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THE INFLUENCE OF HAUL ROAD PARAMETERS ON SAFETY

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Abstract

Using risk assessment in a work process that can influence people, machinery, and environment enables simple and quick method of establishing potential hazards and giving those a risk rating. The big advantage is that hazards are defined for a specific case, and consequently, risk ratings are defined for each hazard. Adding risk ratings for each hazard makes it possible to assess total model risk rating and determine the average risk rating of each model. Distributional risk assessment is an additional method of analysing each model and it provides a visual overview. Additional risk control measures were applied to the least critical model to assess the hazards, and thus model risks were reduced to the least value. Risk assessment was performed on the example of "Očura II" quarry haul road based on a new risk assessment algorithm.

Keywords: risk assessment; mine safety; haul road; project parameters; distributional risk assessment; quarry; Očura II

I. INTRODUCTION

The risk signifies the probability of a potential hazard happening during work process, either as an injury or illness [1]. That is why risk assessment is a relatively simple, but very important step in ensuring the safety of work environment in different industries [2]–[4]. Risk assessment considers classification of hazards based on available information to assess the risks affecting people, property, and environment [5], [6]. The goals of risk assessment are: a) ascertaining hazards, harms, and efforts, b) risk assessment level for industrial accidents, professional illnesses, and ailments relating to profession, c) ascertaining corrective and prevention measures to keep the employees' health safety [1].

Based on the risk assessment (analysis), it is possible to recognize (detect) hazardous events which can cause unwanted consequences, and therefore also detect suitable protection measures. Very common manner of risk assessment is using the risk assessment matrix which juxtaposes the probability of (hazardous) events and the severity of the consequence [7], [8].

Some of the major causes of accidents in large coal open pits are: human error, causes due to machinery operation (loading, unloading, truck driving), and inadequately designed haul roads and parts of the open pit [9]. Considering that in mining large quantities of material are mined and transported, which often means utilization of trucks, it is therefore trucks which are linked to the large number of accidents [10]–[13]. Following this, it is necessary to constantly assess the risks to minimize the severity and number of accidents involving trucks as much as possible. The risk assessment in mining does not only include risk assessment inside the exploitation area but also the analysis and impact outside of it. For example, transporting zinc lead ore from the mine to the harbour can constitute a source of pollution impacting human health if either zinc or lead reach the food chain [14].

Some authors use multicriteria decision-making techniques after risk assessment in order to define the best way of minimizing risks, which is the result of selecting the optimum problem solution, i.e., risk minimization method [15]–[17].

The mining industry invests a lot of effort in gathering valuable data if an accident occurs, so the same or similar situation would not occur again. An example of that is the analysis of the mining landslide incident using several methods (Critical Decision Method, Rasmussen's Risk Management Framework, and Accimap method) to gather as much data as possible regarding the landslide. The safety leadership decisions and actions were analysed and safety measures for minimizing the repeated accident were implemented [18], [19]. Nevertheless, despite all efforts in administering security and protection measures, accidents still happen in the mining industry [13], [20], [21].

In order to automate the assessment of haul roads, many methods are used today that find all areas of the open pits that are suitable for transport. The Multi Dilation-LinkNeSt system [22] can be used to assess the Road network of the open pit mine which enables mapping of haul roads, which are the basis of risk assessment.

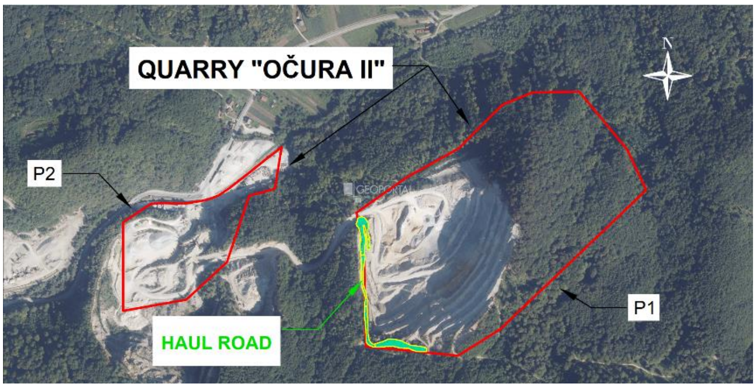
The influence of project parameters on the safety (Table 1) were analysed in the example of the haul road for the quarry "Očura II". All project parameters used must conform to the legal framework to ensure the safety of the designed road, and the safety of the workers (employees) and machinery [1], [23]–[25].

II. Site location

The surface quarry "Očura II" is located in the north-west part of Croatia (Figure 1 - a). It consists of two separate areas (polygon P1 and polygon P2) and has the total area of 29.93 ha (Figure 1 - b).

The haul road, for which the risk assessment and the influence of project parameters on safety were performed, is located at the western area of the quarry "Očura II", next to the edge of the exploitation area (Figure 1 - c).

(a)



(b)

(c)

Figure 1: *Site location of "Očura II" quarry and the haul road*

III. Risk assessment methodology

The hazard assessment of the designed haul road was performed using the process of risk assessment, which was created specifically for that purpose, in accordance with the site circumstances, legal regulations [1], [23], [26], technical specifications, and company's internal safety regulations. Three models of the haul road were observed, each with different project parameters (longitudinal and transversal inclination, length and width of the road, rotational radius) stated in Table 1. The impact of project parameters, i.e., the risks that can occur with each of the models were observed through the consequences they can have on people, machinery, and environment.

The analysis process of possible hazards that can appear in any of the three models was conducted in the manner shown in the algorithm (Figure 2). The process itself consists of three basic parts: analysis, evaluation, and control. The definition of project parameters is not considered as part of the analytical process. The analysis represents comparative analysis of the selected project parameters regarding the legal requirements and recognition, i.e., definition of potential hazards and determining their influence on the selected model of the haul road. The evaluation handles the assessment of recognized risks for the selected model of the haul road, and the evaluation of the model is performed as preliminary step for the next part. The control is where the safest model of the haul road is selected, considering the recognized hazards and administration of safety measures which minimize the hazards to acceptable level or eliminate them completely. The safest model of the haul road is one that meets regulations and safety measures.

3.1. Project parameters

The following data was used as entry data (project parameters) in order to create the models:

- Model 1 – current haul road situation [27],
- Model 2 – mining design documentation [28],
- Model 3 – the new, optimized parameters for the creation of the future haul road [29].

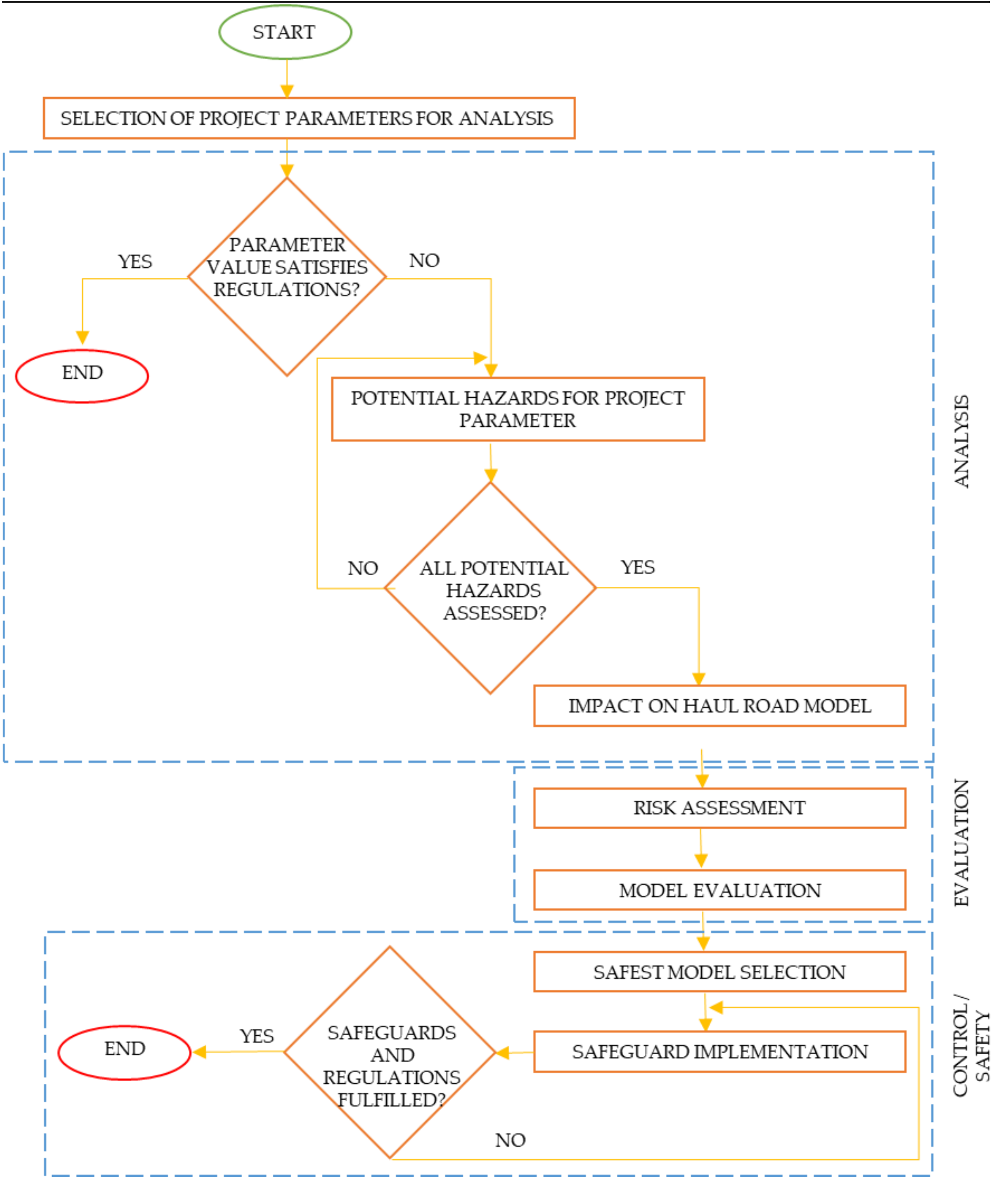


Figure 2: *Risk management process*

Model 1 represents the current state of the haul road in the field and is used in machinery transport and the people passage. The haul road is exposed to the influence of rainfall which pour down the road and erode the filled material that is regularly raised when heavy machinery and people pass.

Model 2 represents the designed haul road which needs to be constructed, and it was designed as part of the mining design intended for the transport of mining machinery and as a connection between areas of the quarry and benches. The haul road model 2 needed to be designed in consideration of the legal regulations which are absent. The decision of the inclination of the haul road was left to the experience of the design engineer.

Model 3 is the suggestion for the new haul road which was designed by taking into account the legal regulations concerning the longitudinal inclination. However, as the exploitation has reached parts of the terrain where the haul road should go, it was necessary to accept certain constraints and accommodate them while determining the project parameters for the haul road.

Based on project parameters shown in Table 1, three models of the haul road were made for the quarry "Očura II".

Table 1: *Project parameters for the quarry "Očura II" haul road*

Project parameters		Model 1	Model 2	Model 3
Longitudinal haul road inclination, % (°)	min	10.0 %	6.2 % (3.5°)	8.0 % (4.6°)
	max	37.6 %	33.1 % (18.4°)	22.5 % (12.7°)
Transversal haul road inclination, %	min	1.0	1.0	1.0
	max	6.0	2.0	2.0
Haul road width, m	min	3.0	6.0	7.0
	max	4.2	8.0	14.0
Haul road bend radius, m	min	7.8	15.0	7.0
	max	14.0	35.0	70.0
Haul road length, m	-	471.3	445.3	479.8

3.2. DETERMINING POTENTIAL HAZARDS AND THEIR INFLUENCE ON MODELS

Each of the analysed project parameters (Table 1) has a smaller or larger degree of influence on people, machinery, and environment. In order to determine the hazards that can occur during machinery and people circulation on the haul road, but also environmental impact arising from it, risk assessment matrix was created (Table 3). Based on the matrix, the probability of a certain risk and its influence is analysed.

The probability of a certain event happening is analysed from 10% (very low) to 90% (very high). The probability of the risk under 10% happening is considered a negligible value, while the probability of a risk over 90% is considered as almost certain appearance of the risk and it must be mitigated immediately. The **event probability** is distributed into five possibilities:

- Very low (10%) – hazard should not occur,
- Low (30%) – little probability of hazard occurring,
- Moderate (50%) – hazard is possible,
- High (70%) – the probability of hazard occurring is high,
- Very high (90%) – the probability of hazard occurring, and repeating, is high.

The considered risk assessment goes from the value of 1 (minor damage) to 5 (catastrophic) depending on the impact of the analysed risk, i.e., the danger it poses. The severity of consequences is also divided into five possibilities:

- Minor damage (1) – the consequences are slight, negligible health damage,
- Damage (2) – no greater consequences, temporary health damage,
- Major damage (3) – no greater consequences but can happen occasionally, significant health damage which can cause permanent diminishment of working capacity,
- Severe loss (4) – serious consequences can occur, severe permanent and/or progressive health damage,
- Catastrophic (5) – extremely severe consequences, very severe health damage with handicap or death.

The risk analysis can be done qualitatively or quantitatively. The quantitative risk analysis gives numerical assessment for the probability of events and their consequences. In qualitative risk analysis, words and/or descriptive scales are used to describe possible hazards and the impact of potential consequences. [5]. For the influence assessment of the project parameters on the safety of quarry "Očura II" quantitative assessment was selected.

The risks are separated into five levels and each level comprises of a certain value range

(Table 2). The risk range is defined considering the recognized hazards and the participants in the risk assessment. Risk levels are split into five categories, and their range is from 0.0 to 4.5. The risk level is additionally colour coded to visually emphasize the risks, from those that have negligible influence (blue colour) to those risks that are critical for the haul road (red colour).

Table 2: *Risk levels*

Risk level	Range		Note / needed actions
Insignificant	0.0	0.5	Risks that do not present immediate hazard but need to be taken into account and can be mitigated relatively simply
Sustainable	0.5	1.5	Risks that need to be followed but can be mitigated or almost eradicated through relatively simple actions
Moderate	1.5	2.5	Risks that must be minimized because there is medium probability of unwanted situations occurring
Severe	2.5	3.5	Risks that must be mitigated as soon as possible, i.e., actions need to be enacted that either mitigate the risks or eliminate them
Critical	0.0	0.5	Risks that can lead to catastrophic consequences and if they are detected, the work needs to stop immediately and actions that minimize the spotted risks must be performed urgently, work must not continue unless the risk cannot be mitigated

The risk assessment was performed on the basis of the risk assessment matrix (Table 3). The risk (cell value) is the resultant of probability of dangerous event occurrence and the impact (severity) of the consequences of that event either in the form of human injury or illness, or damage done to property and environment [8], [30].

Table 3: *Occurrence and impact risk probability matrix*

Probability \ Impact		Minor damage	Damage	Major damage	Severe loss	Catastrophic
		1	2	3	4	5
Very High	90%	0.90	1.80	2.70	3.60	4.50
High	70%	0.70	1.40	2.10	2.80	3.50
Moderate	50%	0.50	1.00	1.50	2.00	2.50
Low	30%	0.30	0.60	0.90	1.20	1.50
Very Low	10%	0.10	0.20	0.30	0.40	0.50

The risk assessment was performed for the three basic risks, out of which a whole plethora of hazards during usage of the haul road arises from, and those are:

- Longitudinal inclination of the haul road,
- The width of the haul road,
- The possibility of further exploitation.

Based on the determined basic risks, specific hazards were defined which are the consequence of those risk, and based on that, the risk assessment for all three models of the haul road was performed.

IV. Results

4.1. Risk analysis and evaluation

The risk assessment based on the project parameters was performed for all three haul road models (Table 4). The hazards which can occur based on three recognized sources of risk occurrences, and as well as their influence on employees, machinery, and environment, were evaluated (13 in total). The risk evaluation of each hazard was obtained as the multiplied probability of the hazard occurring and the hazard's influence on employees, machinery, and environment.

Table 4: Model risk assessment

Risk Description (type of activity)	Hazard	Who/what is at risk?	MODEL 1			MODEL 2			MODEL 3		
			Probability of Occurrence	Impact	Risk Rating	Probability of Occurrence	Impact	Risk Rating	Probability of Occurrence	Impact	Risk Rating
Longitudinal inclination of the haul road	Mechanical damage of machinery	Machinery	0.9	4	3.60	0.7	4	2.80	0.5	4	2,00
	Machinery toppling	Workers Machinery	0.9	5	4.50	0.5	5	2.50	0.3	5	1,50
	Stone jettison from wheels turning	Workers	0.9	2	1.80	0.7	2	1.40	0.5	2	1,00
	Mechanical damage of the haul road	Environment	0.7	3	2.10	0.7	3	2.10	0.7	3	2,10
	Dust emission – inability to moisten the road	Environment	0.9	3	2.70	0.9	3	2.70	0.7	3	2,10
The width of the haul road	Machinery passage	Machinery	0.5	2	1.00	0.5	2	1.00	0.3	2	0,60
	Different types of machinery bypassing – collision	Machinery	0.7	3	2.10	0.5	3	1.50	0.3	3	0,90
	Machinery and people bypassing – collision	Workers	0.5	5	2.50	0.3	5	1.50	0.3	4	1,20
	Road width in alignment with legal regulations	Environment	0.5	4	2.00	0.5	4	2.00	0.3	4	1,20
Possibility of further exploitation development	Unstable haul road	Machinery	0.7	4	2.80	0.5	4	2.00	0.3	4	1,20
	Inability to correctly develop benches	Environment	0.5	3	1.50	0.5	3	1.50	0.5	3	1,50
	Landslides appearing in areas of the haul road	Workers Machinery Environment	0.7	4	2.80	0.5	4	2.00	0.3	4	1,20
	Landslides appearing at wrongly executed benches	Workers Machinery Environment	0.7	5	3.50	0.7	5	3.50	0.5	5	2,50
TOTAL MODEL RISK RATING					32.90			26.50			19.00

After analysing all three models, it is visible that model 1 has two critical hazards (mechanical damage of machinery and machinery toppling) which can lead to very severe consequences. The total risk rating of model 1 was obtained by adding up the individual risk ratings for each hazard, so model 1 has the total of a 32.90 risk rating. The average risk rating for model 1 is 2.53 which classifies it as severe risk model.

Model 2 has the total risk rating of 26.50, i.e., the average risk rating for model 2 is 2.04 and that classifies this model as moderate risk model. Model 2 has three severe risk ratings, while other risks are in the sustainable and moderate risk categories.

Model 3 represents the least risky model considering its total model risk rating is 19.00, i.e., on average it is 1.46 which classifies it as sustainable risk model. Model 3 has risks distributed into sustainable and moderate risk rating categories.

4.2. Distribution risk analysis of models

An additional, tabular distribution risk analysis was performed for all three models which shows in a simple, visual manner how the risks are distributed for each model. The distribution risk analysis table is split into two halves by a transversal line. The upper right half of the table represents the area where risks that can cause severe and/or catastrophic consequences of a model prevail, while in the bottom left half there are risks that will cause minor and/or negligible consequences.

Table 5 shows the distribution risk analysis for model 1.

Table 5: *Distribution risk analysis - model 1*

Probability \ Impact		Minor damage 1	Damage 2	Major damage 3	Severe loss 4	Catastrophic 5
Very High	90%		1	1	1	1
High	70%			2	2	1
Moderate	50%		1	1	1	1
Low	30%					
Very Low	10%					

Model 1 has the total of 4 hazards, with the probability of their occurrence higher than 90% and 5 hazards with probability higher than 70%, with total 3 Catastrophic events that can cause major damage but also the loss of human life. The detected hazards of model 1 are mostly located in the upper right corner of the table which indicates that this model requires additional risk control.

Table 6 shows the distribution risk analysis for model 2.

Table 6: *Distribution risk analysis - model 2*

Probability \ Impact		Minor damage 1	Damage 2	Major damage 3	Severe loss 4	Catastrophic 5
Very High	90%			1		
High	70%		1	1	1	1
Moderate	50%		1	2	3	1
Low	30%					1
Very Low	10%					

The risks of model 2 are distributed over the upper right part of the table but this model does not have any severe loss or catastrophic risks with the probability higher than 90%. The risk distribution gravitates toward the middle of the table which indicates that this model would need additional risk mitigation. Model 2 has a total of four risks which belong to severe loss category with the probability of 70%, and three risks in the catastrophic category, but only one of them has the probability higher than 70%.

Table 7 shows the distribution risk analysis for the model 3.

Table 7: *Distribution risk analysis - model 3*

Probability \ Impact		Minor damage 1	Damage 2	Major damage 3	Severe loss 4	Catastrophic 5
Very High	90%					
High	70%			2		
Moderate	50%		1	1	1	1
Low	30%		1	1	4	1
Very Low	10%					

The risk distribution of model 3 is relatively evenly spread in the middle of the table which indicates a model with less risks from the catastrophic category with the probability of occurrence greater than 90%, and only one risk with the probability of occurrence higher than 70%. Although there are five risks in the severe loss category, their probability of occurrence is moderate to low which indicates that this model could be made safer by applying risk control measures.

4.3. Risk control measures

Model 3 is the model with the least total model risk rating of 19.00 and risk control measures were applied to the model to additionally control the hazards, i.e., to lower the total model risk rating (Table 8). For each of the 13 defined hazards of model 3, risk control was performed and measures to minimize hazards prescribed.

Table 8: *Model 3 risk control measures*

Risk Description (type of activity)	Hazard	Who/what is at risk?	Risk control measures	Residual Probability of Occurrence	Residual Impact	Residual Risk Rating
Longitudinal inclination of the haul road	Mechanical damage of machinery	Machinery	Decrease of longitudinal inclination	0.3	2	0,60
	Machinery toppling	Workers Machinery	Worker education	0.1	4	0,40
	Stone jettison from wheels turning	Workers	Worker education	0.5	1	0,50
	Mechanical damage of the haul road	Environment	Regular maintenance	0.5	2	1,00
	Dust emission – inability to moisten the road	Environment	Compacting and moistening of the haul road	0.3	1	0,30
The width of the haul road	Machinery passage	Machinery	Widening the haul road	0.1	2	0,20
	Different types of machinery bypassing – collision	Machinery	Worker education	0.3	2	0,60
	Machinery and people bypassing – collision	Workers	Enclosed areas for people	0.1	4	0,40
	Road width in alignment with legal regulations	Environment	Rehabilitating parts not in use	0.1	1	0,10

Possibility of further exploitation development	Unstable haul road	Machinery	Design of new mining works	0.3	2	0,60
	Inability to correctly develop benches	Environment	Designing of new haul roads	0.3	1	0,30
	Landslides appearing in areas of the haul road	Workers Machinery Environment	Greening the slopes	0.3	3	0,90
	Landslides appearing at wrongly executed benches	Workers Machinery Environment	Worker education	0.1	2	0,20
TOTAL MODEL RISK RATING						6.10

After applying the risk control measures, the total model risk rating of model 3 is 6.10, considering that the average risk rating is 0.47 which puts this model, i.e., the risk of the model into insignificant category.

A distribution risk analysis was performed for model 3 after risk control measures were applied (Table 9).

Table 9: *Distribution risk analysis - model 3 (after risk control measures)*

Probability \ Impact		Minor damage	Damage	Major damage	Severe loss	Catastrophic
		1	2	3	4	5
Very High	90%					
High	70%					
Moderate	50%	1	1			
Low	30%	2	3	1		
Very Low	10%	1	2		2	

V. Discussion

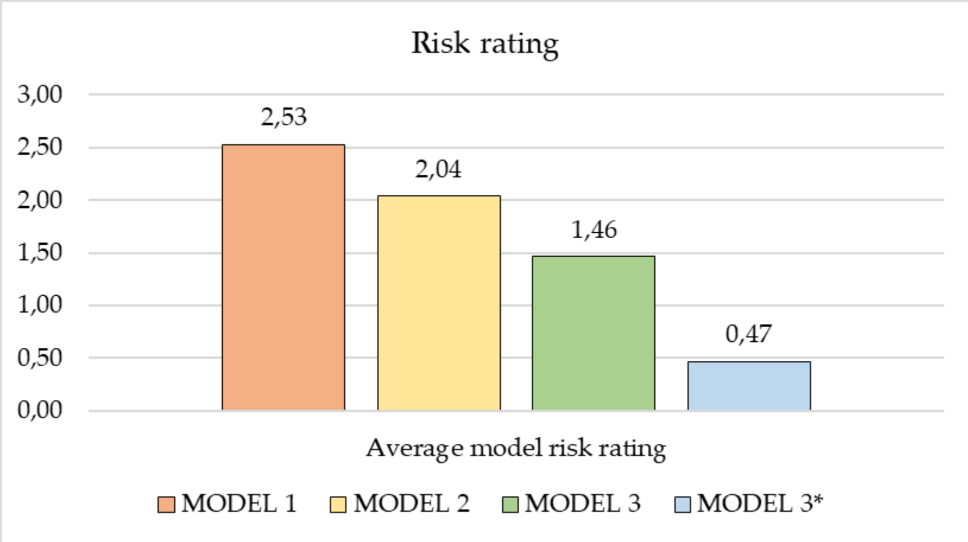
During risk assessment and selection of the safest haul road model, emphasis was given to the influence of project parameters on the safety of employees, machinery, and environment. By evaluating the potential hazards (Table 4) which can occur as the consequence of project parameters, the haul road models for quarry "Očura II" were ranked. The haul road models were ranked based on numerical risk values which were the result of the total sum of risk values of each hazard per each model (total of 13 hazards). The results of the total values of the estimated risk are shown in Table 10.

Table 10: *Haul road model risk rating*

Model	Total model risk rating	Average model risk rating
Model 1	32.90	2.53
Model 2	26.50	2.04
Model 3	26.50	1.46
Model 3*	6.10	0.47

*after risk control measures

The ranking of haul road model is additionally displayed graphically (Figure 3).



*after risk control measures

Figure 3: *Ranking of haul road models*

The model 1 with total model risk rating of 32.90 (average 2.53) represents a very risky model, i.e., represents the actual situation in the field and an urgent implementation of safety measures is necessary to prevent possible severe consequences for people and machinery. A less risky model is the model 2 (moderate category) with total model risk rating of 26.50 (average 2.04). However, implementing model 2 might cause moderate risks which could cause major damage. Model 3 accepts the current situation in the field and its total model risk rating is 19.00 (average 1.46) which classifies this model in the sustainable risk category. Regardless of the sustainable category, risk control measures were performed which in a simple manner minimized the existing hazards and thus minimized the total model risk rating. After the implementation of risk control measures the total model risk rating for model 3 is 6.10 (average 0.47) and that classifies it in the insignificant risks category.

VI. Conclusion

Considering that risk assessment is relatively easy to perform, that it is done specifically for each individual case and that it is most often performed by people with location affiliation, it represents a realistic risk assessment.

For the risk assessment procedure to be complete, it is necessary to carry out certain security measures which will mitigate the risk, and make the consequences acceptable, or will remove the risks completely. The measures that should be implemented to mitigate or eliminate the influence of project parameters are primarily visible in their compliance with official legislative (regulations, directives, laws on the basis of which project design is performed) and professional standards, prescribed measures of work safety and internal investor documents if there are any (for example guidelines for safe work in an open pit, and similar).

Lowering the risk, i.e., increasing the safety for both employees, and machinery and environment, will in this case be performed by creating a new haul road which is foreseen by model 3. The project parameters considered while designing model 3, as one of the options for risk assessment, are in compliance with legislation of the Republic of Croatia, professional standards, and experiential work information from quarry "Očura II".

By implementing Risk control measures on existing models, it is possible to reduce the possibility of risks occurring, i.e., to lower the existing risks to a negligible value. Therefore, for model 3 which is a sustainable risk model, additional risk control measures were performed to minimize the risks which resulted with model 3 being classified in insignificant category. Using distribution risk analysis, it is possible to visually ascertain, in an easy way, whether there are risks that can cause severe consequences or that model risks are, for example, insignificant.

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