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Identification and Ranking of Production Risks in Home Industries Factory Using FMEA

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ABSTRACT

Today, production in factories is threatened by various risks and hazards that reduce efficiency and impact business performance. Industries, particularly those moving towards longer production lines, such as the household and industrial goods industry, face increased risks due to their network composed of independent and related organizations collaborating in controlling, managing, and improving the flow of materials and information from suppliers to end customers. Properly identifying the existing risks in each industry or project allows specific measures to be considered against their occurrence, ensuring the resilience of the targeted company or organization. The objective of this research is to identify and evaluate factory risks in the household and industrial goods industry in Iran, with a specific focus on a representative household and industrial goods company. The aim is to prioritize and determine critical risks based on predefined criteria, enabling senior managers to be prepared to tackle each of them with the available time and resources. This research consists of three stages: in the first stage, existing risks in the company were identified through literature review, interviews with experienced individuals, and using the Failure Mode and Effects Analysis (FMEA) method. In the second stage, the identified risks were evaluated by collecting relevant data through questionnaires and employing the Failure Mode and Effects Analysis (FMEA) method. In the third stage, the identified risks from the first stage were re-evaluated and ranked using the TOPSIS method. The results were compared with the previous findings, ultimately introducing 13 risks as critical factory risks.

1. INTRODUCTION

In the era of industrial development and technological advancement, factories play a crucial role in the production process and economic cycle of countries [15-36]. Workers, as human resources, are considered valuable assets for utilizing advanced technology [12]. Therefore, preserving and enhancing the physical and mental abilities of workers, as the core productive force of society, is an essential necessity [21-24]. Human resources, as the most crucial factor in production and services, are constantly threatened by various factors, with occupational accidents

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being one of the most significant [21-46-59]. In recent years, risk and its management have become a highly important and vital topic for organizations [45-58].

In today's world, resources are recognized as valuable assets for empowering organizations in various management fields, ultimately creating a competitive advantage. Dangerous and complex working conditions, technological advancements, increased use of diverse machinery, and the presence of various hazardous health factors have increased the risk of incidents in work environments [17]. International labor organization statistics show that, on average, 250 million occupational accidents occur annually worldwide [4-16]. The mortality rate due to occupational accidents is four individuals per one hundred thousand [10]. Moreover, the costs that human societies directly or indirectly bear for incidents amount to approximately 2 to 3 percent of the world's gross domestic product [47]. According to the International Labour Organization, approximately 317 million incidents occur annually, and about 6,300 individuals are exposed to work-related diseases. As a result, the economic cost of these incidents is around 4 percent of the world's gross domestic product [31-18-46].

Process risk assessment identifies hazards in a job and, by calculating their risk levels, provides appropriate control measures. In fact, risk assessment is a three-stage process: identifying all hazards, calculating risks, and proposing control measures to reduce the risk level. Risk analysis through standard methods is very useful, and hazard identification is one of the primary objectives in risk analysis [2-3].

Increasing productivity, economic feasibility, achieving stability, and avoiding various challenges in projects due to different factors such as environmental changes are among the important issues in modern management. Managing these risks is essential, and its importance is undeniable [20-22-26].

Despite all the successes in achieving comprehensive safety systems, humanity has not been able to completely prevent accidents from occurring [31]. On the other hand, rapid human advancements in technology have created an inseparable link between human life and high-risk systems. To control the damages and injuries caused by hazardous factors, a proper understanding of the risks is necessary. After identifying the hazards, a hazard control plan is implemented to eliminate or control the identified hazards. Determining the priorities of hazards is required to initiate the hazard control plan. Calculating their risks is the first step in determining the priorities of hazards. Risk is the probability of an undesirable event occurring, obtained by multiplying the probability of a specific adverse event by its consequence.

Failure Modes and Effects Analysis (FMEA), like all risk analysis methods, has the capability to identify and evaluate potential risks. The most significant achievement of this method is determining the vulnerable elements of the process and critical areas of the system. By considering the quantitative index of each failure, it has a substantial impact on reducing risks and operational and maintenance costs. FMEA's hardware-oriented approach provides the system with the ability to identify potential failure modes early and address them. This not only significantly reduces potential damage but also improves the safety and reliability of the process.

The main reasons for the development of risk analysis methods include the complexity of conditions, difficulty in combining information, the existence of uncertainty, and uncertainty in decision-making [20-22-26]. There are numerous well-known techniques for achieving risk assessment goals, and researchers use one of these methods depending on the type of assessment, goals, and the assessed process.

In recent years, considerable efforts have been made to increase our knowledge and understanding of both consequences and probabilities of undesirable events. Risk assessment involves identifying hazards in a process or job, calculating their risk number, and proposing suitable solutions to control them. In essence, valuable data for decision-making in reducing risk hazards, enhancing the surrounding environment, hazardous facility upgrading, emergency planning, acceptable risk levels, inspection policies, and industrial facility establishments are provided through this process [2-3].

FMEA is a systematic method used in various analyses of system design, such as system safety assessment, planning maintenance activities, defining measures for tolerating failure, detecting and isolating failures, identifying design changes, and corrective actions to reduce the impact of a failure on the system.

The factory under study comprises administrative buildings, security, employee welfare services, production building, warehouse, waste building, equipment warehouses, facilities, social halls, and quality control building. It operates in 2 shifts, with an 8-hour working shift. The technical department has 35 employees, the production line has 45 employees, the loading team has 12 employees, services have 2 employees, drivers have 3 employees, security has 2 employees, and the administrative department has 10 employees. The main product of the factory includes various components of household and industrial goods. The main objective of this research is to identify and rank the production risks in this manufacturing factory.

2. LITERATURE REVIEW AND RESEARCH BACKGROUND

The term "risk" is derived from the Arabic word "rizq" or the Latin word "riscu" (Kedar, 1970: 255). The Arabic word "risk" refers to "whatever God has given you, and you benefit from" with an implicit reference to unexpected and desirable outcomes. In contrast, the Latin root of this word refers to a challenge that creates a sea knot for sailors, implying future events that are unexpected and undesirable. In Greek, the word derived from the Arabic root of "risk," used in the twelfth century, generally related to the chances of future events and did not carry any positive or negative connotations (Marina and Al-Tani, 2005: 9). In the seventeenth century, the term "risk" entered the English language from the Italian word "risicare," meaning "to dare," and in this sense, it included the concept of choice rather than chance and destiny (Branchtein, 1996: 8). Over time, the meaning of this term has evolved from an unexpected and unplanned event to decisions or actions related to undesirable future outcomes and their likelihood. In Chinese, the symbols used to indicate the word "risk" evoke two contrasting concepts: "danger" and "opportunity" (Kaskey and Boudreau, 2014: 81). In other words, risk confronts us with simultaneous conditions of danger and opportunity.

Various concepts, including expected value, probability distribution, uncertainty, and occurrence, have been employed. However, two categories of concepts stand out in most definitions: 1. Probability and expected value, 2. Events, futures, and uncertainty (Avon and Ren, 2010: 2 and 3).

The International Organization for Standardization (ISO) in the Risk Management Standard 31000 defines organizational risk as the "impact of uncertainty on organizational objectives" and emphasizes that the impact of risk can be positive, negative, or deviate from expectations. It also notes that organizational risk is often in the form of potential events and their futures, combining the two (ISO 31000, 2009: 1). The concept of risk has been defined in various ways, including an unexpected event and its future consequences (Kaskeo, 2012: 41); the probability of a negative future (Graham and Weiner, 1995: 25); the chance of an event, its size and intensity, or a combination of both (Marina and Al-Tani, 2005: 9); a mental phenomenon involving facing and uncertainty (Esotlozar et al., 2011: 147). As seen, there is no unanimous agreement on the definition of the concept of risk.

However, the history of organizational readiness for business risks indicates that organizations are minimally prepared to face risks related to human capital (Meyer et al., 2011: 312). Risk means the likelihood of incurring damage (Dorfman, 1997). This definition includes two main aspects of risk: the amount of damage must be possible, and there must be uncertainty about that damage. In most definitions of risk, these two aspects, namely damage and uncertainty, are explicitly mentioned. However, the third aspect, namely choice, is usually implicitly referred to, and it implies how attention should be paid to it. These three conditions are the fundamental foundations of risk and the basis for a deeper examination of it (Marina and Al-Tani, 2005: 2). The source of risk is any factor that affects business performance, and when this effect is both uncertain and significant, it leads to the emergence of risk (Marina and Al-Tani, 2005: 3).
Below are some definitions of risk provided by various sources:

- From a managerial perspective, Eastman and Tejpay (1984) define risk as the high probability of failure (Hojaji, 2008).
- The British Standards Institution (1996) considers risk as a combination of the occurrence and outcomes of a hazardous event (Mousakhani et al., 2011).
- According to PMI, risk, as defined by PMI, is an uncertain condition or event that, if it occurs, will impact the achievement of project objectives (Project Management Institute, 2008).

- The definition by the PMI is not unique to organizational risk management, and several definitions have been presented by different authors. The definition by CoSO was approved in this study as it is applicable to various industries (CoSO, 2006).
- Risk is the probability of the occurrence of damage (loss). In other words, risk is the possibility of tolerating loss and harm (Martin, 2005).
- The AS/NZS-4360 standard defines risk as the chance of an event occurring that will impact objectives (AS/NZS-4360, 2004).
- ISO/IEC Guide 73 defines risk as a combination of the probability of an event and its consequences (IEC, 2009).
- Pritchard (2001) introduces risk as the exposure to the possibility of negative events and the potential consequences of these events. Pritchard identifies three fundamental components for each risk: the event, probability, and impact. He sees the event as a description of the risk that may occur in the future and considers a precise description of the risk necessary. According to him, without a precise definition of the intended event, determining its probability and impact will be much more difficult. After defining the event, the probability of its occurrence is examined, followed by the severity of the impact of the consequences of that event. Statistical and probability theory play a crucial role in this section (Pritchard, 2001).
- Chavas (2004) sees a risky event as an event that cannot be identified and defined with certainty and in advance. This definition clarifies points regarding the initial and primary characteristics of risk. Initially, all activities that are certain are excluded from the scope of risky activities. Also, time is a key component in risk, and undoubtedly, many activities that are ambiguous today and have little information about them become more certain over time (Chavas, 2004).
- The U.S. Department of Defense (2003) defines risk as a certain amount of potential inability to achieve overall organizational objectives within time, budget, and other operational constraints. It consists of two components: (1) the probability of failure to achieve a goal and (2) the consequences of failure to achieve that goal (Mousakhani et al., 2011).

Despite the multitude and dispersion of definitions of risk, two crucial and significant aspects can be extracted: "uncertainty of outcomes" and "possible damages." Therefore, the level of probability of events occurring and the potential impacts of those events are two important and defining factors of risk (Martin, 2005).

Risk has a quantitative distribution, meaning the concept of risk becomes apparent when there is a possibility of statistically evaluating the likelihood of a specific event occurring. On the other hand, uncertainty/uncertainty is applied when it is impossible to determine the probability of a specific event happening. In other words, uncertainty arises when no information about the future is available (Hilson and Marie Webster, 2007). Refert (1994) places risk and uncertainty at the two ends of a spectrum, which are completely contradictory in terms of quantitative or qualitative, mental, or objective aspects. Figure (2-15) schematically illustrates the relationship between uncertainty and risk. As evident from the figure, risk is located at the assessable end of the spectrum. In this area, some statistical data may also exist, which can be utilized to assess the probability and severity of the risk. Uncertainty is positioned at the unassessable end. In this area, no data exists, and decision-making needs to rely on informed opinions (Golozar, 2012).

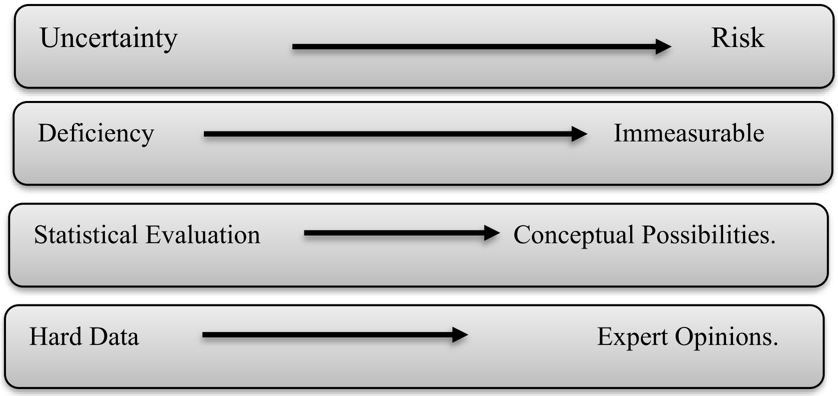

Fig. 1. Spectrum of Risk – Uncertainty (Golzar, 1391)

The space of uncertainty can be expanded or reduced based on the analyst's objective. In the above figure, various layers are represented, each of which is emphasized depending on the analyst's objective and the occurrence or non-occurrence of the phenomenon. In the first stage, before the occurrence of the phenomenon, uncertainty is the focus because there is no information about the phenomenon, its occurrence, and future outcomes. Risk begins with uncertainty and enters the world of risk after the occurrence of the phenomenon. Disturbance (the effect of turmoil) is the result of risk, and after obtaining initial results, it becomes readable. Deviation (failure) is also a consequence of the effects of turmoil (Ivanov & Sokolov, 2009).

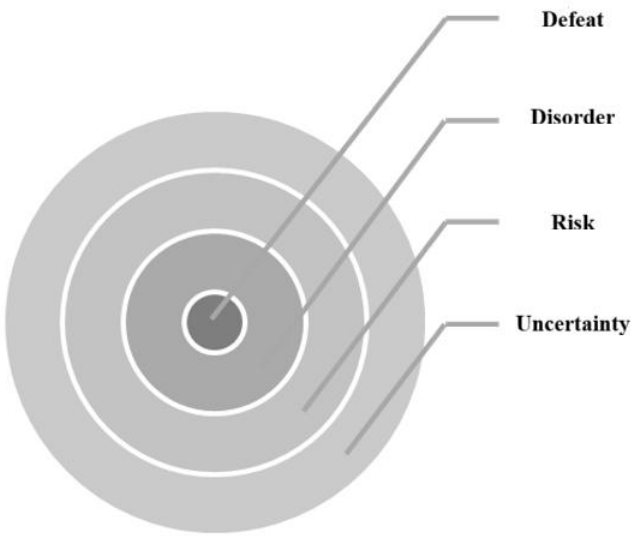

Fig. 2. Expansion of Uncertainty (Ivanov & Sokolov, 2009)

2.1. Classification of risks

In the literature related to risk, various classifications of risk have been presented. Here are a few examples:

- Three general types of risks in creating and managing a system include:
    - Inherent Risk: A potential level of risk existing in the implementation of the intended system, which needs to be addressed to minimize.
    - Residual Risk: A level of risk that persists despite the implementation of control factors and efforts to reduce risk.
    - Acceptable Risk: The remaining level of risk that, although present, does not pose a significant obstacle to achieving the organization's goals and missions (Hadi Jafari et al., 1390).
- Another classification divides risk into low, medium, and high levels (Golazar, 1391).

- Based on the nature of risk, two main types are defined:
  - Real Risk: A risk where the possibility of loss exists, but there is no possibility of gain. Examples include the chance of a car accident, always considered unfavorable.
  - Speculative Risk: In this type of risk, in addition to the chance of loss, there is also the chance of profit. Examples include developing a factory. This type of risk has some attractive aspects as well (Salimi, 1390).
- Cameron and Ramani (2005) classified risks into six categories:
  - Occupational Risks: Such as loss of life or injuries during work.
  - Asset-Related Risks: Natural disasters, depreciation of asset value, decline in stock values, etc.
  - Environmental Risks: Air pollution, water resources, hazardous industrial waste, etc.
  - Commitment Risks: Contractual issues, bankruptcy, failure to provide services or produce desired products, etc.
  - Risks Related to Business Interruption: Equipment breakdowns, equipment cost increases, etc.
  - Project Risks: Project credit issues, exceeding project costs from allocated funds, project delays from scheduling, etc. (Golazar, 1391).
- Risks can also be classified based on sources, including:
  - Time Risk,
  - Qualitative Risk,
  - Scope Risk,
  - Performance Risk,
  - Resource Risk,
  - Stakeholder Status Risk (Khoshghalb, 1390).
- Based on the impact of the occurrence of risk, another classification can be made:
  - Execution-related risks in terms of objectives, quality, and technical matters.
  - Time-related risks.
  - Cost-related risks, which can be closely related to time risk. This type of risk can lead to executive risk.
  - Incremental risk.
  - Catastrophic risks: Risks that individually have significant effects and impact other risks. The chance of these risks occurring is very low, but their importance is very high. Examples include critical waste disposal technologies that require special equipment.
  - Environmental Health and Safety Risks: These risks cause harmful effects on the environment. Serious incidents under this type of risk will have severe effects on time and cost (Khoshghalb, 2011).

The source of risk is any factor that affects the performance of a business, and when this impact is both uncertain and significant, it leads to the emergence of risk (Marna and Eltani, 2005: 14). Each organization has its own specific interpretation of risk that aligns with the market, culture, and mission of that organization. Therefore, organizations provide different classifications of resources with various types of risks, helping to align the risk management process with organizational systems and procedures (Spencer Pickett, 2010: 208).

The most important business risks are categorized as information technology, financial, legal or regulatory risks, accounting and reporting risks, human resources, market dynamics, mergers and acquisitions, governance, supply chain, and physical assets (Ernst and Young, 2008: 10). In 2011, the Canadian Conference Secretariat identified and ranked types of risks affecting businesses in 161 companies of various sizes and industries in North America, Europe, Asia, and Oceania. Human capital risk ranked fourth in terms of impact and tenth in terms of how organizations manage these risks among the 11 identified risks for businesses (Yangyi and Hexter, 2011: 4).

More precisely, we can say that employees in an organization are exposed to two types of risks:

2.2. Human Risk

The risk of employees causing harm to themselves or the organization, which may occur either accidentally (due to lack of necessary competencies) or intentionally (due to deviation from prescribed risk control laws). This type of risk is characterized by human behavior and can be identified and predicted through human resources data.

2.3. Human Resources Risk

Risks arising from the organization's human resources system (i.e., selection, training, performance evaluation, and compensation services). Examples of these risks include the loss of key employees, lack of succession plans, excessive dependence on employees, etc.

3. RESEARCH METHOD

The present study is cross-sectional research conducted in 1397 in one of the home industry-related companies in Kerman city. This company had a workforce population of 410 individuals, and its production included industrial and household components. In the first stage of conducting this study, a team was formed, consisting of the following individuals: production manager, supervisor of workers, occupational health and safety professional, technical specialist, and study executives. The initial task of this team was collaboration to gather necessary information, examine documents, and evidence for selecting suitable and necessary occupations for evaluation. The selection of occupations was based on the history of accidents and the hazardous nature of the job, utilizing techniques such as document review, preliminary examination, direct observation of processes at different times, filming and photography, using checklists, and interviewing workers and unit officials. After a thorough evaluation of occupations, three units were selected for risk assessment.

Following a detailed evaluation of the jobs, three operator jobs in the cutting, forging, and pressing sections were chosen as important and prioritized for risk assessment. In the forging operator job, the operator was engaged in tasks on a four-hundred-ton press machine, responsible for placing the part under the press and removing the prepared piece. The movement of the press machine was controlled by a foot pedal. In the cutting section, a rod was cut using a rotating saw, and the operator's task was to feed the machine. In the pressing section, an operator in a seated position was responsible for feeding the pressing makeup machine. Document reviews indicated various undesirable incidents in these three sections.

After determining the three desired jobs, with the collaboration of the mentioned team and the use of methods such as direct observation, filming, and interviewing machine operators, the breaking down of tasks into sub-tasks was precisely done. In fact, the risk assessment process consisted of four main stages: 1) breaking down the job, 2) identifying hazards in each sub-task, 3) evaluating hazards and determining the risk level, and 4) presenting appropriate control solutions.

To identify hazards, the job safety analysis (JSA) method was used. However, to complete the assessment process and identify hazards more accurately, alongside JSA, the William Fine method was also employed. Using the JSA method, after breaking down tasks into sub-tasks, the hazards related to each sub-task and the potential consequences of each hazard were identified. To determine the risk level, a risk assessment matrix was used. In this matrix, based on the severity of consequences and the likelihood of hazard occurrence, a numerical value was assigned to each identified risk. These numbers ranged from 1 to 24, and based on them, the classification of risk levels was made. Risk levels were categorized into four classes: severe, relatively severe, moderate, and low, based on the numbers in the risk assessment matrix. The execution of this work was done through a questionnaire method and by using the Failure Modes and Effects Analysis (FMEA) model.

Table 1. Risk Assessment Matrix using Job Safety Analysis (JSA) Method

Minor	Border	Critical	Catastrophic	Severity of the consequence	Probability of danger
13	7	3	1	Frequent	
16	9	5	2	Possible	
18	11	6	4	Occasional	
19	14	10	8	Very little	

20	17	15	12	Unlikely	
24	23	22	21	Out of the question	

Table 2. Criteria for decision-making and judgment based on Rex's indicators in the occupational safety analysis method.

Acceptable balance	Risk classification	Risk criterion
Unacceptable	Severe	**5-1**
Undesirable and requires technical, engineering and managerial action	Fairly severe	**9-6**
Acceptable but needs revision Yes	Medium	**15-10**
Acceptable and no need for revision	Down	**24-16**

Rank	Impact severity criterion	Description
10	Dangerous - no warning	Devastating damage and complete destruction
9	Dangerous - with warning	The severity and loss are unfortunate but come with a warning
8	Too much	The severity of the impact and damage is irreparable
7	A lot	The severity of the effects and damage is great
6	Medium	The severity of the effect and damage is low
5	Low	The severity of the effects and damage is very low
4	Very little	The severity of the effect and damage is very low, but most people feel it
3	Minor effects	Leaves a slight impression
2	Very minor	It has a very minor effect
1	None	No effect

Rank	Identification capability	Risk identification criteria
10	Absolutely nothing	There are no controls or, if there are, they are unable to detect potential losses
9	Very small	There is a very small chance that the source of the loss will be detected and revealed with existing controls
8	Insignificant	There is a low probability that the source of the loss will be detected and revealed with existing controls
7	Very little	There is a very low probability that the source of the loss will be detected and revealed with existing controls
6	Low	There is little chance that the source of the loss will be detected and revealed with existing controls
5	Medium	In half of the cases, it is likely that the potential loss will be detected and revealed by existing controls
4	Relatively high	There is a relatively high probability that potential loss will be detected and revealed with existing controls
3	A lot	There is a high probability that potential loss will be detected and revealed with existing controls
2	Too much	There is a very high probability that potential damage will be detected and revealed with existing controls
1	Almost certain	Potential loss will almost certainly be detected and revealed with existing controls

Rank	Probability of occurrence	Probability criterion
10	out of 2 or more 1	Very high – the risk is almost unavoidable. It is inescapable
9	of 3 1	
8	of 8 1	High - Repeated occurrence of risk
7	of 20 1	
6	of 80 1	Medium - Occurrence Risk case
5	of 400 1	
4	of 2000 1	

3	in 15,000 1	Low - relatively rare occurrence of risk
2	in 1,500,000 1	
1	Less than 1 in 15,000,000	Unlikely - the risk is unlikely to occur

4. RESEARCH FINDINGS

The research findings indicate that, based on the identification of hazards in the three examined occupations, a total of 37 hazards were identified. Out of this number, 14 hazards were related to the forging operator, 10 hazards were associated with the cutting operator, and 13 hazards were linked to the press makeup machine operator. The results of risk assessment using the job safety analysis method in each of the three examined occupations are illustrated in the diagram below. This diagram presents the percentage of different risk levels in each of the three studied occupations.

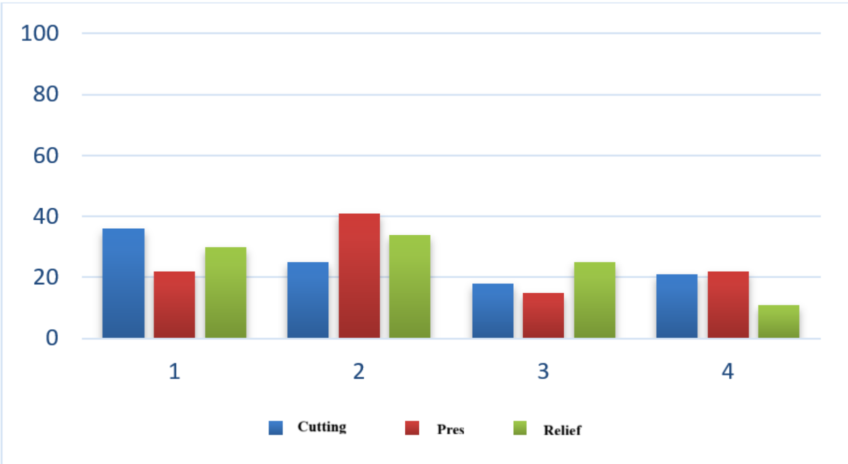

Fig. 1. Results of risk assessment using the Job Safety Analysis (JSA) method in all three examined jobs

The chart below examines the risks present in the factory based on the critical levels and the declared RPN (Risk Priority Number) from the questionnaires.

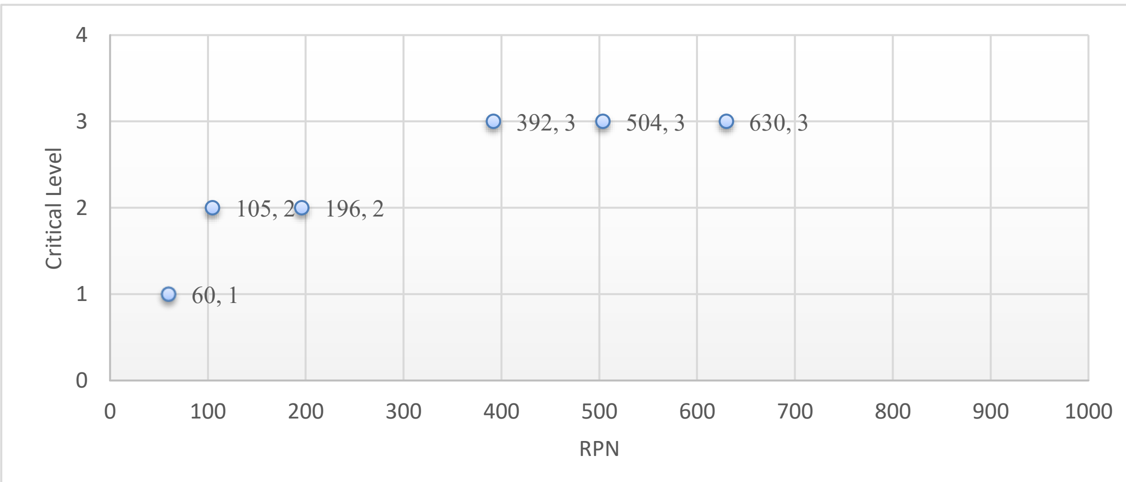

Fig. 2. Examination of existing factory risks based on critical levels and RPN values reported in the questionnaires

5. DISCUSSION AND CONCLUSION

The findings of this study indicate that metal industries may harbor various risk factors, each of which has the potential to contribute to accidents and occupational injuries. Close and continuous attention to the health of workers, especially in heavy occupations, is essential for maintaining a dynamic and healthy industry. The identification of various types of hazards in the present study effectively highlights the existence of diverse risk factors for the health of workers in industrial environments such as metal industries. The high level of risk for many identified hazards in this study is attributed to the high probability of their occurrence. Therefore, in many cases, such as improper body postures during work, the level of risks can be reduced to an acceptable level through simple training and awareness-raising for workers.

Given the cost constraints for industries, solutions for risk control should always seek ways to achieve the maximum reduction in risk levels with the minimum possible cost. Considering the importance of eliminating and controlling occupational hazards, which necessitates a precise assessment of these hazards, the job safety analysis method seems to be a suitable and rigorous option for this purpose.

6. COMPATIBILITY WITH PREVIOUS RESEARCH FINDINGS

Until now, very few studies have been conducted on the assessment of safety and occupational health hazards in metal industries in our country. This limitation is particularly evident regarding job safety analysis methods and William Fine. As mentioned, among various occupations, metal industries are considered one of the most hazardous in the world, with a higher reported rate of occupational accidents than other industries. In many of these industries, machines that introduce a massive force are used for shaping and cutting metals. In the current study industry, the presence of devices such as various presses and rod cutting machines indicates the existence of potential and diverse risks. Based on the results of exploratory and confirmatory factor analysis, the obtained components for each research factor are consistent with the results of other previous studies, including the studies by Sik in 2009 and Wallace et al. in 2004, which were among the articles used in this research.

Regarding the final results obtained, it may not be accurate to compare them with previous research due to the differences in the study population. It should be acknowledged that these results are valid for the target statistical population, and comparing them with past research and generalizing them to other communities requires precision, adjustments, and addressing limitations.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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