**Determining Best Controls On Occupational Risks Using The Best-Worst Method In An Indonesian Furniture Company**

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**Abstract**. Work safety is an essential aspect that must be seriously paid attention to. However, this issue is often ignored in Indonesia due to many factors, especially its implementation in small and medium scale industries. Accordingly, a more structured and applicable risk assessment is strongly necessary. This study aims to introduce occupational risk assessment integrating the traditional approach and multi-criteria decision-making (MCDM) technique. A case study in the medium-sized furniture manufacturer situated in Yogyakarta, Indonesia, is selected involving three decision-makers (DMs), who are: senior staff, head of the production section, and certified occupational health and safety (OHS) expert. The traditional risk assessment method is proposed to identify and analyze the risks, whilst the best-worst method (BWM) is developed to determine the best control strategies. The result indicates that there are five critical risks of 12 occupational risks that have been considered. Then, based on the controls’ optimal weights screened using the α-cut value, the control personal protective equipment (*PE*) is the best control to reduce all critical risks followed by administrative controls (AC) and engineering controls (EC). Meanwhile, the AC is effectively recommended to mitigate chemical risks. Meanwhile, the AC is effectively recommended to mitigate chemical risks. Despite the understandable decision-making process, further study is encouraged to consider the hazard risks such as biological and psychosocial risks to lead broader discussion.

**INTRODUCTION**

The occupational hazard risk is still a serious concern that various parties in Indonesia should be addressed. For instance, based on data reported by the Ministry of Manpower of the Republic of Indonesia, during the last two years, there was a significant increase in the number of work accidents from 144.000 cases in 2019 to 177.000 cases [1]. Further, the figure has been predicted to be higher, especially for workers in the informal sector who have not been insured by national health insurance (BPJS Ketenagakerjaan). As reported that in Indonesia, there were at least 397 daily cases, including 25 anatomical or functional disability cases, one permanent disability case, and nine death cases between 2012 and 2014 [2]. Consequently, the increasing number of work accidents has negatively impacted economic productivity and labor welfare.

A case study on occupational risks is carried out in this study. A small and medium-sized company manufacturing furniture in Yogyakarta, Indonesia, is selected since the furniture industry is associated with a dirt area, lack of technology implementation, and hazardous production. Since the manufacturing process in the industry must be highly mechanized, it has caused that the highest occupational accidents affected humans; moreover, this sector is obviously deemed as a labor-intensive operating sector [3]. Besides, the company’s scale factor, which is considered as small-medium size, also contributes to the increasing hazard cases as the implementation of occupational health and safety management has been poorly paid attention to and applied [4]. In this research, the potential occupational hazards in the furniture company are identified and assessed. Subsequently, the recommended controls for each critical risk are selected using the best-worst multi-criteria decision-making method. Thus, the best-worst method (BWM) can determine the best controls for each typical risk based on the optimal weights obtained.

Several studies have carried out the integration of ergonomic risk assessment and MCDM techniques. In general, MCDM techniques have been utilized to prioritize occupational risks ([5]-[6]. Delice and Can [5] introduced a three-phase ergonomic risk assessment demonstrated on manual lifting tasks in the tube manufacturer. The study integrated the Modified Kemeny Median Indicator Ranks Accordance (KEMIRA-M) and a novel two-dimensional best-worst method (BWM) to determine the criteria weights of ergonomic risks into two sets (lifting-related criteria and human-related criteria [5]. Then, phase 2 was to rank workers using three comparative MCDM methods, which are: multi-objective optimization based on simple ratio analysis, multi-objective optimization by ratio analysis (MOORA), and COPRAS, before the study aggregated the three ranks using the technique of precise order preference. Another study was delivered by Marhavilas et al. [7] that identified the potential destructive causes in a sour-crude-oil process industry (SCOPI) affecting three aspects, including economic, health, and environmental. The study took Typical AHP and Fuzzy AHP to prioritize the risks. The use of AHP to assess occupational risks has also been conducted by Ӧzdemir et al. [8], Gul et al. [9], and Mete [10]. Ӧzdemir et al. [8] proposed the Fuzzy AHP to select the occupational accidents onboard criteria, while Gul et al. [9] assessed the risks for health staff in a leading hospital in Turkey using the integrated FAHP to determine the weight of risks and FVIKOR to rank hazard types in each department. Mete [10] conducted a study on occupational risk assessment on concrete coating process in a natural gas pipeline construction project using FMEA-based AHP-MOORA integrating an approach under Pythagorean fuzzy sets. Besides, Bakhtavar and Yousefi [6] calculated the occupational risks on Kerman underground collieries in the southeast of Iran using a multi-goal fuzzy cognitive map (FCM) and multi-criteria decision-making based on sensitivity analysis.

Several researchers have also developed new models of occupational risk assessment using MCDM methods. Mohandes et al. [11] developed a risk assessment model (RAM) with prudent mitigation actions applied in any project. The model was initially exemplified in a medium-sized company in Hong Kong using the Fuzzy Best Worst Method (FBWM) with the Interval-Valued Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (IVFTOPSIS). Subsequently, Khalilzadeh et al. [12] proposed a multi-step risk assessment demonstrated in the oil and gas construction projects (OGCP) in Iran. The multiple steps involved identifying health and safety executive (HSE) risks and determining the risks weights using the fuzzy SWARA method. Then, FMEA and PROMETHEE were used to prioritize the main risk factors before a binary multi-objective linear programming approach was developed to select the risk response strategies. Overall, the occupational risk assessment using MCDM conducted by previous studies has been addressed to prioritize the occupational risks that have been identified using the conventional risk identification method such as HAZOP [7]. Furthermore, several scholars have developed new risk assessment models using two or three MCDM techniques as conducted by Delice and Can [5]. A more complex risk assessment approach using MCDM has also been introduced by Khalilzadeh et al. [12]. The study has prioritized the risks and selected the control strategies using a linear programming approach.

In this study, although the occupational risks are identified and assessed using the traditional HIRARC, the MCDM method is taken to select the best controls as the idea that has been previously done by Khalilzadeh et al. [12]. However, a different approach using BWM is introduced in this study demonstrated in a medium-sized furniture company. The BWM method is selected in this study as producing optimal controls’ weights with the min-max optimization model in a more consistent comparison [13]. The risk control strategies will be formulized based on the five types of hazard risk control hierarchy referring to OHSAS 18001:2007 [14] for each very high risk or so-called critical risk. Therefore, this study contributes to bringing a more structured and simple framework for risk assessment and mitigation, inviting the DMs to determine the effective control strategies using an MCDM approach.

**METHOD**

This study has two phases: phase 1 to identify and assess the occupational risks and phase 2 to select the best controls for critical risks using BWM. In phase 1, occupational risk management is initially conducted by identifying the company hazard risks, particularly in the production section. The result of risk identification is illustrated in the risk breakdown structure categorizing the risks based on the typical activities. Next, the risk score is calculated using equation (1), taking into account two variables-likelihood (L) and consequence (C). The risk assessment principle is derived from AS/NZS 4360:2004 [15].

 (1)

The likelihood scale ranged from 1 (rare) to 5 (almost certain), while the consequence scale is defined between 1 (negligible) and 5 (severe). The obtained risk score will indicate the risk level determined based on the risk level matrix as shown in Table 1 [15]. Finally, the critical risks – a risk with very high level – must be prioritized to be controlled considering the five hierarchical controls of OHSAS 18001:2007, which are: elimination (*EL*), substitution (*SU*), engineering controls (*EC*), administrative controls (*AC*), and personal protective equipment (*PE*) [14].

**TABEL 1**. The matrix of the risk level according to AS/NZS 4360:2004 [15]

|  |  |
| --- | --- |
| **Likelihood** **scale** | **Consequence scale** |
| **1** | **2** | **3** | **4** | **5** |
| **Negligible**  | **Minor** | **Moderate** | **Major** | **Severe** |
| 5 | Almost certain | Medium | High  | High | Very High | Very High |
| 4 | Likely  | Medium | Medium | High | High | Very High |
| 3 | Possible | Low | Medium | High | High | High |
| 2 | Unlikely  | Low | Low | Medium | Medium | High |
| 1 | Rare  | Low | Low | Medium | Medium | High |

In phase 2, BWM is proposed to determine the best control strategies based on the five hierarchical controls. In this phase, the decision-makers (DMs) are invited to determine the best and the worst strategies. Subsequently, the DMs will define pairwise comparisons between strategies for each critical risk to obtain the best-to-others (BO) vector, and the others-to-worst (OW) vector in the form of a Likert scale between 1 and 9 [16] where *aBj* indicates the preference of the best strategy *B* over strategy *j* and *ajW* indicates the preference of the strategy *j* over the worst strategy *W*. To calculate the optimal weight, the last step is solving the formulated min-max optimization models as shown in equation (2) – (9) [16].

 (2)

Subject to:

 (3)

 , for all j (4)

Converted min-max optimization model:

 (5)

Subject to:

 (6)

 (7)

 (8)

 , for all j (9)

Once the weights of strategies in all critical risks are achieved, the best control strategies will be determined using the value of *α*-cut. The value of *α*-cut indicates the threshold value that is able to screen the best controls indicated by the greater weight values compared to the *α*-cut. The *α*-cut is calculated using equation (10) [17].

 (10)

**RESULTS AND DISCUSSION**

**Identifying The Occupational Risks**

Firstly, the occupational risks are identified by involving two DMs, senior staff and head of the production section, and collecting the accident history data on the production floor during the last five years. There are 12 occupational risks categorized into five groups depending on working tasks, which are: containment risks (*C*), assembly risks (*A*), finishing risks (*F*), welding risks (*W*), and packaging risks (*P*) as depicted by the risk breakdown structure in Fig.1.

The figure also describes the two types of risks identified, namely physical hazards and chemical hazards. The physical hazards include physical hazard risks arising from either equipment or material (*C*1, *C*2, and *A*3), slippery or uneven ground (*C*4), manual handling risk (*A*1), the harmful energy source due to electricity (*A*2), and falling finish goods (*P*1). Meanwhile, the chemical hazard risks are wood particle contact with the body or parts of the body (*C*3, *F*1, *W*1) and inhalation of particles or hazardous substances (*F*2 and *W*2). As shown that physical hazard risks dominate the potential risk on the company’s production floor since the working tasks producing furniture products belong to physically demanded. On the other hand, the chemical hazard risks are often found in welding and finishing activities.



**FIGURE 1**. The occupational risk breakdown structure in the company’s production section

**Analyzing The Occupational Risks**

Secondly, the risk score is calculated using equation (1), considering two variables (likelihood and consequence). Table 2 provides the result of the risk score that indicates the risk level and the treatment. As clearly seen in Table 2, the risks varies from low to a very high level. There are two low-level risks such as the harmful energy source caused by electricity (*A*2) and hazardous particle contact with the eyes (*F*1). In other words, although *A*2 has a possible frequency of occurrence regarding likelihood scale, it brings negligible consequence for workers, especially at the assembly section as the electronic equipment have been mostly standardized and mitigated the electrocuted risk that can cause more serious physical injury. Besides, there are two medium risks and three high risks assessed at containment (*C*), assembly (*A*), dan packaging (*P*), and thus, the high risks should be considered seriously since bringing major impacts for workers. However, in this study, the very high risks must be prioritized and treated immediately as the percentage of the very high risks is 41.67% of all analyzed risks. This situation indicates that almost half of the production tasks in the company are very high risks. It can be seen that five critical risks are comprising both physical and chemical hazard risks. These are physical hazards arising from materials (*C*2), hazardous particles contact with the body (*C*3), inhalation of particles (*F*2), sparks contact with the body (*W*1), dan inhalation of welding fumes (*W*2). Almost all chemical hazards have a very high level, while all welding tasks are even classified as critical risks.

**TABLE 2**. The risk score, risk level, and treatment for all occupational hazard risks [18]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Risk ID** | **Likelihood** | **Consequence** | **Risk Score** | **Risk Level** | **Treatment** |
| *C*1 | 3.00 | 5.00 | 15.00 | High | Action plan |
| *C*2\* | 4.00 | 5.00 | 20.00 | Very high | Immediate action |
| *C*3\* | 4.00 | 5.00 | 15.00 | Very high | Immediate action |
| *C*4 | 3.00 | 2.00 | 6.00 | Medium | Specific monitoring |
| *A*1 | 4.00 | 3.00 | 12.00 | High | Action plan |
| *A*2 | 3.00 | 1.00 | 3.00 | Low | Business as usual |
| *A*3 | 3.00 | 3.00 | 9.00 | High | Action plan |
| *F*1 | 2.00 | 2.00 | 4.00 | Low | Business as usual |
| *F*2\* | 5.00 | 4.00 | 20.00 | Very high | Immediate action |
| *W*1\* | 4.00 | 5.00 | 20.00 | Very high | Immediate action |
| *W*2\* | 4.00 | 5.00 | 20.00 | Very high | Immediate action |
| *P*1 | 2.00 | 3.00 | 6.00 | Medium | Specific monitoring |

\*Very high risk (critical risk)

**Determining The Best Controls Using BWM**

The following phase is to determine the best controls using the BWM method. Based on OHSAS 18001:2007, the five control strategies have been recommended to mitigate occupational hazard risks, namely eliminating hazards through design modifications (*EL*), finding alternative hazardous materials as well as reducing energy (*SU*), applying engineering practices to the working environment (*EC*), installing warning systems (*AC*), and personal protective equipment (*PPE*) [14]. In this step, a certified OHS expert is involved to select the best and the worst control strategies for each critical risk and to produce the preferences of the best and the worst towards the other controls. The BO vector and the OW vector for the five critical risks are as follows:

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 ,

 ,

 ,

 ,

Based on the BO and the OW vector, the DM has identified that there are two best controls, namely *PE* for risk *C*2, *C*3, *W*1, and *W*2, and *AC* for risk *F*2, whilst the worst controls for *C*2, *C*3, *F*2, *W*1, and *W*2 are *AC*, *SU*, *SU*, *EC*, and *EC*, respectively. Next, the optimization model for the five critical risks can be developed to obtain the optimal control weights as exemplified in equation (11) – (20) for the risk *C*2.

 (11)

Subject to

 (12)

 (13)

 (14)

 (15)

 (16)

 (17)

 (18)

 (19)

 (20)

By using the same notation, the optimization models for the other four criteria can also be built. The control weights are obtained after the mathematical models have been solved, as shown in Table 3.

**TABLE 3**. The controls’ weights for the five critical risks based on BWM

| **Weight****α-cut = 0.200** | **Risk ID** | **Normalized total weight** |
| --- | --- | --- |
| ***C*2** | ***C*3** | ***F*2** | ***W*1** | ***W*2** |
| Elimination (*EL*) | 0.116 | 0.118 | 0.106 | 0.101 | 0.090 | 0.106 |
| Substitution (*SU*) | 0.145 | 0.072 | 0.057 | 0.122 | 0.108 | 0.101 |
| Engineering Controls (*EC*)  | 0.193 | \*0.237 | 0.106 | 0.077 | 0.058 | 0.134 |
| Administrative Controls (*AC*) | 0.057 | 0.158 | \*0.465 | \*0.203 | \*0.270 | 0.231 |
| PPE (*PE*) | \*0.489 | \*0.416 | \*0.265 | \*0.497 | \*0.474 | 0.428 |

\*the weights are greater than the α-cut indicating best controls

Table 3 also provides the information about the best control strategies screened using the α-cut value. The controls having greater weight than the α-cut are selected since indicating the significance of the action. As clearly reported that the best control strategies for *C*2 is *PE*, *C*3 is *PE* and *EC*, *F*2 is *PE* and *AC*, *W*1 and *W*2 are *PE* and *AC*. Overall, the control *PE* has the highest weight value compared to the others and becomes the best control strategy for all critical risks. On the other hand, this indicates that the company has not considered the importance of PPE as mandatory equipment for workers so that they are at risk of being exposed to physical and chemical risks. Further, the use of PPE is often considered uncomfortable and complicates working tasks [19]. Moreover, the deteriorating use of PPE affected the productivity output [20]. In this case, helmets, wear packs, and masks are recommended to mitigate the risks of *C*2, *C*3, and *F*2 for workers in the containment and finishing sections, and standardized welding goggles and masks to reduce the risks of *W*1 and *W*2. Based on the DM’s justification, the control *PE* is effectively suggested to directly impact, protect employees, improve the safety culture, and become less costly.

In addition, the control *AC* is the second-best strategy to control *F*2, *W*1, and *W*2, which previously are categorized as chemical hazard risks. In this case, the proposed *AC* is the health access for workers that may be provided in-house (in-house first aid service) or occupational safety insurance and health insurance. The insurances should be provided by the company even if it is a medium-sized company as the Indonesian government has also provided various schemes regarding the OHS services. Thirdly, the control *EC* is also considered to respond to *C*3 using a tailor-made tool cover adjusted to the material and equipment to avoid particles contact. Finally, this study can provide a better and more appropriate solution in a more structured and understandable stage. Developed in this case, the furniture manufacturer should not apply all the controls to mitigate the critical risks. The company is only encouraged to pay attention to the most significant risk controls instead. Moreover, the BWM taken in this study makes a more consistent risk control through a quantitative decision-making process.

**CONCLUSION**

This study elaborates the occupational risk assessment decision-making process more structured and better by integrating the traditional risk assessment method and MCDM. The BWM method applied in this study can provide the risk control priority from the best to the worst more consistently. Based on a case study demonstrated, the control *PE* is the best control strategy for all types of critical risks, and *AC* and *EC* are also considered for particular chemical risks. Additionally, the screened controls may also reflect the actual deteriorating working environment.

A further study is strongly encouraged as the case taken in this study only addresses two hazard risks. Meanwhile, other hazard risks such as biological risks and psychosocial risks may lead to different approaches. As the working environment becomes more complex, the discussion will be more intense not only on the context but also on the method’s capacity.

**ACKNOWLEDGMENT**

The authors acknowledge the support from the Department of Industrial Engineering of Universitas Sarjanawiyata Tamansiswa Indonesia to carry out this research.

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