders a structured representation of a list of causes for a specific effect in the form of an image. The cause-and-effect analysis should be performed by a team of experts well aware of the problem requiring solutions. The IEC/ISO 31010:2009 describes the basic steps in the cause-and-effect analysis.

Lehman et al. (1998) generally consider the research process as a series of 10 steps: (1) problem definition, (2) determining information needs, (3) setting research objectives, (4) selection of type of research, (5) design of data collection, (6) development of a plan of analysis, (7) data collection, (8) analysis, (9) drawing conclusions and (10) reporting.

Experts in the field were consulted by means of a two questionnaires survey in order to evaluate or supplement the undesirable events or problems that will drive to a decrease in the Net Present Value (NPV) of the considered technologies.

The NPV was used for the economic evaluation of the assessed technologies, Seidl et al. (2011), the NPV was determined as the head of the Ishikow diagram. This choice was also supported by the fact that the threats considered negatively affect the value of the causal attributes of NPV.

Based on Lehman et al. (1998), Aaker et al. (2003), and Malhotra (2010), no hypotheses were stated as the purpose of the research was to obtain experts' opinions and statements on the given problem.

The first questionnaire dealt with continuous conveyance, and the second questionnaire dealt with discontinuous transport technology. Questionnaires you can see at https://data.mendeley.com/drafts/2vcv8tcpjd. Both questionnaires included seven major risk categories, consisting of specific risks: human factor, supplier, legislation, technology, costs, environment, and market, based on the work developed by (Vaněk et al., 2012). The seven major risk categories are based on the analysis of the macro- and micro-economic environment of the business. According to Janíček (2013), an ideal expert team should have 5 – 7 members and should include respondents from various levels of the company management. The specific risks were identified using Ishikawa diagrams by the authors' team and five experts from the management of coal companies.

By applying the cause-and-effect analysis, it is possible to identify a rather high number of risk sources. These risk sources are later evaluated using the FMEA analysis.

Risk analysis: Failure Mode and Effects Analysis.

The second step in risk assessment, according to ISO 31000 (2018), is risk analysis, which purpose is to comprehend the nature of risk and its characteristics, including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, controls, and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives.

Failure Mode and Effects Analysis (FMEA) is one of the structured, systematic, and proactive techniques used in failure analysis. The purpose of FMEA is to list out all possible failure modes and evaluate their causes as well as their subsequent effects on the performance of the system under consideration (Bozdag et al., 2015).

According to Nicholas and Steyn (2012), FMEA is used to determine the ways a technical system may fail, as well as how the effects of failure may affect the system's performance, safety, and environment. The model measures the risk level by means of a risk priority number (RPN), a semi-quantitative criticality measure computed by multiplying the severity, the probability of occurrence and the likelihood of detection, of each potential failure mode, using rates from 1 to 10, like the one described in Tab. 1 (Bozdag et al., 2015).

Tab. 1. Severity, probability of occurrence and likelihood of detection scales

Rating	Severity	Probability of occurrence	Likelihood of detection
10	Hazardous without warning	Extremely high	Absolute uncertainly
9	Hazardous with warning	Very high	Very remote
8	Very high	Repeated failures	Remote
7	High	High	Very low
6	Moderate	Moderately high	Low
5	Low	Moderate	Moderate
4	Very Low	Relatively low	Moderately high
3	Minor	Low	High
2	Very minor	Remote	Very high
1	Almost none	Nearly impossible	Almost certain

Source: Bozdag et al., 2015

To ensure as objective inputs as possible, experts in the field were also consulted. Considering the issue under interest, a low number of respondents were expected.

The fundamental difference in the degree of risk in the observed technologies will lay in the RPN interval and in the difference of modus. Potential failure modes are then categorized by the RPN; the highest RPNs have the highest priority (Nicholas, 2012).

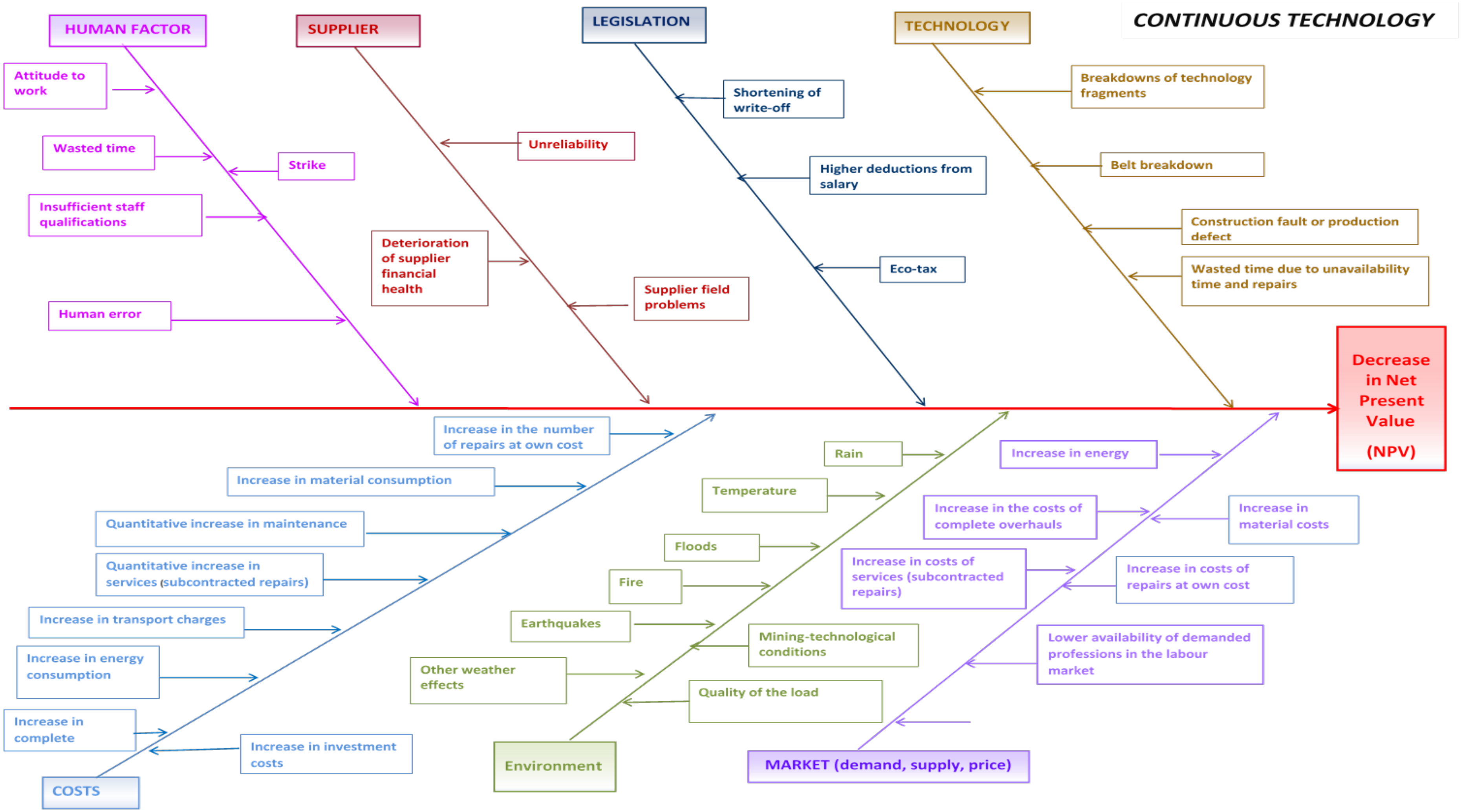

Fig. 1. Ishikawa diagram for continuous technology. Source: own processing.

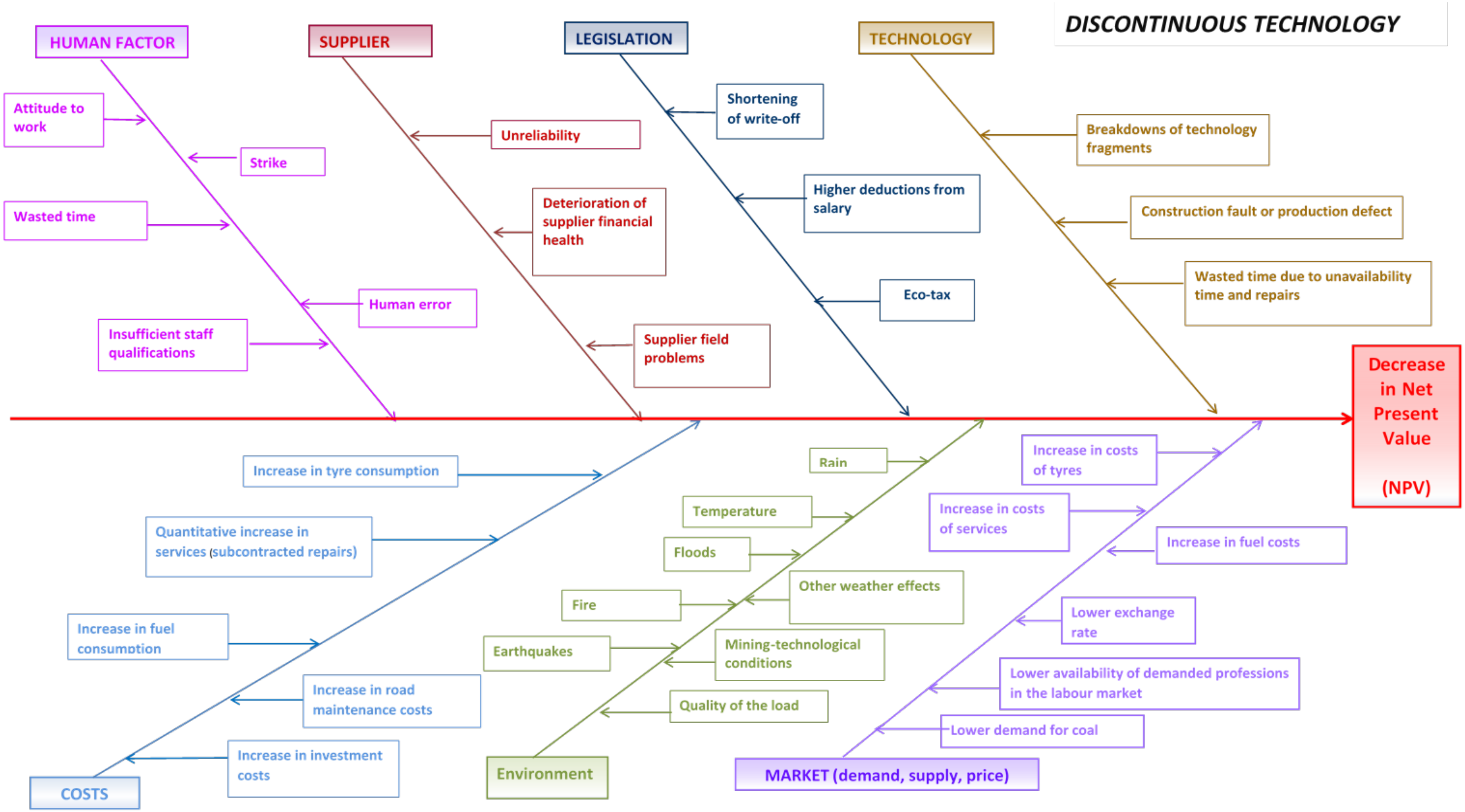

Fig.2. Ishikawa diagram for discontinuous technology. Source: own processing

Results

The first step in the process of risk assessment of the stripped overburden transport options is to identify the risks. Risks were identified using the cause-and-effect analysis (Ishikawa diagram). After making this analysis, it was presented to experts in the field in order to obtain their review. The final form of the analysis, which became the starting point for the subsequent risk analysis, is presented in Fig. 1 (continuous technology) and Fig. 2 (discontinuous technology).

The risk analysis was carried out by means of FMEA. In order to obtain an objective evaluation of the transport option risks, we also addressed experts in the field. Considering the uniqueness of the field, we consider the number of respondents sufficient. In line with the methodology, from the obtained values the modus for severity, probability, and detectability of the risk was calculated and, subsequently, the value of RPN, that are presented for the continuous transport technology (Tab. 2) and the discontinuous transport technology (Tab. 3).

Tab.2. RPN for the continuous transport technology

Area of risk	Type of risk	Severity	Probability	Detectability	RPN	RPN [%]
Human factor	Attitude to work	9	7	5	315	5.7
	Wasted time	9	5	2	90	1.6
	Human error	7	4	2	56	1.0
	Insufficient staff qualifications	9	1	9	81	1.5
	Strike	10	1	1	10	0.2
Supplier	Unreliability	9	3	2	54	1.0
	Deterioration of supplier financial health	7	3	2	42	0.8
	Supplier field problems	7	5	2	70	1.3
Legislation	Shortening of write-off period	9	6	1	54	1.0
	Higher deductions from salary	4	2	9	72	1.3
	Eco-tax	9	4	1	36	0.7
Technology	Breakdowns of technology fragments	6	5	9	270	4.9
	Belt breakdown	10	6	6	360	6.6
	Construction fault or production defect	9	5	4	180	3.3
	Wasted time due to unavailability time and repairs	7	3	10	210	3.8
Costs	Increase in complete overhauls	7	1	3	21	0.4
	Increase in the number of repairs at own cost	8	6	5	240	4.4
	Increase in material consumption	8	5	6	240	4.4
	Quantitative increase in services (subcontracted repairs)	4	2	3	24	0.4
	Increase in transport charges	6	6	2	72	1.3
	Increase in energy consumption	8	7	1	56	1.0
	Quantitative increase in maintenance	8	7	4	224	4.1
	Increase in investment costs	10	7	6	420	7.7
Environment	Floods	10	2	1	20	0.4
	Earthquakes	10	1	1	10	0.2
	Fire	10	2	1	20	0.4
	Temperature	9	4	1	36	0.7
	Rain	8	5	5	200	3.6
	Quality of the load	8	8	5	320	5.8
	Other weather effects	8	1	1	8	0.1
	Mining-technological conditions	7	5	3	105	1.9
Market (demand, supply, price)	Increase in costs of services (subcontracted repairs)	8	7	1	56	1.0
	Increase in the costs of complete overhauls	7	7	4	196	3.6
	Increase in energy costs	9	6	1	54	1.0
	Increase in costs of repairs at own cost	7	7	6	294	5.4
	Lower demand for coal	9	7	8	504	9.2
	Increase in material costs	8	7	3	168	3.1
	Lower availability of demanded professions in the labor market□	7	6	5	210	3.8

Source: own processing

Tab.3. RPN for the discontinuous transport technology

Area of risk	Type of risk	Severity	Probability	Detectability	RPN	RPN [%]
Human factor	Attitude to work	9	8	5	360	6.6
	Wasted time	9	4	5	180	3.3
	Human error	9	3	3	81	1.5
	Insufficient staff qualifications	9	6	10	540	9.9
	Strike	10	1	1	10	0.2
Supplier	Unreliability	8	1	1	8	0.1
	Deterioration of supplier financial health	6	2	1	12	0.2
	Supplier field problems	7	3	5	105	1.9
Legislation	Shortening of write-off period	9	5	5	225	4.1
	Higher deductions from salary	5	2	9	90	1.6
	Eco-tax	6	5	1	30	0.5
Technology	Breakdowns of technology fragments	5	5	5	125	2.3
	Construction fault or production defect	5	2	3	30	0.5
	Wasted time due to unavailability time and repairs	9	6	5	270	4.9
Costs	Increase in tire consumption	8	10	3	240	4.4
	Quantitative increase in services (subcontracted repairs)	8	2	4	64	1.2
	Increase in fuel consumption	10	8	1	80	1.5
	Increase in investment costs	8	5	1	40	0.7
	Increase in road maintenance costs	9	9	9	729	13.4
Environment	Floods	10	2	1	20	0.4
	Earthquakes	10	1	1	10	0.2
	Fire	9	2	1	18	0.3
	Temperature	3	2	1	6	0.1
	Rain	9	4	1	36	0.7
	Quality of the load	8	3	4	96	1.8
	Other weather effects	3	2	1	6	0.1
	Mining-technological conditions	8	8	1	64	1.2
Market (demand, supply, price)	Increase in costs of services	7	5	1	35	0.6
	Increase in costs of tires	10	8	9	720	13.2
	Increase in fuel costs	9	10	9	810	14.8
	Lower availability of demanded professions in the labor market	6	7	6	252	4.6
	Lower exchange rate	9	6	1	54	1.0
	Lower demand for coal	10	8	2	160	2.9

Source: own processing

The significance of the different risks is clearly presented in Fig. 3 (continuous transport technology) and Fig. 4 (discontinuous transport technology).

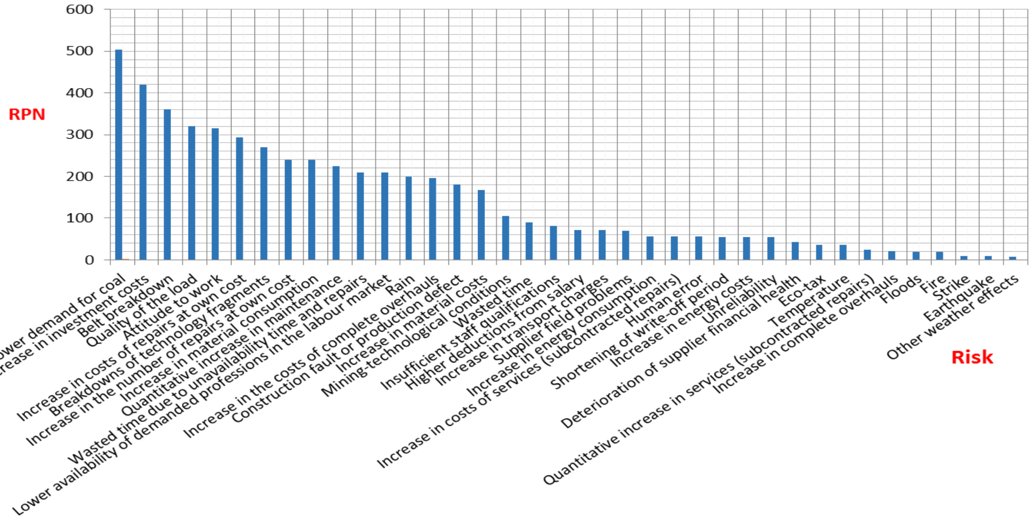

Fig. 3. Risk pattern of continuous transport technology, according to RPN. Source: own processing

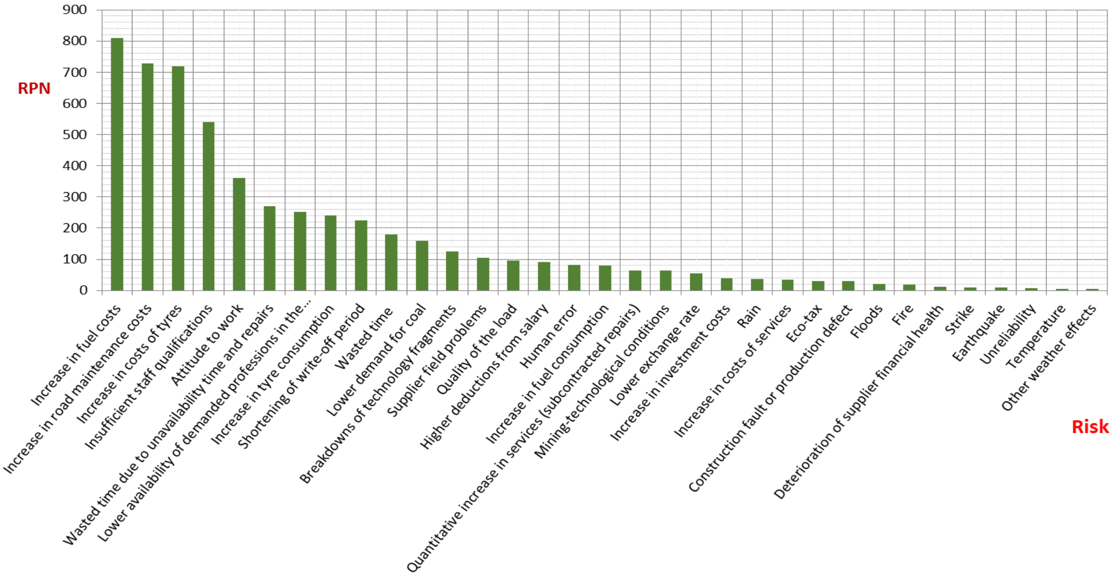

Fig. 4. Risk pattern of discontinuous transport technology, according to RPN. Source: own processing

Discussion

The transport of the stripped overburden during large-scale surface mining of mineral products belongs to the key processes that cardinally influence the overall exploitation of the mineral under interest. Therefore, the choice of transport cannot be underestimated.

Tab. 4 gives the riskiest factors (top five) based on Pareto's analysis in the considered transport alternatives.

It is apparent from Tab. 4 that the top four risks in the discontinuous technology are higher than the most severe risk in continuous technology.

Tab. 4. Comparison of the top five most significant risks.

Continuous technology		Discontinuous technology	
Item	RPN	Item	RPN
Lower demand for coal	504	Increase in costs of fuel	810
Increase in investment costs	420	Increase in road maintenance costs	729
Belt breakdown	360	Increase in costs of tires	720
Load quality	320	Insufficient staff qualifications	540
Attitude to work	315	Attitude to work	360

Source: own processing

Those risks are also specific for this transport technology. They are operational risks and, thus, principally contribute to the overall degree of risk of the technological option under consideration. The occurrence of such risks in practice brings an increase in the costs of operation and, thus, lower cash flow from the investment and a fall in the net present value.

Although input data generated based on brainstorming are subjective, it is useful to distinguish between RPN of continuous and discontinuous transport technology by descriptive statistics (see Table 5).

Tab. 5. Distinguish between RPN of continuous and discontinuous transport technology

Item	Continuous transport	Discontinuous transport
Total number of identified risks	38	33
RPN range	496 (8 – 504)	804 (6 – 810)
The risk median	76.5	80.0
The average value of the risk	142	166
The variance of the value	16,114	48,069
The coefficient of variation	0.8936	1.314

Source: own processing

Figure 5 shows the distribution of risks in the observed transport technologies. It implies that the risk pattern is analogous to both the technologies. The highest number of risks concentrates in the third quartile. The third quartile of the continuous technology includes 23.68 % of risks and 27.27 % of risks in the discontinuous one. The range of RPN in the third quartile of the continuous technology is 144, and in the discontinuous technology, it is 145.

It is also clear from Figure 5 that the fundamental difference in the degree of risk in the observed technologies lies in the RPN interval and the difference in the maximum values of RPN.

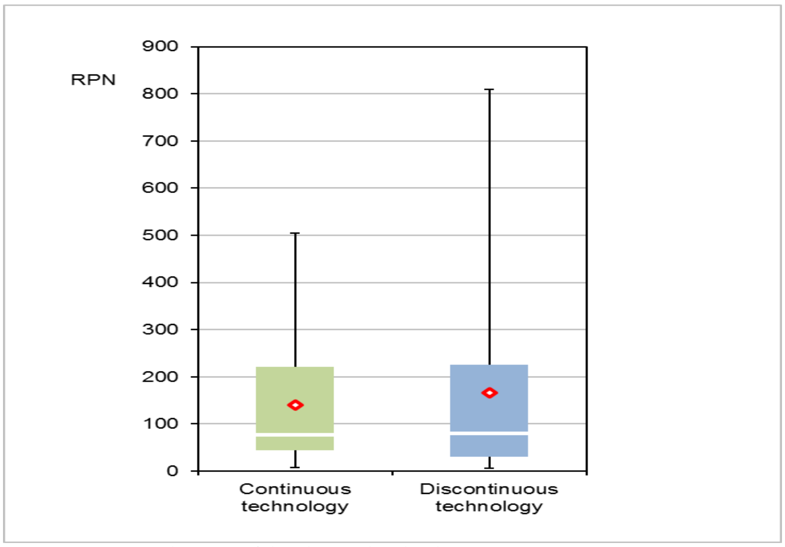

Fig. 5. Box diagram of the observed technology RPN. Source: own processing

The data, as mentioned above, imply that the continuous transport technology shows a 306-point-lower RPN value than the discontinuous one. The discontinuous technology also has a higher risk range, i.e., of 308. This state is caused by four of the most important risks (increase in costs of fuel – RPN 810, increase in road maintenance costs – RPN 729, increase in costs of tires – RPN 720, insufficient staff qualifications – RPN 540).

Figure 5 shows that the risk of both transport technology is almost the same from the large part. However, from a complexity point of view, the data lead to an unambiguous conclusion that the existing continuous technology is less risky than the discontinuous one.

In contrast to the study by Vaněk et al. (2013), using different methods and stating that both the transport technologies are more or less equivalent as for the level of risks involved, the results of the FMEA herein partly disagree. Vaněk et al. (2013) considered the technologies by means of the probability distribution of NPV, while the probability distribution of the evaluation indicator was implemented via scenarios and statistical characteristics (variance, standard deviation, variation coefficient). The risks discussed in Vaněk et al. (2013) were the results of sensitivity analysis. This analysis works only with risks quantified in monetary units. Therefore, it does not cover the whole range of risks.

The methods applied in the research herein enabled us to identify and subsequently analyze a much wider spectrum of risks, and thus offer a more complex view on the issue.

Conclusion

Risk analyses may be carried out using a number of approaches and applying several analytical methods. The choice of the approach or method depends on the purpose of the analysis.

In this case, the purpose of the analysis lay in the assessment of two technological options which may be used to transport the stripped overburden in the giant pit quarries. However, the analysis may serve as the starting point to frame the measures to be implemented within the risks management phase.

Risk identification was carried out by means of a Cause-and-effect analysis, taking into account seven major risk categories (human factor, supplier, legislation, technology, costs, environment, and market), based on the work developed by (Vaněk et al., 2012). The seven major risk categories are based on the analysis of the macro- and micro-economic environment of the business, and addressing a possible decrease in the Net Present Value (NPV) of the considered technologies.

The risk analysis was carried out using the FMEA analysis. The analysis implies that discontinuous technology involves more risks than continuous conveyance. This finding is also the answer to the research question asked by the authors in the Introduction. However, the higher degree of risk in discontinuous technology does not necessarily mean that it cannot be used when deciding on overburden transport technology.

Risk assessment is only a partial assessment. To make a qualified assessment of the technological alternatives, complex approaches must be taken.

By complex approaches, i.e., economic, environmental, etc., the anticipation of risks in the technological options all the way to the discount rate value should be considered. A difference in the discount rate value may thus render a more objective evaluation of the whole economy of the stripped overburden transport in the long run.

The results may be applied by managers of analogous giant pit quarries or in other fields. The knowledge obtained is influenced by the number of localities where brown coal is currently exploited in the Czech Republic. Although the article contributes to filling the gap of knowledge about the risks of technologies used to transport overburden in giant open-pit mines, it is necessary to provide further research. The research should focus on the complex assessment of the economic efficiency of the stripped overburden transport technologies, as well as the possibilities of using other risk analysis methods.

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