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RESEARCH

# Occupational risk assessment based on employees' knowledge and awareness of hazards in mining

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**Abstract**
Analyses and assessments of hazards occurring in work processes are carried out by teams, in which there is usually one representative of the personnel, as the embodiment of the active participation of employees in the assessment of occupational risks. This is why the article presents research on all employees' knowledge and awareness about risks in their work environment. The research was carried out in the form of an employee survey in one of the open-pit mines, at workstations dealing with the loading and transporting of excavated material. The survey included a list of 40 hazards divided into four groups: (1) hazards related to machines and equipment used, (2) hazards related to exposure, (3) hazards with an impact extending beyond the workstation and (4) hazards of an ergonomic nuisance nature, where employees were required to indicate which hazards apply to their workplaces and determine their level of significance, probability of occurrence and the scale of possible effects. In this way, a hierarchical identification of threats occurring at the analyzed workplaces was made, and the obtained results were used to determine the amount of occupational risk both for specific workstations and for the whole technological process. The measures of the magnitude of occupational risk obtained using the proposed method have showed that, according to the respondents, greatest risks at the workstation are associated with moving machines and vehicles and with mobile equipment. Equally important risks, which were often mentioned by employees, were those directly related to their health, i.e., related to ergonomic nuisance and exposure. Threats resulting from geological and mining conditions, considered typical for mining, were important for the surveyed miners but they were not the most important owing to proper prevention, good organization of work and high safety culture The active involvement of the crew in the process of assessing occupational hazards allowed to identify the significance of each hazard, in the opinion of the personnel working at various places and to use this ranking for determining occupational risk levels in the mining company concerned. The research has also outlined another goal to be achieved: a comparison of the relative significance of hazards identified by the employees and of the hazards listed in occupational risk assessment matrices used by mines.

**Keywords** Hazards in mining · Occupational risk assessment · Employee survey · Open-pit mining

## 1 Introduction

Jobs in the mining industry are characterized by features that distinguish them from positions in other industries and, undoubtedly, work is done in difficult, very diverse and specific conditions. The most important of them include:

(1) Variable and sometimes difficult to predict geological conditions of mineral deposits;
(2) Inherent natural hazards;
(3) Many dangerous, harmful and burdensome factors;
(4) Different, usually higher, levels of risks from typical hazards encountered in other work processes (Korzeniowski and Nowak-Senderowska 2015, 2021).

Knowledge about the existence of hazards and their sources and severities is necessary to perform analyses in enterprises for the purpose of assessment of occupational risk, for morbidity and accident rate, for employee training or for work optimization (Niciejewska et al. 2021; Qiu et al. 2021; Shekarian et al. 2021; Klimecka-Tatar and Matevž,

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2020; Niciejewska and Obrecht 2020; Dzeng et al. 2016; Kariuki and Löwe 2007; Gajdowska and Ramiącek 2019; Szopa 2004). Therefore, the analysis of occupational hazards in any work process, and in particular in mining, should provide information on a wide range of diversity in order to take effective and comprehensive actions to reduce occupational risks, and not only be a fulfillment of legal requirements (Council Directive 89/391/EEC of 12 June 1989; Swuste 2008; Labor Code of 26 June 1974). In practice, ready-made reference risk sheets are used, which are usually compiled by uncomplicated and "instant" methods, do not require too much of data input (Kokangül et al. 2017; Ozdemir et al. 2017) and are not "customized" for job-specific occupational risk assessments (Nowak et al. 2020).

It should be noted that it is rare for occupational risk assessment to take into account the subjective perception of hazards by individual employees (Nowak et al. 2020; Yule et al. 2007). Therefore, the authors have developed a method for assessing hazards based on specific environmental knowledge and hazard awareness of employees in order to obtain an additional source of information about the hazard in the working environment of miners and to enable a more effective use of risk analysis results in occupational safety management (Karczewski 2020). This method, based on certain elements of the method described in PN-N-18002 and on the Risk Score, provides results which reflect the level of knowledge about, and awareness of, hazards faced by employees and which are easier to understand for employees themselves and useful for managerial staff.

The knowledge and awareness of employees about occupational hazards in their work environments can also be used to identify hazards and this information base makes it possible to measure the significance of hazards, as perceived by people working at various places, by assigning hazards into two groups: global hazards (affecting the entire technological process in question) and local hazards (occurring only within the area of a single workplace). In addition, data and results obtained based on the hazard identification and risk analysis using the employee potential offer benefits in the actual management of occupational safety throughout the mining enterprise (Nowak-Senderowska and Patyk 2021).

## 2 The collection of data and information on the technological process in terms of identifying occupational hazards

The capture of data and information about hazards occurring in the mining plant during the implementation of the technological process began with the author's getting familiar with the existing occupational risk sheets compiled using the Risk Score method and developed by the mine's OHS supervisors. A total of 55 different hazards or hazardous factors occurring at different workplaces were identified. Some of these hazards had to be merged and given new names, which was done in consultation with the Mine Operations Manager and the OHS service. Ultimately, 40 hazards were left, which were divided into 4 groups (Fig. 1).

In addition, the process of identifying hazards to specific jobs in the technological process used inputs from the employee survey. The results of the survey shed more light on what hazards employees are exposed to at specific workplaces and how individual hazards affect the technological process.

## 3 The assumptions of the new method of work-related risk assessment based on employees' knowledge about, and awareness of, hazards

### 3.1 The employee survey and parameters of occupational risk assessment

The employee survey became a basis for determining severities of occupational risks occurring locally, at workplaces, and globally, throughout the technological process. The survey used a dedicated questionnaire (Fig. 2) in which the surveyed employees were supposed to identify each hazard affecting their workplaces and, then, measure the hazard in terms of (1) Importance of hazard; (2) Probability of occurrence; and (3) Size of the possible consequences of hazard.

These parameters underlie the method developed especially for the purpose of risk assessment, which is a combination of some elements taken from the risk assessment method according to PN-N-18002 and from the Risk Score method (Pietras 2012; Trotsky 2013). In the proposed method, the level of each risk is defined as a product of three parameters, the elements of the Risk Score method (Kinney and Wiruth 1976), which are rated on the five-point scale taken from the PN-N-18002 method. The parameters are "importance", "probability" and "size" and the weights range from "5" ("very high") to "1" ("low") (Table 1).

After determining the risk factor which is the product of the three parameters expressed on the five-point scale (Eq. (1)), the risk (risk level) evaluation should be started. There are the following three risk levels, as presented in the risk assessment matrix (Fig. 3).

$$R = I \cdot P \cdot C \quad (1)$$

where, $I$ is the importance of hazard, pts; $P$ is the probability of occurrence of hazard, pts; $C$ is the size of the possible consequences of hazard, pts.

The first level, marked in green, is the "small risk". This means that a given hazard occurring at a particular

| **Group 1 - Hazards related to machines and equipment used (HM)** | **Group 2 - Hazards related to exposure (HF)** |
|---|---|
| HM1. contact with sharp edges or rough surfaces | HF1. mechanical vibration |
| HM2. sudden outflow of liquid or gas under pressure | HF2. noise |
| HM3. confined and enclosed spaces | HF3. hot or cold surfaces |
| HM4. sharp and moving objects | HF4. electrocution |
| HM5. moving machinery and vehicles | HF5. infrared or ultraviolet radiation (e.g., during welding) |
| HM6. moving or falling objects | HF6. stress |
| HM7. impact from mobile equipment | HF7. chemical substances and preparations |
| HM8. fall on a single plane (tripping, slipping) | HF8. vibrations of a general nature |
| HM9. fall from a height (level difference) | HF9. electrostatic discharge |
| HM10. rotating or moving parts of machines and tools | HF10. biological hazard |
| HM11. traffic accident on the premises | HF11. dust (of limestone, clinker or cement), eye irritation from airborne particles |
| HM12. protruding objects | HF12. changing weather conditions (work in the open) |
| | HF13. variable microclimate in operator cabins |
| **Group 3 - Hazards with an impact extending beyond the workstattion (HI)** | **Group 4 - Hazards of an ergonomic nuisance nature (HE)** |
| HI1. sudden inflow of water (flooding) | HE1. aggression from others |
| HI2. uncontrolled detonation of explosives | HE2. monotony and perceptual load |
| HI3. fire or explosion | HE3. load on the musculoskeletal system |
| HI4. movement of rock or earth masses | HE4. (over)load of the organ of vision |
| HI5. falling into crevices, water bodies or hollows of excavations | HE5. mental strain |
| HI6. off-site traffic accident | HE6. lighting (natural, artificial) |
| | HE7. electromagnetic radiation |
| | HE8. working in a forced position |
| | HE9. manual handling |

**Fig. 1** The list of identified hazards occurring during the implementation of the technological process in the open-pit mine

workplace is "acceptable" and there is no need to take any corrective action for this risk. At most, random checks of the risk are recommended. The second level of risk, marked in yellow, is the "medium risk", which means that the tested level of hazard at a given workplace is "tolerable" (conditional acceptance). But it is recommended to constantly monitor the risk to check whether its level does not increase (to make sure that it remains, at worst, at the same level). In addition, it is recommended to implement appropriate corrective measures aimed at eliminating or mitigating the factors causing the risk. The last level of risk, marked in red, is the "high risk" which is "unacceptable". In this case, an immediate action should be taken to reduce the level of this occupational risk at least to the acceptable level (e.g. through appropriate protection measures). Further, the planned work must not be started until the risk level has been reduced at least to the "tolerable" level (PN-N-18002:2011).

### 3.2 The determination of severity of an occupational risk in local and global terms

The occupational risk for a specific workplace was expressed as a mean of the products of the interviewed employees for a given hazard. Accordingly, the risk of a given hazard according to each employee was calculated first and, then, these values were averaged for each workplace separately.

To determine the occupational risk in global terms, the values obtained from the products of each employee were averaged, thus creating the value of occupational risk from a given hazard in the entire technological process.

In order to determine the level of occupational risk occurring at as given workplace and in the entire technological process, all the point values for given hazards should be summed up and then divided by the number of identified hazards (Eq. (2)). This is how the mean occupational risk level, $A_R$, related to the area studied is obtained.

**Survey questionnaire**

The objective of the questionnaire is to answer the question to which hazard the employees are exposed while performing their duties

**Dear employees**

All answers are anonymous and the questionnaire is a part of studies aimed at identification of occupational risks related to specified job positions. The results of the questionnaire will be used to identify the most critical hazards related to mining activities in the entire mining process.

Specify your job position: [Enter your job position]

From the table below, please first mark with an 'X' all the hazards that apply to your workplace and then please state the significance of the hazard, the probability of it occurring and the magnitude of the possible consequences of the hazard.

**Importance of hazard:** 5 - very high, 4 - high, 3 - considerable, 2 - moderate, 1 - low.

**Probability of occurrence hazard**: 5 - very high, 4 - high, 3 - considerable, 2 - moderate, 1 - low.

**Size of the possible consequences of the hazard**: 5 - very high, 4 - high, 3 - considerable, 2 - moderate, 1 - low.

Table. Occurring hazards.

| X | Hazards | Importance of hazard<br>scale from 5 to 1 | Probability of occurrence<br>scale from 5 to 1 | Size of the possible consequences of the hazard<br>scale from 5 to 1 |
|---|---|---|---|---|
| **Hazards related to machines and equipment used (HM)** | | | | |
| | contact with sharp edges or rough surfaces | | | |
| | sudden outflow of liquid or gas under pressure | | | |
| | confined and enclosed spaces | | | |
| | sharp and moving objects | | | |
| | moving machinery and vehicles | | | |
| | moving or falling objects | | | |
| | impact from mobile equipment | | | |
| | fall on a single plane (tripping, slipping) | | | |
| | fall from a height (level difference) | | | |
| | rotating or moving parts of machines and tools | | | |
| | traffic accident on the premises | | | |
| | protruding objects | | | |

**Fig. 2** Fragment of the employee survey questionnaire

**Table 1** The scale for the assessment of weights of the parameters used for the occupational risk assessment for the workplaces and for the technological process

| Parameter\weight | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| Importance Severity of hazard | Very high | High | Considerable | Moderate | Low |
| Probability of occurrence of hazard | Very high | High | Considerable | Moderate | Low |
| Size Severity of possible effects of hazard | Very high | High | Considerable | Moderate | Low |

$$A_R = \frac{\sum R_i}{n_{Ri}} \tag{2}$$

where, $A_R$ is the averaged risk level of the analyzed area, pts; $\Sigma R_i$ is the sum of the point values of the analyzed hazards, pts; $n_{Ri}$ is the number of analyzed hazards, units.

An additional element of the new method is the possibility of empirical determination by how much it is possible to reduce the level of occupational risk occurring in a given workplace, through the use of appropriate corrective and preventive measures (correction factor *xj*). The minimized value of the occupational risk, $M_R$, is calculated by multiplying the previously obtained risk level, $A_R$, for a given hazard in the analyzed area by the correction factor. The value of the correction factor depends on the previously obtained risk level and is equal to 0.75 for moderate-risk hazards and 0.5 for high-risk hazards. The values obtained for all the hazards are added together and then divided by the number of identified hazards (Eq. (3)).

$$M_R = \frac{\sum R_i \cdot x_j}{n_{Ri}} \tag{3}$$

where, $M_R$ is the minimized risk factor in the analyzed area, points; $\Sigma R_i$ is the sum of the point values of the analyzed hazards, points; $n_{Ri}$ is the number of analyzed hazards; $x_j$ is

*I* - Importance of hazard

| P x C | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 |
| 2 | 2 | 4 | 6 | 8 | 10 |
| 3 | 3 | 6 | 9 | 12 | 15 |
| 4 | 4 | 8 | 12 | 16 | 20 |
| 5 | 5 | 10 | 15 | 20 | 25 |
| 6 | 6 | 12 | 18 | 24 | 30 |
| 8 | 8 | 16 | 24 | 32 | 40 |
| 9 | 9 | 18 | 27 | 36 | 45 |
| 10 | 10 | 20 | 30 | 40 | 50 |
| 12 | 12 | 24 | 36 | 48 | 60 |
| 15 | 15 | 30 | 45 | 60 | 75 |
| 16 | 16 | 32 | 48 | 64 | 80 |
| 20 | 20 | 40 | 60 | 80 | 100 |
| 25 | 25 | 50 | 75 | 100 | 125 |

Legend:

1 - 24 points - acceptable risk (small); 25 - 74 points - tolerable risk (medium)

75 - 125 points - unacceptable risk (high)

**Fig.3** Risk assessment matrix according to the proposed method

the risk correction factor depending on the result of the risk estimation:

$$x_j = \begin{cases} 0.75, \; if \;\; 24 < A_R \leq 74 \\ 0.5, \quad if \;\; A_R \leq 74 \end{cases}$$

Based on Eqs. (2) and (3), it can be concluded that the level of the analyzed occupational risk, $P_R$, for a specific area is therefore located between the $M_R$ and $A_R$ values (Eq. (4)).

$$\frac{\sum R_i \cdot x_j}{n_{Ri}} \leq P_R \leq \frac{\sum R_i}{n_{Ri}} \tag{4}$$

The new method of occupational risk assessment allows identification of the most significant hazards and their risk levels at a given workplace (workplace hazards) and in the entire analyzed process (global hazards). For the occupational risk assessment to be reliable, the data must come from at least two employees. For better accuracy, it is advisable that all employees take part in the survey.

## 4 The results of the survey and the occupational risk assessment according to the proposed method

### 4.1 The size of the occupational risk at the level of the analyzed workplaces

The employees completed the survey forms in accordance with the established rules. They completed 13 survey forms. After the completed occupational risk assessment using the results of the employee survey about hazards in their working environment, the hazard associated with HM5 (*moving machinery and vehicles*) was identified as the most risky (Fig. 4). This hazard is unacceptable in the case of the two analyzed positions (mine foremen—100 points, mechanics 81.3 points) and requires immediate corrective actions aimed at reducing the level of risk. For the both positions it is suggested to increase visibility of employees by adding reflectors and red lights to employees' helmets. In addition, the machines can be equipped with additional cameras to facilitate the maneuvering of vehicles. Such measures would reduce the likelihood of the occurrence of this hazard, and the level of risk from high to moderate. Regarding other workplaces, none of the analyzed hazards involves a high level of risk (Figs. 4 and 5).

The mine foremen identified in the questionnaire forms only 16 hazards that occur at their workplace. These were respectively 3 hazards from group 1, 4 hazards from groups 2 and 3, and 5 hazards from group 4 (Figs. 4 and 5). Among the 16 identified hazards, 8 hazards involve an acceptable risk while the remaining 8 a tolerable or unacceptable risks, which means that the risks are acceptable in for 50% of the hazards. These workers paid particular attention to the hazards associated with the machinery: HM5 (*moving machinery and vehicles*) and HM7 (*impact from mobile equipment*); hazards related to exposure (environment): HF2 (*noise*), HF6 (*stress*) and HF11 (*dust*); hazards occurring outside the workplace: HI4 (*movement of rock or earth masses*) and HI6 (*off-site traffic accidents*); as well as hazards of an ergonomic nature: mainly HE5 (*mental strain*). These hazards are characterized by moderate and high risks (Figs. 4 and 5).

Loading machine operators identified a total of 39 hazards but 22 of them (56%) are characterized by acceptable risks. These employees identified the following in the group of hazards involving moderate risk: 6 hazards from group 1 (HM), 4 from group 2 (HF), 2 from group 3 (HI) and 5 from group 4 (HE). This means that, for these employees, the most important are the hazards from the HM and HE groups.

Another group of employees in terms of the number of identified hazards were haul track drivers. These workers identified a total of 40 hazards, of which 20 are characterized by a low level of occupational risk. The moderate-level hazards included 7 hazards from group 1 (HM), 8 from group 2 (HF), 1 from group 3 (HI) and 4 from group 4 (HE) (Figs. 4, 5 and 6). This means that, for these workers, the most significant are the hazards from groups 1 (HM) and 2 (HF).

The last of the surveyed groups of employees were mechanics who identified a total of 40 hazards, but only 16 of them (or 40%) are characterized by risk at the acceptable

| Hazards / Job position | Mine foreman | Loader machine operator | Haul truck driver | Mechanic |
|---|---|---|---|---|
| **Group 1 - Hazards related to machines and equipment used (HM)** | | | | |
| HM1. contact with sharp edges or rough surfaces | 0.0 | 26.0 | 22.6 | 36.3 |
| HM2. sudden outflow of liquid or gas under pressure | 0.0 | 29.7 | 29.2 | 15.0 |
| HM3. confined and enclosed spaces | 0.0 | 20.0 | 8.5 | 21.0 |
| HM4. sharp and moving objects | 0.0 | 19.5 | 20.5 | 27.0 |
| HM5. moving machinery and vehicles | 100.0 | 26.0 | 63.0 | 81.3 |
| HM6. moving or falling objects | 0.0 | 68.0 | 31.2 | 42.0 |
| HM7. impact from mobile equipment | 27.0 | 23.7 | 24.0 | 41.7 |
| HM8. fall on a single plane (tripping, slipping) | 9.5 | 22.5 | 25.6 | 39.3 |
| HM9. fall from a height (level difference) | 0.0 | 36.0 | 32.6 | 45.0 |
| HM10. rotating or moving parts of machines and tools | 0.0 | 36.0 | 29.6 | 51.7 |
| HM11. traffic accident on the premises | 0.0 | 16.3 | 27.2 | 34.0 |
| HM12. protruding objects | 0.0 | 5.0 | 11.0 | 14.3 |
| **Group 2 - Hazards associated with exposure (HF)** | | | | |
| HF1. mechanical vibration | 0.0 | 42.0 | 44.8 | 53.3 |
| HF2. noise | 54.0 | 26.7 | 48.8 | 61.0 |
| HF3. hot or cold surfaces | 0.0 | 20.0 | 24.2 | 36.3 |
| HF4. electrocution | 0.0 | 39.0 | 19.8 | 29.3 |
| HF5. infrared or ultraviolet radiation (e.g., during welding) | 0.0 | 14.0 | 14.2 | 20.7 |
| HF6. stress | 39.0 | 17.7 | 30.4 | 27.3 |
| HF7. chemical substances and preparations | 0.0 | 7.0 | 10.5 | 13.7 |
| HF8. vibrations of a general nature | 0.0 | 21.7 | 41.4 | 40.0 |
| HF9. electrostatic discharge | 0.0 | 12.0 | 10.3 | 13.3 |
| HF10. biological hazard | 0.0 | 1.0 | 9.7 | 14.0 |
| HF11. dust (of limestone, clinker or cement), eye irritation from airborne particles | 36.0 | 32.5 | 44.2 | 36.0 |
| HF12. changing weather conditions (work in the open) | 12.0 | 16.0 | 42.4 | 40.3 |
| HF13. variable microclimate in operator cabins | 0.0 | 6.0 | 31.5 | 17.5 |

**Fig. 4** The results of occupational risk assessment for the analyzed positions—hazards from groups 1 and 2

level. This group, like the mine foremen, pointed out a high and, at the same time, unacceptable risk for the hazard associated with HM5 (*moving machines and vehicles*). In addition, the workers in question identified in each hazard group the largest number of hazards characterized by moderate or high risk (Figs. 4, 5 and 6). Based on the analysis carried out, it can be concluded that this position is the main target area for the introduction of preventive and corrective measures.

## 4.2 The size of the occupational risk at the level of the analyzed technological process

The professional risk analysis of the entire technological process presents an averaged assessment of all risk values for the individual workplaces carrying out loading and transport operations as part of the analyzed process. The analysis shows that in the whole process there are 16 hazards with acceptable risk and 24 hazards characterized by tolerable risk (Fig. 7).

Most of the hazards characterized by a moderate level of risk belong under the HM, HF and HE groups of hazards. In the HI group, such hazards are only those related to HI4 (*movement of rock or earth masses*) and HI6 (*off-site traffic accidents*).

The obtained results of the size of occupational risk at the level of the technological process (global approach) showed the average occupational risk at a level slightly above acceptable: 25.69 points (Fig. 8). According to the developed

| Hazards \ Job position | Mine foreman | Loader machine operator | Haul truck driver | Mechanic |
|---|---|---|---|---|
| **Group 3 - Hazards with an impact extending beyond the workstattion (HI)** | | | | |
| HI1. sudden inflow of water (flooding) | 0.0 | 10.0 | 10.3 | 13.3 |
| HI2. uncontrolled detonation of explosives | 20.5 | 23.3 | 10.8 | 17.3 |
| HI3. fire or explosion | 0.0 | 26.7 | 10.0 | 11.0 |
| HI4. movement of rock or earth masses | 50.0 | 60.0 | 31.4 | 51.7 |
| HI5. falling into crevices, water bodies or hollows of excavations | 7.5 | 13.0 | 2.8 | 3.3 |
| HI6. off-site traffic accident | 25.0 | 11.0 | 23.3 | 35.0 |
| **Group 4 - Hazards of an ergonomic nuisance nature (HE)** | | | | |
| HE1. aggression from others | 1.0 | 12.5 | 7.2 | 9.7 |
| HE2. monotony and perceptual load | 0.0 | 29.3 | 7.0 | 11.0 |
| HE3. load on the musculoskeletal system | 0.0 | 59.3 | 51.8 | 61.3 |
| HE4. (over)load of the organ of vision | 8.0 | 37.5 | 45.4 | 57.7 |
| HE5. mental strain | 27.0 | 18.5 | 24.2 | 43.7 |
| HE6. lighting (natural, artificial) | 7.0 | 28.0 | 22.4 | 39.0 |
| HE7. electromagnetic radiation | 7.5 | 0.0 | 1.0 | 1.0 |
| HE8. working in a forced position | 0.0 | 56.0 | 35.6 | 62.3 |
| HE9. manual handling | 0.0 | 4.0 | 3.3 | 4.5 |

**Fig. 5** The results of occupational risk assessment for the analyzed positions—hazards from groups 3 and 4

method, the average level is tolerable (tolerated risk) but the analyzed hazards should be monitored at all times.

A special job position in the assessment is the one of the mechanic whose averaged risk level is more than 6 points higher than the process risk (Fig. 8).

## 4.3 Reducing the level of the estimated occupational risk

The developed method also allows the use of the so-called correction factor, which is supposed to indicate how much it is possible to reduce the average level of risk, $A_R$, for a specific hazard (Eq. (2)), which allows you to quickly determine the mode of action to reduce the level of occupational risk for a specific position, and thus for the entire process. In the case of the analyzed process (including the loading and transport of spoil), the resulting value of the average level of occupational risk can be corrected by about 17%: from 25.69 to 21.26 points (Figs. 8 and 9). The correction factor applied reduces the level of risk analyzed from the tolerable level to the acceptable level, with some exceptions. These exceptions include the position of the mechanic which remains at the tolerable level even after the application of corrective measures, which is associated with constant monitoring of the hazards occurring at this position.

In the case of the analyzed positions, the risk value may be reduced by 17% up to 27% (in the case of the mine foremen), which involves a number of corrective and preventive measures introduced for individual positions and for entire areas in the technological process.

## 4.4 The summary of the analysis

The analysis is summarized by the graphical depiction (Fig. 10) of the level of risk occurring in the entire analyzed technological process and in its individual components, including robots at given workplaces. This illustration shows:

(1) The averaged occupational risk level ($A_R$) for both the whole process and the jobs analyzed;
(2) The minimized level of risk for the analyzed area ($M_R$) for the entire process and the analyzed workplaces;
(3) The number of hazards with the acceptable level of risk and their percentage in relation to all the hazards identified;
(4) The most significant hazards at a given workplace and throughout the process;
(5) The hazards with the highest level of risk.

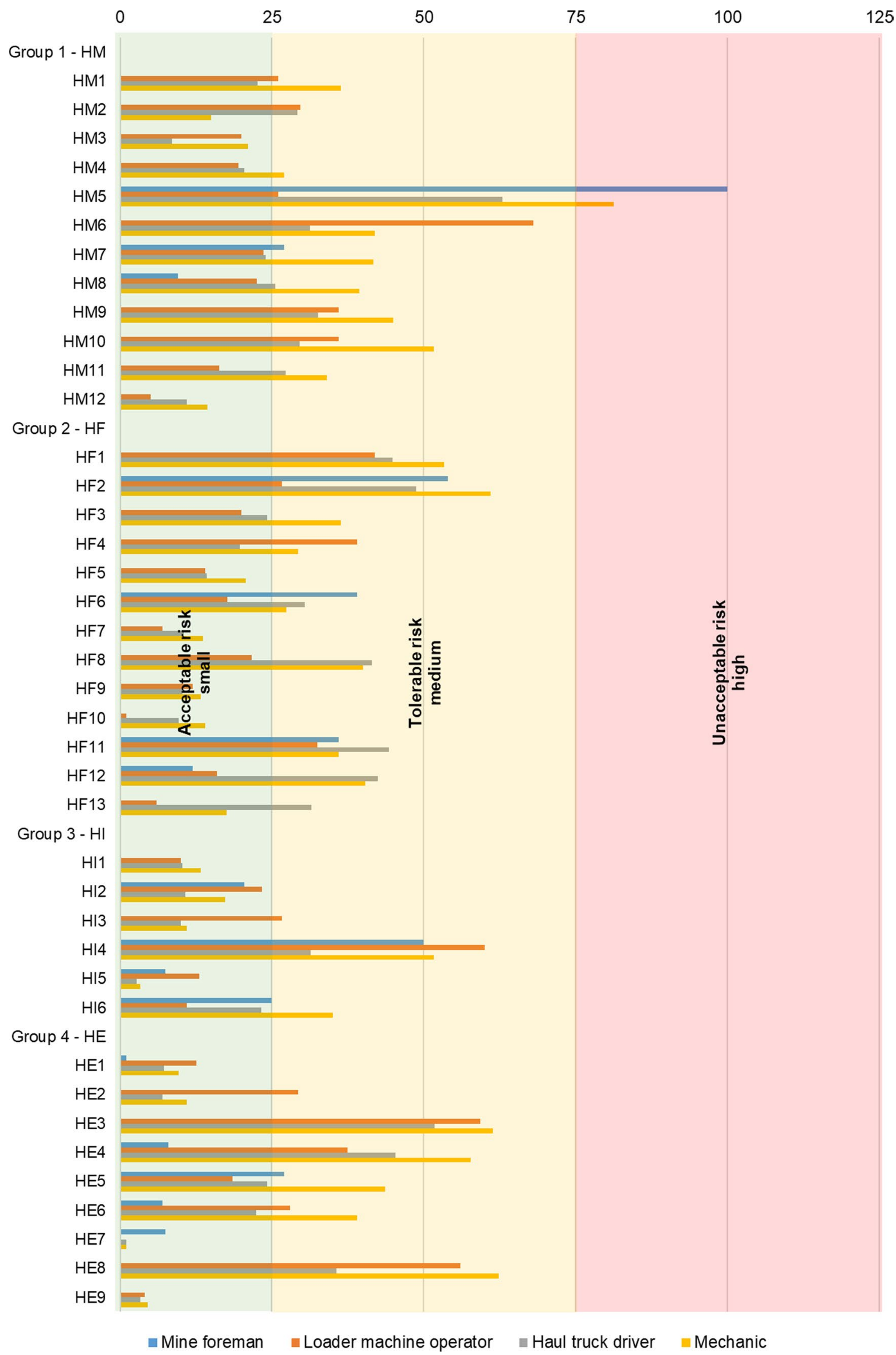


**Fig. 6** Size of the occupational risk at the job positions

| Hazards | Occupational risks in the technological process | Hazards | Occupational risks in the technological process |
|---|---|---|---|
| Group HM | | Group HF | |
| HM1 | 27.4 | HF1 | 46.4 |
| HM2 | 25.5 | HF2 | 47.3 |
| HM3 | 15.2 | HF3 | 27.0 |
| HM4 | 22.4 | HF4 | 27.2 |
| HM5 | 64.4 | HF5 | 16.1 |
| HM6 | 41.8 | HF6 | 28.1 |
| HM7 | 28.5 | HF7 | 10.8 |
| HM8 | 25.8 | HF8 | 35.6 |
| HM9 | 37.0 | HF9 | 11.6 |
| HM10 | 37.5 | HF10 | 9.7 |
| HM11 | 26.1 | HF11 | 38.8 |
| HM12 | 10.8 | HF12 | 32.4 |
| | | HF13 | 23.9 |
| Group HI | | Group HE | |
| HI1 | 11.2 | HE1 | 7.7 |
| HI2 | 17.2 | HE2 | 14.9 |
| HI3 | 14.8 | HE3 | 56.5 |
| HI4 | 45.5 | HE4 | 43.9 |
| HI5 | 5.6 | HE5 | 28.6 |
| HI6 | 24.5 | HE6 | 24.9 |
| | | HE7 | 2.9 |
| | | HE8 | 48.5 |
| | | HE9 | 3.8 |

**Fig. 7** The results of the occupational risk assessment for the technological process

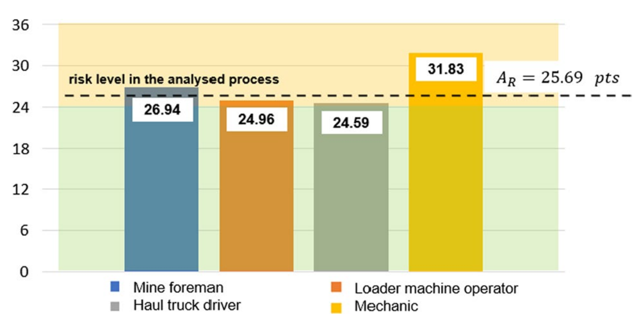


**Fig. 8** The averaged risk level ($A_R$) in terms of position and process

## 5 Conclusions

(1) The occupational risk assessment carried out, based on the results of employee surveys and the adopted assessment methodology, on the example of the analyzed technological process of the open-pit mine, made it possible to take into account in a significant way the attitude to the hazards presented by the employees. Involving employees in the process of occupational risk assessment, which results in both generating up-to-date knowledge and stimulating and raising employee awareness, are essential to the building of the work safety culture in the plant.

(2) The workers who took part in the survey identified HM5 (*moving machinery and vehicles*) as the hazard involving the highest risk. This risk for different stations was estimated as high (the mine foreman and the mechanic) or moderate (the loader / machine operator and the haul truck driver). Another hazard is HE3 (*load on the musculoskeletal system*), especially in the case of the mechanic, loader / machine operator and the haul truck driver).

(3) A very interesting observation is that workers identified more often the hazards accompanying them in continuous work, i.e. the hazards found in the groups concerning ergonomic nuisance (HE) and risks related to exposure (HF).

(4) On the basis of the study, hazards with a global impact, i.e. at all workplaces, are hazards such as HF2 (*noise*), HF6 (*stress*) and HF11 (*dust*). The study has also identified hazards characterized by local impact (lack of transfer between sites), i.e. hazards occurring only at given workplaces. 10 hazards of this type have been distinguished.

(5) The developed methodology and the occupational risk assessment carried out according to it for the entire technological process has shown that the analyzed process is characterized by the tolerable (moderate) risk level: 25.69 points, slightly exceeding the level for the acceptable risk (24 points). The global approach to risk allowed us to identify the workplace (area) that is the weakest link in this technological process. This is the position of the mechanic whose averaged risk value was 6 points higher than the averaged occupational risk for the process. The current level of risk is not a problem in the normal work of employees in this position, although hazards that are characterized by moderate (tolerable) risk must be constantly monitored. In the case of other positions, the level of averaged risk indicated the tolerable risk, but after applying appropriate corrective

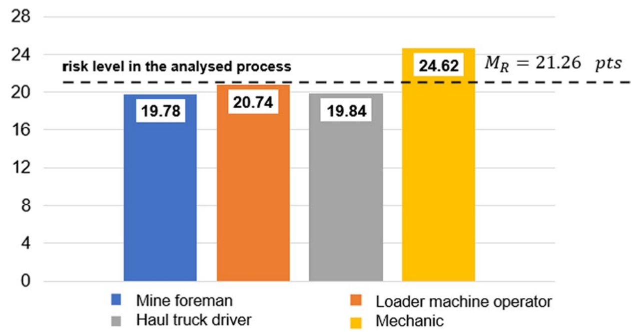


**Fig. 9** The minimized level of risk ($M_R$) in terms of position and process

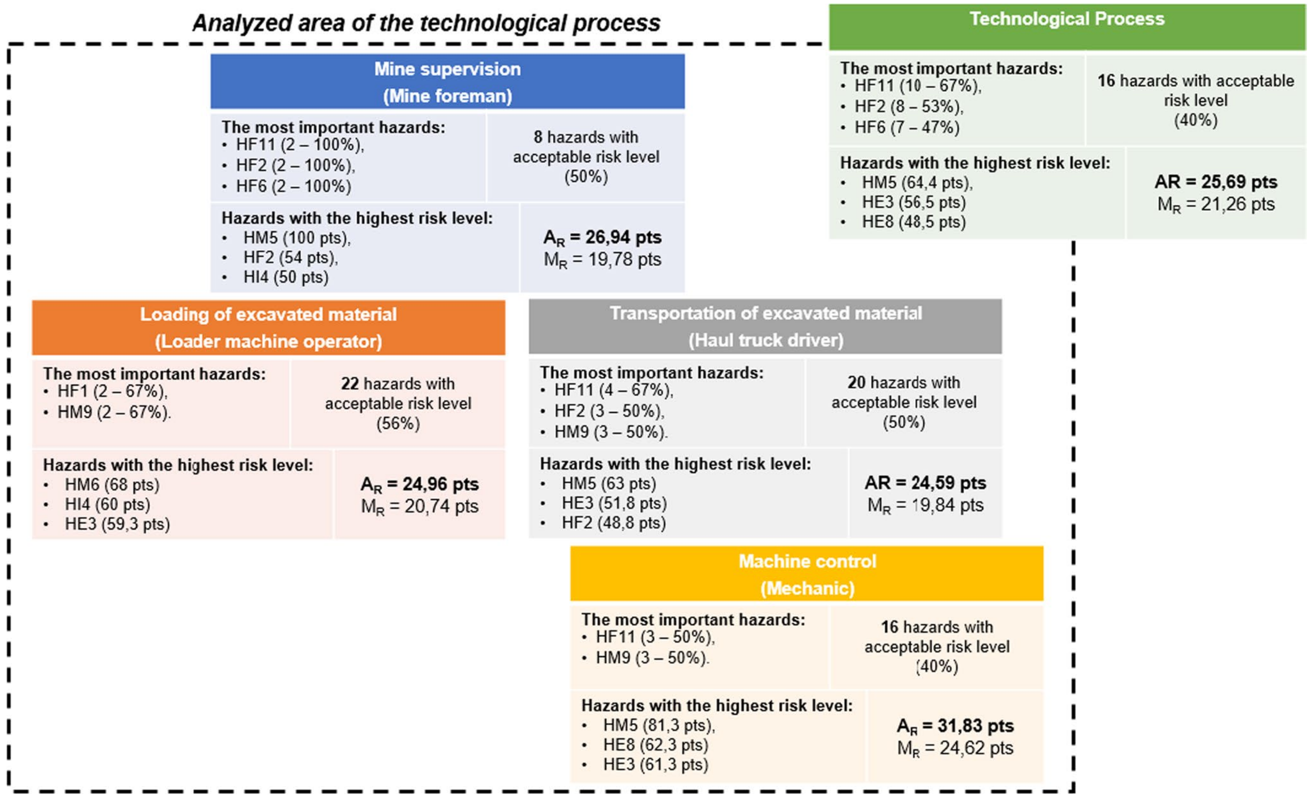


**Fig. 10** The size of the occupational risk at the level of the analyzed job positions and the technological process—summary of the analysis

measures it is possible to reduce this level to acceptable.

(6) Unfortunately, the survey did not cover employees involved in blasting works and working at the crushing plant. On the other hand, completed questionnaires were received from employees involved in the control of the condition of machines: mechanics and employees supervising the work of people (the mine foremen). These two additional groups of employees enriched the analysis by taking a broader look at the implementation of the technological sequence, which is limestone mining.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.



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