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A MULTICRITERIA ANALYSIS OF THE WORKING ENVIRONMENT AT OPEN PIT MINE LOADING AND TRANSPORT

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Abstract: The working conditions in the loading and the transport sectors in mines are quite difficult. Operators and drivers are exposed to both physical and chemical hazards. Accordingly, the ranking of the workplaces at loading and transport in the mine was conducted in order to determine the workplace characterized by the most difficult working conditions. Five workplaces in the Open Pit Mine “Veliki Krivelj” were analyzed on the basis of the regularly measured parameters of the working conditions there (measures have done in 2018 year). The AHP/PROMETHEE methods were used as the ranking method. The AHP (Analytic Hierarchy Process) method enables us to determine the criteria weight of coefficients and the PROMETHEE (Preference Ranking Organization Method for the Enrichment of Evaluations) method enables the final ranking of the workplaces. The three scenarios were considered, as follows: the ranking of the loading workplaces, the ranking of the transport workplaces and the ranking of all the workplaces. The results indicate that the workplace of the Marion Excavator Operator is the most difficult workplace at loading. The workplace of the Euclid R 170 Truck driver is the most difficult workplace at transport. Finally, a comprehensive analysis of all the workplaces generated the results indicative of the fact that the workplace of the Marion Excavator Operator is the most difficult workplace. The obtained results indicate a clear distinction between the old and the new equipment. The results clearly suggest the importance of having modern equipment, which is the key element in taking care of the workers’ health.

Keywords: workplaces ranking; AHP; PROMETHEE; mining

1 INTRODUCTION

Loading and transport are the “bloodstream” of each mine. They are the key operation processes in a mine, performed by powerful machines operated by qualified workers. The equipment includes excavators and high-capacity heavy trucks, managed by

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operators and drivers. These workplaces are characterized by very difficult working conditions as the workers in these workplaces are exposed to physical and chemical hazards and they are required to make a great mental effort.

The major risk factors posing potential threats to the health of the workers in these workplaces are high or low temperatures, vibrations, noise, dust, oil fumes, bad lighting, shiftwork, long periods of sitting, awkward body postures, repetitive movements and the complexity of the work, among other factors (Buchholz et al., 1997; Stern and Haring-Sweeney, 1997; Zimmerman et al., 1997).

The most frequent health issues the workers at loading and transport are faced with are musculoskeletal disorders, as a consequence of vibrations and awkward body postures, an uneasy feeling, caused by their exposure to extreme temperatures and oil fumes; a physical discomfort and vibration-induced nausea; eye fatigue due to bad lighting, oil fumes and high labor intensity, as well as the complexity of the work; hearing impairment caused by noise and so forth (Eger et al., 2014).

In their study, Dupuis and Zerlett suggested a relationship between the operations with the earth-moving equipment and the health problems of the workers operating that equipment (Dupuis and Zerlett, 1987). Onate and Meyer (2012) studied the relationships between mine risks and harmfulness, on the one hand, and the mental and emotional exhaustion of the workers, on the other. Scott et al. (2009) analyzed the chemical hazards that had occurred in American mines and the diseases the workers suffered from, as the consequence of them. The previously mentioned studies, as well as many other ones, indicate that the mine workers were exposed to numerous risks leading to the health issues and causing many diseases (Courtney and Evans, 1993; Hulshof and Veldhuijzen van Zanten, 1987; Kittusamy and Buchholz, 2001; Wikstrom et al., 1994).

Mining companies are obliged to conduct periodic testing regularly in order to increase their workers' safety, in order to improve the safety of the workers (Trade Union Congress, 2001). In Serbia, the process of measuring working conditions is defined by the Regulations on the Testing of the Working Equipment and the Working Environment Conditions (Official Gazette of Republic of Serbia No. 101/05). The purpose of the Regulations is to implement appropriate measures for the better protection of workers, determine their benefits and so on.

Considering the fact that many risks originating from the working environment area simultaneously pose a threat to human health, the permitted values of the parameters are defined by the relevant Laws and Directives, the Regulations of the Republic of Serbia, as well as by the Standards (Occupational Safety and Health - Law Code of Republic of Serbia; Directive 89/391/EC, 1989; Directive 2003/10/EC, 2003; ISO 1999/90, 1990; ISO 9612/97, 1997; ISO 7726/98, 1998; ISO 7730/05, 2005; JUS U.C9.100/62, 1962). The aim of these Acts is to define the optimal working conditions and reduce risk at work.

This paper presents the ranking of the workplaces at loading and transport in the mine, based on several criteria at the same time. The aim of the ranking is to indicate the most difficult workplaces that threaten the workers' health the most. The combined AHP/PROMETHEE method was used for the ranking. The most important advantage of this combined method is that it minimizes subjectivism in the course of carrying out the ranking process. Therefore, the AHP method is used for assigning the objective weight coefficients criteria. The weight coefficient criteria obtained in that way are then used in the PROMETHEE method for the purpose of establishing the final ranking of the workplaces. The three scenarios were considered, namely: the ranking of the loading workplaces, the ranking of the transport workplaces and ultimately the ranking of all the workplaces.

The basic limitations of this study relate to the fact that it was conducted solely in the open pit mine of Veliki Krivelj and that the study is based on the five alternatives and the six criteria. The number of the alternatives and the criteria is limited by the existing equipment in the open pit mine Veliki Krivelj and the methodology for measuring the working environment parameters that determine the working conditions.

2 THE OPEN PIT

The Open Pit Mine "Veliki Krivelj" is a part of the Copper Mine Bor Complex (RTB Bor official site). It is located 3 km far away to the northeast of the town of Bor. The mine started operating in 1979. So far, about 194.6 million tons of ore and about 178.8 million tons of tailings have been excavated. The average copper content in the excavated ore has been about 0.342 %, which makes a total of about 665,000 t of copper in the ore.

The remaining certified geological ore reserves are greater than 617 million tons of ore, with the average copper content of 0.32 %.

The mine is of a conventional type and massive exploitation is performed by means of the high-capacity equipment. The drills of 250 to 310 mm in diameter are used for drilling, whereas the excavators of a great capacity, with the ladles of 15 m³ and 22 m³ of the volume, are used for the loading of the excavated ore. The ore and the overburden are transported to the crusher plant by the 220-t-capacity trucks. The annual capacity of the mine is about 10 million tons of the ore and up to 20 million tons of the overburden.

The new equipment and mechanization, as well as the old equipment and mechanization, are used for mine operations. They are mainly used for loading and transporting the ore and the overburden.

The old Marion excavators, together with the most modern excavators of Komatsu PC 4000, are used for the performance of the loading operations in the mine "Veliki Krivelj".

As for the transport operations, the situation is more complicated. There is a great number of old and less reliable Euclid R 170 and Unitrig MT 3600 trucks in the mine. Additionally, there are some new and modern 150-220-ton-capacity Belaz trucks.

Not only is the outdated equipment less reliable and less efficient, but it also requires more complex and more expensive maintenance. Besides, there are certain working environment parameters for such equipment that are frequently above the permitted limits, which seriously affects the equipment operators' health.

3 THE MULTICRITERIA METHOD

In order to rank the loading and the transport workplaces on the basis of the working conditions, the multicriteria decision AHP/PROMETHEE method was used. This combined method enables us to consider all the workplaces and all the criteria in order to obtain a high-quality result, i.e. the ranking.

For problems to be solved, only one of the mentioned methods (either PROMETHEE or the AHP) can be used. Both methods have some advantages and some disadvantages. The aim of their combining is the minimization of the disadvantages and the strengthening of the advantages of both methods. Some characteristics of the analytical hierarchical process (AHP) method may improve the implementation of the PROMETHEE method at the level of the structuring of the decision problem and the defining of the weight coefficient. The criteria weight coefficients obtained by the AHP method are characterized by the minimal level of subjectivism, a high level of connectivity, better correlation, consistency and accuracy in relation to the coefficients obtained through intuition or the domain of expert knowledge, mostly implemented in the PROMETHEE method (Macharis et al., 2004).

For the purpose of ranking the loading and the transport workplaces in mines, the combined AHP/PROMETHEE method suggested in this paper includes four basic stages, namely: (1) data collection, (2) AHP calculations, (3) PROMETHEE calculations, (4) results and discussion – Figure 1. The alternatives (the loading and the transport workplaces) and the criteria to be used for their evaluation are defined in the data collection stage.

The second stage implies AHP calculations in order to assign the criteria weight coefficients. The AHP is a powerful tool for the multicriteria decision making developed by Saaty (1980). The AHP calculation starts with the decomposing of the complex problem of multicriteria decision making into the multidimensional hierarchical structure of the goals, the criteria and the alternatives. The next step is the estimation of the influence of the criteria, which is then followed by the comparison of the alternatives related to every single criterion and the determination of the total priority for each alternative and the final ranking of the alternatives.

The calculation of the relative influence of a single criterion and the comparison of the alternatives related to the criteria should be made with the help of the data given in the tables – the matrix of the comparison, including the grading scale from 1 to 9 – Table 1. This process comprises the following:

- the formation of the comparison matrices at each hierarchy level, starting from the second level downwards;
- the calculation of the weight coefficients for each element of the hierarchy, and
- the estimation of the consistency degree in order to check the consistency of the process as a whole.

Table 1 Scale of decision element comparison

Dominance	
Description	Grade
Equal	1
Weak domination	3
Strong domination	5
Very strong domination	7
Absolute domination	9
2, 4, 6, 8 are intermediate values

Figure 1 Schematic overview of combined AHP / PROMETHEE method

Upon completion of the comparison and the formation of the appropriate matrix, the weight coefficients are calculated by implementing the Saaty procedure and the obtained result is the coefficient vector $w = [w_1, w_2, \dots, w_n]$.

The next thing to check is the degree of consistency. The consistency level should be less than 0.1.

Determining the final range of the alternatives is to be done by the synthesis of the results obtained at all levels.

In this paper, the AHP procedure ends with assigning the weight coefficients to all of the six criteria. Criterium DecisionPlus is the software used for this calculation.

In the third stage of the PROMETHEE-based calculation, first, the appropriate preference function and the corresponding parameters must be determined. After that, the complete ranking of the alternatives, i.e. the workplaces, is processed by using the Decision Lab software. The three scenarios for the ranking were considered: the first scenario was for the ranking of the loading workplaces; the second one was for the ranking of the transport workplaces; ultimately, the third scenario was for the ranking of all the workplaces.

The preference function defines the way of the ranking of a specific alternative in comparison with another and transforms the deviation between the two alternatives into the unique parameter related to the preference function. The preference degree is in the form of the increasing deviation function. The PROMETHEE method applies six forms of preference (the Usual, the U-shape, the V-shape, the Level, the Linear and the Gaussian). Each form of the preference function depends on two indifference thresholds (the Q and the P thresholds). The indifference threshold (Q) is the greatest deviation considered as irrelevant in decision making, whereas, on the other hand, the indifference threshold (P) is the smallest deviation and is considered to be the crucial one in the decision-making process, where P is not less than Q. The Gaussian threshold (s) is the average value of the thresholds P and Q (Brans, 1982; Brans et al., 1984; Brans and Vincke, 1985; Herngen et al., 2006).

The PROMETHEE method determines the positive – input stream (Φ^+) and the negative – output stream (Φ^-) for each alternative of the outranking relations. The positive stream of preference indicates the degree to which the specific alternative is better than the other alternatives, i.e. the greater the value ($\Phi^+ \rightarrow 1$), the more significant the alternative. The negative stream of preference indicates the degree to which the specific alternative is worse than the other alternatives. An alternative is more significant if the output stream value is less ($\Phi^- \rightarrow 0$). The complete ranking is performed on the basis of the net flow value (Φ), presenting the difference between the positive and the negative streams of preference. The alternative with the highest net flow value is the best-ranked alternative (Albadvi et al., 2007; Anand and Kodali, 2008; Brans and Mareschal, 1994).

The last stage, discussion and the results, presents the analysis of the obtained results for the ranked workplaces specified by the AHP/PROMETHEE method. The three scenarios were considered, namely: the ranking of the loading workplaces (Scenario 1); the ranking of the transport workplaces (Scenario 2), and ultimately the ranking of all the workplaces (Scenario 3).

4 THE RESULTS

As it has previously been mentioned, we chose five workplaces in the Open Pit Mine “Veliki Krivelj”, i.e. five alternatives for carrying out a multicriteria analysis. The workplaces taken into account were two workplaces at loading – the Marion excavator (the excavation operator – Alternative A1) and the Komatsu PC 4000 excavator (the excavation operator – Alternative A2). As for transport, three workplaces were taken into consideration – the Euclid R 170 truck (the driver’s workplace – Alternative A3), the Belaz (the driver’s workplace – Alternative A4) and the Unitrig MT 3600 (the driver’s workplace – Alternative A5).

The criteria are the parameters of the working environment that are subject to regular measuring that specify the working conditions. The total number of the criteria is six, including the air temperature (the criterion C1), the light (the criterion C2), noise (the criterion C3), dustiness (the criterion C4), chemical hazards (the criterion C5) and vibrations (the criterion C6).

The air temperature is one of the most significant microclimatic parameters. The testing of the air temperature was performed in the workplaces where the employees spend more than two hours in one working shift. The testing of the air temperature in the summer was performed at the outer temperature higher than 15°C, and in the winter, when the outer temperature was lower than 5°C.

The light in the workplace is tested in accordance with the adopted testing and measuring methodology (British Standard BS 667:2005). The light is a very important parameter of the working environment and significantly influences the quality of operations and the workers’ health (Steidle and Werth, 2014).

Noise, vibrations and harmful radiation – excluding ionizing radiation – are included in the group of physical hazards. Due to all these causes, noise, vibrations and harmful radiations should be measured in each workplace (Handbook of Friction-Vibration Interactions, 2014; Thompson, 2014; Wolfgang and Burgess-Limerick, 2014). The increased values of physical hazards affect the workers’ health (Faramarzi et al., 2014; Petavratzi et al., 2005).

Table 2 Criteria – work environment parameters

Criterion	Work environment parameters	Allowed ranges of work environment measured parameters	Influence on human health
C1	Air temperature	max 28 ⁰	Unease feeling, activity disturbance, chronic disease
C2	Light	min 150Lx	Activity disturbance, eye fatigue, risk of injury, headache
C3	Noise	max 75dBA	Hearing impaired, disruption of receiving sound signals, inability of direct and indirect communication, activity disturbance
C4	Dustiness	max 10mg/m ³	Activity disturbance, risk of injury, chronic disease
C5	Chemical Hazards – Petroleum oils	max 300mg/m ³	Activity disturbance, risk of injury, chronic disease, headache
C6	Vibrations from 25Hz	max 1 m/s ² to 1/3 octave	Activity disturbance, risk of injury, chronic disease, headache, unease feeling

Chemical hazards include gases, fumes, smokes and dusts. Air humidity and the wind speed have a great influence on the concentration of chemical hazards (Csavina et al., 2014).

In order to protect the workers' health, the specific permitted values of the working environment are defined by laws and directives (The Occupational Safety and Health Law of the Republic of Serbia, Directive 89/391/EC and Directive 2003/10/EC), the Regulations of the Republic of Serbia and the standards (ISO 1999/90, ISO 9612/97, ISO 7726/98, ISO 7730/05 and JUS U.C9.100/62). Table 2. shows the parameters of the working environment (the criteria), the permitted values within the working environment and the influence on workers' health.

The weight coefficient for the criteria of the working environment can be determined by applying the AHP method. It is the basis for the creating of the comparison matrix, by using the scale given in Table 1. Table 3. shows the comparison matrix (of the dimensions 6x6) created on the decision maker's empirical estimation, with the aim to determine the significance of each individual criterion for the ranking of the loading and the transport workplaces in the mine "Veliki Krivelj". The maximum significance vector

for the criteria was obtained by applying the Criterium DecisionPlus software 3.0. (InfoHarvest Inc., Seattle, U.S.A.).

Table 3 Criteria comparison matrix

Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
C ₁	1	5	1	1/2	1	1/6
C ₂	1/5	1	1/7	1/3	1/5	1/8
C ₃	1	7	1	5	6	1/3
C ₄	2	3	1/5	1	2	1/7
C ₅	1	5	1/6	1/2	1	1/8
C ₆	6	8	3	7	8	1

Table 4. shows the calculation results obtained from the comparison matrix.

According to the AHP calculations, it is evident that the most important criteria for ranking a workplace are as follows: vibrations (C₆) and noise (C₃), followed by dustiness (C₄), temperature (C₁) and chemical hazards (C₅), whereas the ultimate criterion of the light is the least influential (C₂). As the consistency degree is 0.080, which is less than 0.1, the obtained results (the weight coefficient of the criteria) can be used in the further workplace ranking process.

Table 4 Results obtained by AHP calculations

Criteria	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	Consistency degree
Weight coefficient	0.076	0.028	0.261	0.089	0.067	0.478	0.080<0.1

The evaluation of the workplace is performed by PROMETHEE method and the evaluation matrix is created on the basis of the given criteria. All the criteria in this process have quantitative structures. The values of the criteria, i.e. the parameters of the working environment are obtained through the periodical testing of the conditions in the working environment. The testing is done in each working place every three years. This paper presents the parameters of the working environment obtained in the course of the last testing, done in the summer of 2018 year – in the Copper Mine “Veliki Krivelj” (Table 5.).

Further, the process deals with the workplace analysis (the alternatives), i.e. the ranking in relation to the measured values of the parameters of the working environment (the criteria) by applying the PROMETHEE method. Considering the fact that the data in Table 5 are of a quantitative character, the linear function was chosen as the preference function for all of the defined criteria, with the indifference and the preference thresholds (Q and P) within the zones between 5% and 30%, respectively.

Table 5 Evaluation matrix

Criteria	Air temperature (C1)	Light (C2)	Noise (C3)	Dustiness (C4)	Chemical hazards – Petroleum oils (C5)	Vibration from 25Hz (C6)
	Max	Min	Max	Max	Max	Max
Weight coefficient	0.076	0.028	0.261	0.089	0.067	0.478
Preference function	Linear	Linear	Linear	Linear	Linear	Linear
Indifference threshold (Q)	5 %	5 %	5 %	5 %	5 %	5 %
Preference threshold (P)	30 %	30 %	30 %	30 %	30 %	30 %
Measure unit	°	Lx	dBA	mg/m ³	mg/m ³	1 m/s ² per 1/3 octave
Excavator operator Marion (alternative A1)	24.5	200	93	1.9	0	1.2
Excavator operator Komatsu PC 4000 (alternative A2)	22.5	200	82	1.4	0	0.8
Truck driver Euclid R 170 (alternative A3)	23.5	290	84	2.9	10	1.2
Truck driver Belaz (alternative A4)	23	470	85	2.1	5	1.2
Truck driver Unitrig MT 3600 (alternative A5)	24	500	85	2.9	25	1.2

Table 6 Preference net flow

Alternatives	Φ^+	Φ^-	Φ
Scenario 1			
Excavator operator Marion (alternative A1)	0.0627	0	0.0627
Excavator operator Komatsu PC 4000 (alternative A2)	0	0.0627	-0.0627
Scenario 2			
Truck driver Euclid R 170 (alternative A3)	0.0280	0.0134	0.0146
Truck driver Belaz (alternative A4)	0.0140	0.0341	-0.0201
Truck driver Unitrig MT 3600 (alternative A5)	0.0355	0.0280	0.0055
Scenario 3			
Excavator operator Marion (alternative A1)	0.0628	0.0168	0.0461
Excavator operator Komatsu PC 4000 (alternative A2)	0.0210	0.0324	-0.0114
Excavator operator Euclid R 170 (alternative A3)	0.0436	0.0359	0.0077
Truck driver Belaz (alternative A4)	0.0070	0.0389	-0.0319
Truck driver Unitrig MT 3600 (alternative A5)	0.0207	0.0312	-0.0105

The ranking of the parameters of the working environment defined in such a way, performed by applying the PROMETHEE method, was done by using the Decision Lab 2000 1.0. (Visual Decision Inc., Montreal, Canada) software package. The values of the positive (Φ^+) and the negative (Φ^-) flows for all of the three scenarios accounted for in Table 6. were obtained on the basis of the data displayed in Table 5.

PROMETHEE II did the complete ranking of the workplaces, starting from the hardest (the worst working conditions) to the easiest, taking into consideration the given restrictions, i.e. the criteria for all the three scenarios (Figure 2).

Figure 2 PROMETHEE II complete alternative ranking for scenario 1 (a), scenario 2 (b) and scenario 3 (c)

5 THE ANALYSIS OF OBTAINED RESULTS

The loading and the transport workplaces in the Open Pit Mine “Veliki Krivelj” were ranked on the basis of the PROMETHEE calculations. After only the loading workplaces (Scenario 1) had been analyzed, the workplace of the Marion excavator operator (Alternative A1) was found to be a more difficult workplace in comparison with the Komatsu PC 4000 excavator operator (Alternative A2). The reason for that lies in the fact that the Marion excavator is far older machinery than the Komatsu PC 4000 excavator. Therefore, it is in a worse condition and the installed technology is older, thus providing less protection to the workers, for the reason of which it is more difficult to operate and manage. Also, many original parts on the Marion excavator had been replaced with those made in Serbia, which, however, are of a lower quality. Due to bad

handling and bad maintenance in the past, its functionality is not at the appropriate level, either.

When the transport workplaces are concerned, the most difficult is the workplace of the Euclid R 170 truck driver (Alternative A3), which is followed by the workplace of the Unitrig MT 3600 truck driver (Alternative A5). The best working conditions are those provided for the Belaz truck driver (Alternative A4). The reasons for the said are similar to those for Scenario 1. The Euclid R 170 and the Unitrig MT 3600 trucks have been engaged in exploitation for many years and are in a much worse condition than the Belaz truck, purchased three years ago. Besides, the Euclid R 170 and the Unitrig MT 3600 trucks are frequently out of order and the maintenance staff focus on repairs which provide their higher availability and operability, whereas the driver's comfort is of less importance. Quite the opposite, the Belaz truck is a modern truck, manufactured according to all the required parameters, including the driver's comfort and safety.

Finally, the thorough analysis of all the loading and the transport workplaces in the mine "Veliki Krivelj" generated the results proving that the most difficult workplace is the workplace of the Marion excavator operator (Alternative A1), which is followed by the Euclid R 170 truck driver's workplace (Alternative A3), the Unitrig MT 3600 truck driver's workplace (Alternative A5) and the Komatsu PC 4000 excavator operator's workplace (Alternative A2), whereas the easiest workplace is the Belaz truck driver's (Alternative A4). The obtained results are indicative of the clear distinction between the old and the outdated equipment (the Marion excavator, the Euclid R 170 truck and the Unitrig MT 3600 truck), on the one hand, and the new modern equipment (the Komatsu PC 4000 excavator and the Belaz truck), on the other. The working conditions in the positions where the old equipment is used are very difficult and it is necessary that the Management of the Open Pit Mine should undertake specific measures in order to improve the working conditions and provide better safety and health protection. On the other hand, the modern equipment provides significantly better working conditions, greater safety and security for the workers. There are many reasons for this. The technological innovations in mining equipment have led to an increased occupational health and safety performance (better ergonomic solutions, better acoustic insulation, better lightening etc.). Also, new equipment has fewer vibrations, a better visibility and the air conditioner and so on. Generally speaking, working conditions and exploitation equipment worsen with the aging of the equipment (Trudel et al, 2015). The obtained results clearly show the importance of developing the loading and the transport equipment in mines and the necessity of procuring the modern equipment that is the key element for the performance of all mining operations, considered in all their aspects, including the worker's safety and health.

6 CONCLUSION

The multicriteria combined AHP/PROMETHEE method for the ranking of workplaces, considering the aspect of the working environment at loading and transport, was applied in this paper. The aim of the research is to indicate the workplaces where the workers' health is threatened the most.

As a part of the suggested combined method for ranking, the AHP method was used for the purpose of assigning the criteria weight coefficient (the parameter of the working environment), whereas the PROMETHEE method was used for the ranking of the alternatives (the workplaces). The weight coefficients obtained by making the AHP calculations are used in the PROMETHEE calculations, leading to the ranking of the alternatives on the basis of the coefficients. The paper presents the calculation of the criteria weight coefficients essential in the implementation of the PROMETHEE method, which may change the ranking order of the alternatives.

This paper reports the case study of the Open Pit Mine "Veliki Krivelj", a part of the RTB Company Bor, Serbia. The Company regularly measures the parameters of the working environment, such as the microclimate, physical hazards and chemical hazards. Consequently, the five workplaces were taken into consideration (the two loading and the three transport workplaces) and the six parameters defining the conditions of the working environment, including the air temperature, the light, noise, dustiness, chemical hazards and vibrations, together with appropriate weight parameters. The most influential criteria for the ranking of all the workplaces obtained by the AHP method are vibrations (Criterion C6) and noise (Criterion C3). Given the fact that they occurred in the majority of the cases, it is quite logical that the measured values of the parameters were above the maximum permitted values.

The three scenarios were the subject matter of our consideration: the ranking of the loading workplaces, the ranking of the transport workplaces and ultimately, the ranking of all the workplaces.

After conducting the analysis of the loading workplaces (Scenario 1), the Marion excavator operator's workplace was found to have more difficult conditions in comparison with the Komatsu PC 4000 excavator operator's.

The results of the ranking of the transport workplaces show that the Euclid R 170 truck driver's workplace is the most difficult, and is followed by the Unitrig MT 3600 truck driver's and ultimately the Belaz truck driver's.

Finally, the comprehensive analysis of all the loading and the transport workplaces in the mine "Veliki Krivelj" resulted in the fact that the workplace of the Marion excavator operator, which is followed by the workplaces of the Euclid R 170 truck driver, the Unitrig MT 3600 truck driver and the Komatsu PC 4000 excavator operator, is the most difficult, whereas the easiest is the Belaz truck driver's workplace.

The obtained ranking results indicate a clear distinction between the old and outdated equipment in the mine “Veliki Krivelj”, on the one hand, and the new and modern equipment, on the other. The old equipment (the Marion excavator, the Euclid R 170 truck and the Unitrig MT 3600 truck) is in much worse condition than the new modern equipment (the Komatsu PC 4000 excavator and the Belaz truck). Also, the maintenance of the old equipment focuses on increasing its availability and operability, whereas the driver’s comfort is of less importance. On the other hand, however, the modern equipment provides the significantly better working conditions, greater safety and security for the workers. The obtained results clearly show the importance of developing the load and the transport equipment and the necessity of having modern equipment which is considered as the key element for the performance of all mining operations, in all the aspects, including the workers’ safety and health.

Based on the foregoing facts, it can be confirmed that the suggested combined method of multicriteria decision making can successfully be applied to finding a solution to the problem of ranking and the identification of the most difficult workplaces. All the required information can be used for providing the necessary measures for the purpose of improving the working conditions in order to protect the workers’ health and achieve better results.

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