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CREATING A SCORE-MODIFIED ISHIKAWA CAUSE-AND-EFFECT DIAGRAM FOR MINING AND PROCESSING ENTERPRISES

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Abstract. This work intended to study and solve the problem of risk analysis at mining and processing enterprises. The mining industry in Ukraine and many other countries is the key sector of the national economies, but it also involves significant hazards and harmful impacts on workers and the environment. Therefore, effective risk analysis is an important step to ensure employee safety and reduce negative environmental impacts. The authors of the article first of all identify the drawbacks of the traditional method of risk analysis based on the creation of Ishikawa cause-and-effect diagrams. These drawbacks include the difficulty of prioritising risks and the lack of visual elements in this method. However, this method is often used in the mining industry due to its common acceptance. The authors propose to use a score-modified version of the Ishikawa diagram as a modern tool for risk analysis at mining and processing enterprises. This modification includes the addition of visual elements that make the analysis more understandable and informative. Besides, the modified diagram includes a risk priority number scale, which allows to prioritise risks both within groups and individual risks. The article also proposes an algorithm for creating modified cause-and-effect diagrams and provides an example of its application in practice. Using this algorithm, the authors study the harmful factors for three working professions at a crushing plant of one of the mining and processing enterprises in Ukraine. The result of the modified cause-and-effect diagram is the visualisation of data on risks and their possible consequences. This allows for management decisions on occupational health and safety aimed at reducing the impact of hazardous and harmful factors on employees and the environment. The use of the modified diagram facilitates the systematisation and analysis of data, making it a valuable tool for risk management at mining and processing enterprises. Overall, this article makes an important contribution to the field of risk analysis in the mining and processing industry and provides a new approach to ensure the safety of workers and the environment at these enterprises. The modified Ishikawa diagram is becoming a powerful tool for risk management and can be used not only in the mining industry, but also in other areas where safety and risk management is important.

Keywords: occupational safety; occupational health; data visualization.

1. Introduction

The issue of maintaining the safety and occupational health of the working population is one of the most important in terms of ensuring the country's stable economic development, so identifying the risks that affect the safety and health of workers is a key task in production.

The first occupational health and safety management systems began to appear after the intensification of production, approximately in the 70s of the last century [1]. However, technological processes are changing, and therefore corresponding changes need to be made to OHSMSs. Having analysed the occupational health and safety management system of one of the Ukraine's mining and processing enterprises, the authors concluded that the risk assessment and mitigation system is somewhat "morally" outdated and does not meet modern standards. After all, according to statistics from the State Labour Service for the scientific and production journal Labour Protection [2] for the reporting period from the beginning of 2022 to 03.01.2023, the number of victims of fatal accidents related to production, by type of activity, is 2.5% for the mining and non-metallic industry.

Another source of information is DSTU IEC/ISO 31010:2013 [3], which contains various approaches to general risk assessment that are recommended for use in inter-

national practice, but one of the drawbacks of this document is that it does not offer ready-made solutions for a specific industry or enterprise.

Therefore, with the help of this standard, specialists at the enterprise can choose a specific method of risk assessment that will best suit the needs of the enterprise. It was this DSTU with the help of which such a method of risk assessment as a cause-and-effect diagram was taken for modification [4].

2. Theoretical and experimental paths

To create the score-modified Ishikawa cause-and-effect diagrams (Fish Skeleton Diagrams) as an element of adaptive analysis of risks affecting occupational safety and health at mining / ore processing enterprises.

3. Results and discussion

Risk assessment involves identifying potential hazards that may arise during work, assessing their severity and determining the risk amount associated with them. Conducting a risk assessment is an effective method of preventing incidents. It takes into account both past adverse events and accidents, as well as potential hazards that have not yet led to negative consequences. Different risk analysis algorithms are used in the world practice, based on the algorithm shown in Figure 1

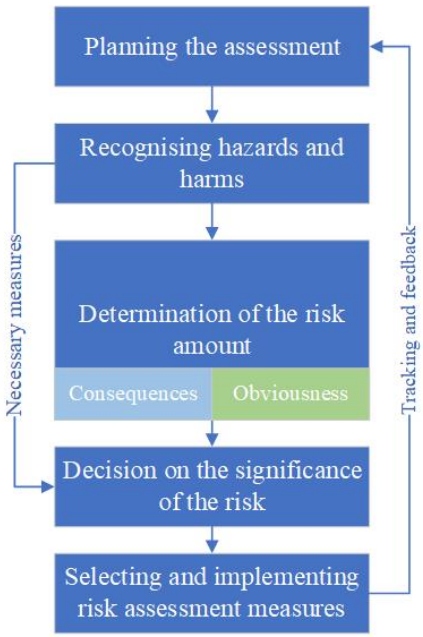

Figure 1 – Basic algorithm for risk assessment and management

Having studied various methods of risk analysis, the authors came to the conclusion that the best method for analysing and visualising available information is the Ishikawa diagram.

A cause-and-effect diagram ("C&ED") is a useful tool for identifying the root causes of a problem or issue. While it can be a useful tool for safety professionals, there are also some potential limitations or drawbacks that should be considered:

– Complexity: The diagrams can become complex and difficult to interpret, especially when multiple factors are involved. This complexity can hinder the identification of the true root cause of a problem and make it difficult to develop effective solutions.

– Limited perspective: If key stakeholders are not involved, or if relevant data is not available, the diagram may not accurately reflect the root causes of the problem.

– Over-reliance: There is a risk of over-reliance on cause-and-effect diagrams, especially if they are used as a stand-alone tool. While diagrams can be useful in identifying potential causes, they should be used in conjunction with other tools and methods to verify and confirm the root causes.

– Lack of standardisation: There is no standard or consistent way of developing diagrams, which can lead to variability in the quality and usefulness of the resulting diagrams. This can make it difficult to compare or evaluate different diagrams, and to ensure consistency in problem solving.

– Time-consuming: Developing the diagrams can be a time-consuming process, especially if a greater detail is required. This can make it difficult to use the tool in fleeting or time-sensitive occupational health conditions.

Overall, while diagrams ("C&ED") can be a useful tool in the field of workplace safety, it is important to be aware of their limitations and to use them in conjunction with other tools and methods to ensure that the root causes of problems are accurately identified and resolved.

Therefore, the authors propose an algorithm [5] for creating score-modified Ishikawa diagrams to eliminate most of the above drawbacks.

The algorithm for creating a score-modified Ishikawa diagram is shown in Figure 2.

According to the algorithm, the following steps were performed:

1. Identifying of workplaces to build cause-and-effect diagrams, namely: mill operator, flotation machine operator and conveyor operator.

2. An expert commission consisting of the authors of the article was created to assess and select the most dangerous jobs in terms of hazards and dangers.

3. Categories (groups) of hazards were established, namely: human factor, work environment, equipment.

4. Hazardous and harmful factors were identified by category, and harmful and dangerous risks affecting the safety of a mill operator were ranked and grouped by calculating the PRN (Priority Risk Number), which is calculated by the formula:

$$PRN=S\times O, \quad (1)$$

where S – risk probability, O – severity of risk.

5. Origination of causes and hazards was determined, organisational and technical measures and means were proposed for preventing or reducing the impact of hazardous production factors on employees:

Human factors:

1. Use (non-use) of personal protection equipment (PPE).

Risks associated with the source of the hazard:

– Risk of injury.
– Risk of occupational diseases.

Recommendations for reducing the impact of the hazard source:

– to control the use of PPE. To conduct safety training.
– to conduct meetings with employees to demonstrate how to use PPE correctly. To provide PPE in the required quantity.

This is the analogy for steps 6–7 of the algorithm for other professions.

6. The visualisation of the score modified cause-and-effect diagram is shown in Figures 3-5 for the professions mentioned in step 1, and Tables 2–4 contain their description.

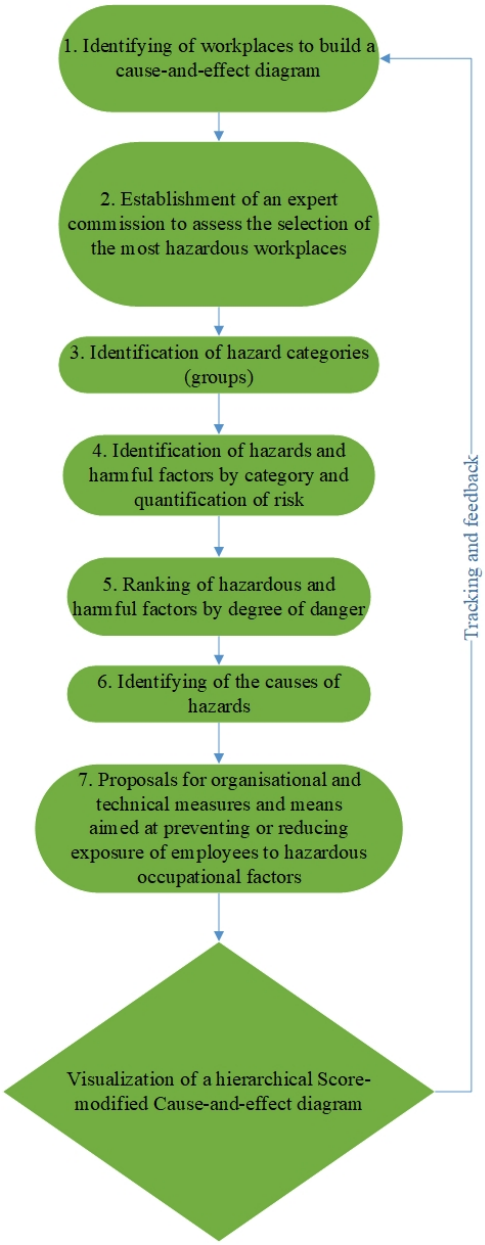

Figure 2 - Algorithm for constructing a score-modified cause-and-effect diagram

The result of steps 1–5 is shown on the example of the profession of a mill operator and is recorded in a special table (Table 1).

Table 1 – Grouping and ranking of factors affecting mill operator safety

№	Group of reasons for the decline in safety	Causes of the decline	S	O	PRN	PRN max	PRN, %
1	Human factor	Emotional and mental overload	10	3	30	100	18,2
		Use (non-use) of PPE	10	10	100		
2	Work environment	Corrosion wear and tear, replacement of decks and stair treads	5	30	150	150	27,3
		…	…	…	…		
		…	…	…	…		
3	Equipment	…	…	…	…	300	54,5
		…	…	…	…		
		Hoisting machines, mechanisms and devices (sling, rope, hook suspension)	10	30	300		
Total			-	-	-	550	100

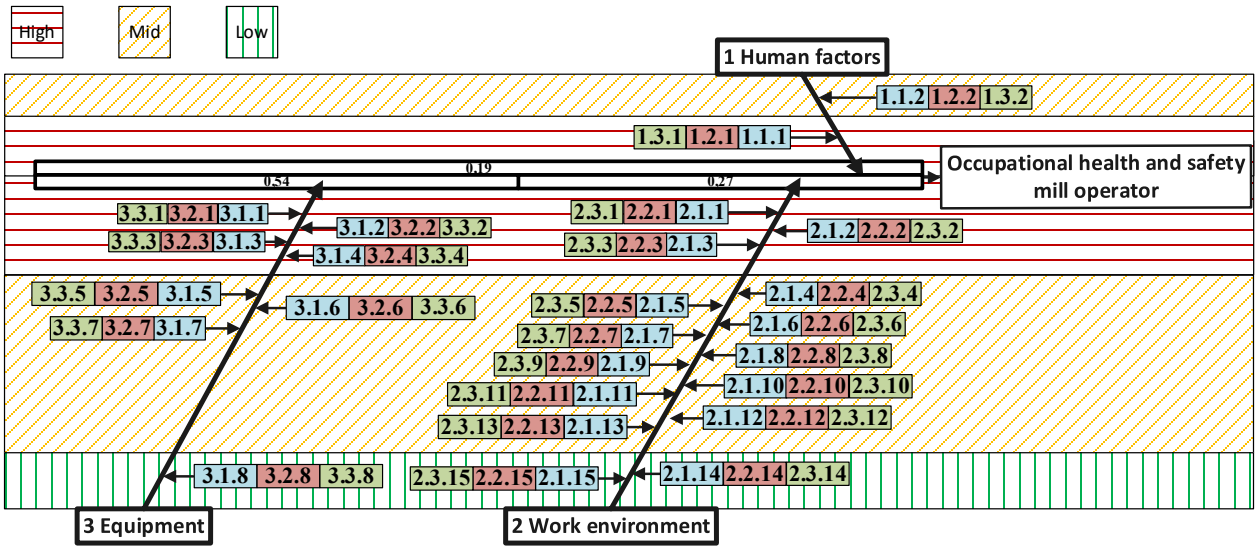

Figure 3 – A score modified cause-and-effect diagram for a mill operator
(1 - problem; 2 - cause; 3 - solution)

Table 2 – Interpretation of the score-modified cause-and-effect diagram for the mill operator

1. Human factors		
High risk		
1 Problem	2 Cause	3 Solution
1.1.1 Use of PPE (not using PPE) (100; High)	1.2.1 Non-use of PPE, non-compliance of PPE with anatomical features of the employee	1.3.1 Conducting of safety training and demonstrations on how to use PPE correctly. Controlling the use of PPE, providing PPE in sufficient quantities.

Continuation of the Table 2

Medium risk		
1.1.2 Emotional and mental overload (30; Middle)	1.2.2 Working at night, which causes a risk of overwork.	1.3.2 Conducting of safety training and professional selection, as well as conversations with employees about the need for rest. Rational organisation of work and rest, preventing employees from showing signs of fatigue and poor well-being.
2. Work environment		
High risk		
1 Problem	2 Cause	3 Solution
2.1.1 Corrosion wear and tear, replacement of decks and staircases (150; High)	2.2.1 Falling from a height. Falling while moving.	2.3.1 Conducting of safety training , diagnostics, and repair of metal structures. Provision of lighting, installation of fences for hazardous areas.
2.1.2 An increased voltage value in the an electrical circuit that can be short-circuited through the human body. (150; High)	2.2.2 Electric shock from direct contact	2.3.2 Conducting of safety training , special training and knowledge testing. Controlling the use of PPE and the serviceable condition of equipment and electrical networks, ensuring that electrical equipment and installations are grounded or zeroed.
2.1.3 Movement on an extension ladder. Location of the workplace at a height relative to the ground (floor, surface). (100; High)	2.2.3 Falling while moving, loss of balance, falling loose material and tools, ladder stability	2.3.3 Conducting of safety training , ensuring control over the performance of work. Ensuring diagnostics and repair of metal structures, as well as timely testing of ladders
Medium risk		
2.1.4 Falling objects from a height (50; Middle)	2.2.4 Ejection of fragments, debris, tool parts. Falling fragments, debris, grinding bodies, linings.	2.3.4 Conducting of safety training. Control over the use of PPE and the safe performance of work.
2.1.5 Insufficient lighting in the work area. (50; Middle)	2.2.5 Insufficient or uneven lighting	2.3.5 Providing lighting for the work area in accordance with the established standards. Providing employees with portable flashlights
2.1.6 Uneven and slippery surfaces (including ice-covered surfaces). (50; Middle)	2.2.6 Slipping, stumbling on uneven and slippery surfaces when moving	2.3.6 Maintaining the routes in good condition, providing sorbent in the required quantity. Fencing of dangerous places.
2.1.7 Increased level of vibration. (30; Middle)	2.2.7 Local vibration when using manual mechanisms	2.3.7 Control over the use of PPE. Conducting discussions with employees on the rational use of work and rest periods.
2.1.8 Moving along staircases. (30; Middle)	2.2.8 Loss of balance on slippery surfaces when moving around the territory, production facilities (including stairs)	2.3.8 Maintaining the routes in good condition, providing sorbent in the required quantity. Fencing of dangerous places, control of movement routes.
2.1.9 Foreign objects. (30; Middle)	2.2.9 The presence of foreign objects, protrusions and other obstacles in the way of movement	2.3.9 Controlling the use of PPE and maintaining routes of travel in good condition. Control over the storage of materials in specially designated areas, as well as the timely removal of garbage.
2.1.10 Increased dust and gas pollution in the working area. (15; Middle)	2.2.10 Inhalation of suspended solids (dust).	2.3.10 Monitoring the use of PPE, conducting of safety training . Conducting demonstrations of the correct use of PPE, providing PPE in the required quantity, conducting medical examinations.

Continuation of the Table 2

2.1.11 Moving on an extension ladder. (15; Middle)	2.2.11 Falling from a height	2.3.11 Conducting of safety training, monitoring the use of PPE. Timely testing of ladders, provision of serviceable ladders.
2.1.12 Location of the workplace relative to the ground (floor, surface). (3; Middle)	2.2.12 Absence of or damage to fences.	2.3.12 Conducting of safety training, performing work only with a work permit. Maintain personal safety, use PPE, do not resist or go beyond the fence.
2.1.13 Work in confined spaces. (3; Middle)	2.2.13 Flooding of enclosed spaces in the work area	2.3.13 Use of PPE. Compliance with general and personal security measures.
Low risk		
2.1.14 Increased temperature of surfaces equipment and materials. (0.3; Low)	2.2.14 Touching hot surfaces of equipment, objects or materials	2.3.14 Controlling the use of PPE, conducting of safety training. Provision of non-contact temperature measurement equipment
2.1.15 Abrasive particles to be impacted. (0.3; Low)	2.2.15 Discharge of fragments, particles of ore spillage and pulp, and paintwork on equipment	2.3.15 Monitoring the use of PPE, conducting demonstrations on how to use PPE correctly
3. Equipment		
High risk		
1 Problem	2 Cause	3 Solution
3.1.1 Lifting machines, mechanisms and devices (sling, rope, hook suspension). (300; High)	3.2.1 Falling of the load, load-lifting solenoid, loading hopper. Falling of the hook suspension. Breakage of the rope/sling. Being in the danger zone (in the zone of release of stored energy) when a sling or rope breaks. Crane malfunction or emergency stop.	3.3.1 Conducting of safety training, monitoring compliance with security measures, conducting professional selection. Control over compliance with slinging schemes and sound alarms, control over timely discarding of slings, ropes, and load-gripping devices. Ensuring that organisational and technical measures are taken in accordance with the applicable rules during the performance of work. Control over the use of PPE.
3.1.2 Sharp edges, burrs and roughness on workpiece surfaces, tools and equipment. (100; High)	3.2.2 Exposure to friction or contact with abrasive, rough surfaces.	3.3.2 Controlling the use of PPE, conducting of safety training, monitoring the safe performance of work
3.1.3 Machinery and moving parts. (100; High)	3.2.3 Sagging of the lining armour. Pinching (of body parts) between the roller conveyor roller and the rod. Ejection of parts and tooling. Ejection of fragments, elements of the destroyed tool, fragments and particles of parts, grinding media.	3.3.3 Control over the use of PPE. Monitoring compliance with safe work practices. Conducting of safety training.
3.1.4 Mechanical impact during when working with impact tools. (100; High)	3.2.4 Debris ejection, tool sealing.	3.3.4 Control over the use of PPE. Control over the safe performance of work. Conducting of safety training
Medium risk		
3.1.5 Working with the instrument. (30; Middle)	3.2.5 The trapping of (body parts) between the roller conveyor and the rod.	3.3.5 Control over the use of PPE. Monitoring compliance with safe work practices. Conducting of safety training. Modernisation of the technological process. Monitoring compliance with slinging schemes and signalling.

Continuation of the Table 2

3.1.6 Sheltering the mill's loading unit. Fall of unstably stacked objects (containers with 3 grinding media or empty containers). (15; Middle)	3.2.6 Entrapment (of body parts) between the lid and the mill body, clogging. Pinching between containers during slinging.	3.3.6 Conducting of safety training. Control over compliance with the security measures specified in the security clearance. Conducting professional selection. Provision of mobile fences. Monitoring compliance with slinging schemes and signalling. Ensuring that organisational and technical measures are taken in accordance with the applicable rules during the performance of work.
3.1.7 Tools, spare parts and accessories. (3; Middle)	3.2.7 Injuries to limbs caused by tools, spare parts, and devices.	3.3.7 Conducting of safety training. Conduct special training and knowledge tests. Control over the timely rejection of tools. Control of the use of PPE.
Low risk		
3.1.8 Conveyor fencing, rollers. (1.5; Low)	3.2.8 Limb compression	3.3.8 Ensuring diagnostics of metal structures and timely repair (replacement). Ensuring control over the safe performance of work. Conducting of safety training.

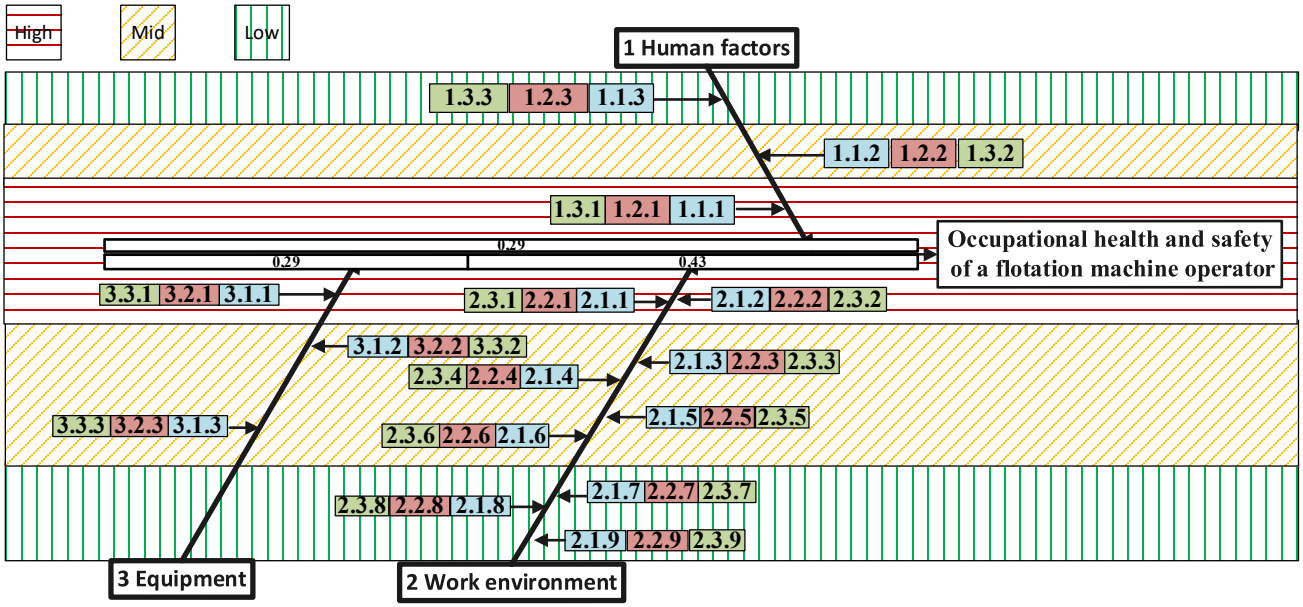

Figure 4 – A score modified cause-and-effect diagram for a flotation machine operator (1 - problem; 2 - cause; 3 - solution)

Table 3 – Interpretation of the score-modified cause-and-effect diagram for a flotation machine operator

1. Human factors		
High risk		
1 Problem	2 Cause	3 Solution
1.1.1 Use of PPE (not using PPE). (100; High)	1.2.1 Non-use of PPE, non-compliance of PPE with anatomical features of the employee	1.3.1 Conducting of safety training and demonstrations on how to use PPE correctly. Controlling the use of PPE, providing PPE in sufficient quantities

Continuation of the Table 3

Medium risk		
1.1.2 Emotional and mental overload. (30; Middle)	1.2.2 Working at night, which causes a risk of overwork.	1.3.2 Conducting of safety trainingand professional selection, as well as conversations with employees about the need for rest. Rational organisation of work and rest, preventing employees from showing signs of fatigue and poor well-being
Low risk		
1.1.3 Static physical overload (1; Low)	1.2.3 Performing work in a forced, uncomfortable position associated with excessive body strain	1.3.3 Conducting of safety training. Conducting discussions on the rational use of work and rest regimes
2. Work environment		
High risk		
1 Problem	2 Cause	3 Solution
2.1.1 An increased voltage in an electrical circuit that can be short-circuited through the human body. (150; High)	2.2.1 Electric shock in case of direct contact.	2.3.1 Controlling the use of PPE and the serviceable condition of equipment and electrical networks, ensuring that electrical equipment and installations are grounded or zeroed. Conducting of safety training, special training and knowledge testing
2.1.2 Corrosion wear and tear, replacement of decks and staircases. (150; High)	2.2.2 Falls from a height Falls while travelling	2.3.2 Provision of lighting, installation of fences for hazardous areas. Ensuring diagnostics and repair of metal structures.
Medium risk		
2.1.3 Insufficient lighting in the work area. (50; Middle)	2.2.3 Insufficient or uneven lighting	2.3.3 Providing employees with portable flashlights. Ensure lighting of the work area and routes of movement in accordance with the established standards.
2.1.4 Toxic substances. (30; Middle)	2.2.4 Contact with toxic substances, breathing toxic substance vapours, ingestion (use) of toxic substances, contact of emissions with skin and eyes	2.3.4 Monitoring the use of PPE, conducting discussions and demonstrations with employees on the correct use of PPE. Control over the presence of labels on containers with chemicals, and the storage of chemicals in specially designated areas.
2.1.5 Foreign objects. (30; Middle)	2.2.5 The presence of foreign objects, protrusions and other obstacles in the path.	2.3.5 Control over the storage of materials in specially designated areas, as well as the timely removal of garbage. Controlling the use of PPE and maintaining routes of travel in good condition
2.1.6 Movement along the staircase. (30; Middle)	2.2.6 Loss of balance on slippery surfaces when moving around the territory, production facilities (including stairs).	2.3.6 Fencing of dangerous places, control of movement routes. Maintaining transport routes in good condition, providing sorbent in the required quantity
Low risk		
2.1.7 Detergents. (1.5; Low)	2.2.7 Contact with cleaning agents	2.3.7 Control over the presence of labels on containers with chemical (detergent) substances, storage of chemicals in specially designated areas. Monitoring the use of PPE, conducting discussions and demonstrations with employees on the correct use of PPE.

Continuation of the Table 3

2.1.8 Abrasive particles to be exposed. (0.3; Low)	2.2.8 Release of fragments, particles of ore spillage and pulp, and paintwork on equipment	2.3.8 Monitoring the use of PPE, conducting discussions with employees, demonstrating how to use PPE correctly
2.1.9 Slippery surfaces. (0.3; Low)	2.2.9 Falls on slippery surfaces	2.3.9 Maintaining the transport routes in good condition. Provision of sorbent in the required quantity.
3. Equipment		
High risk		
1 Problem	2 Cause	3 Solution
3.1.1 Sharp edges, burrs and roughness on the surfaces of workpieces, tools and equipment. (100; High)	3.2.1 Exposure to friction or contact with abrasive, rough surfaces.	3.3.1 Controlling the use of PPE, Conducting of safety training, monitoring the safe performance of work
Medium risk		
3.1.2 Machines and mechanisms, that move. (15; Middle)	3.2.2 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.2 Use of protective fences, remote control, automation, use of automatic shutdowns, as well as work order and similar access systems for repair work. Conducting of safety training, monitoring compliance with routes, correct use of PPE
3.1.3 Moving parts of of production equipment. (15; Middle)	3.2.3 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.3 Conducting of safety training, monitoring compliance with routes, correct use of PPE. Use of protective fences, remote control, automation, use of automatic shutdowns, as well as work order and similar access systems for repair work.

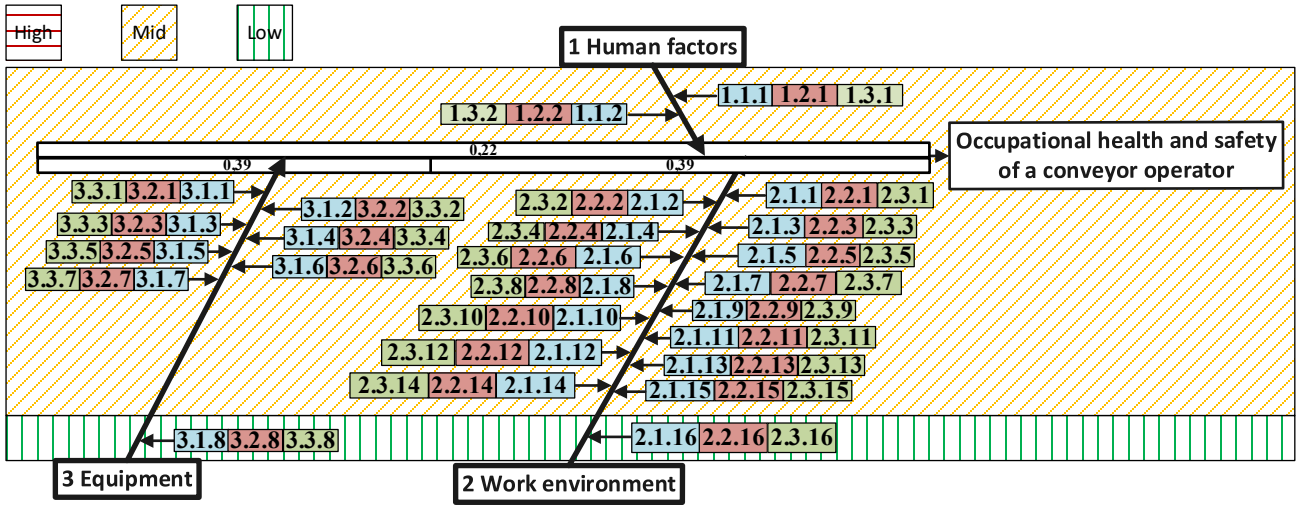

Figure 5 – A score modified cause-and-effect diagram for a conveyor operator
(1 - problem; 2 - cause; 3 - solution)

Table 4 – Interpretation of the score-modified cause-and-effect diagram for a conveyor operator

1. Human factors		
Medium risk		
1 Problem	2 Cause	3 Solution
1.1.1 Emotional, mental overload. (30; Middle)	1.2.1 Working at night, which causes a risk of overwork.	1.3.1 Conducting of safety training and professional selection. Rational organisation of work and rest regimes. Preventing employees with signs of ill health and fatigue, discussions about the need for rest before the night shift.
1.1.2 Use of PPE (not using PPE). (30; Middle)	1.2.2 Failure to use personal protective equipment	1.3.2 Conducting of discussions and safety trainingwith employees on the need to use PPE. Purchase of PPE based on the anatomical characteristics of employees.
2. Work environment		
Medium risk		
1 Problem	2 Cause	3 Solution
2.1.1 Insufficient lighting in the work area. (50; Middle)	2.2.1 Injury due to insufficient or uneven lighting	2.3.1 Conducting specialised training and knowledge tests, controlling routes, conducting medical examinations, providing lighting for work areas
2.1.2 Oil spills. (50; Middle)	2.2.2 Falling on a slippery surface	2.3.2 Conducting medical examinations, controlling movement, providing lighting for the work area, controlling the use of PPE, and the availability of an oil-absorbing sorbent
2.1.3 Uneven and slippery surfaces (including those covered with ice) . (30; Middle)	2.2.3 Slipping, stumbling on uneven and slippery surfaces when moving around the territory, production and administrative premises (including stairs)	2.3.3 Conducting of safety training, installing warning signs and visualising hazards. Maintaining the routes of movement in proper condition, availability of anti-slip material, providing employees with ice shoes.
2.1.4 Location of the workplace at a height relative to the ground (floor, surface). (30; Middle)	2.2.4 Breakage of a safety rope, resulting in a fall of an employee while working from a height	2.3.4 Ensure control over the performance of work, the use of PPE, and the serviceable condition and secure attachment of the safety rope. Conducting special training and knowledge checks, controlling routes of movement.
2.1.5 Working in enclosed spaces. (30; Middle)	2.2.5 Injuries due to compressed conditions	2.3.5 Conducting special training and knowledge checks, controlling routes of movement and use of PPE. Preliminary medical examinations are required, as well as lighting of the work area and the use of serviceable tools. Ensuring the number of employees is at least two.
2.1.6 Overhanging ore in the unloading flows. (30; Middle)	2.2.6 Injury or falling asleep as a result of large pieces of ore falling and sliding off the slopes of the workings	2.3.6 Conducting of safety training monitoring the use of PPE and compliance with movement routes. Use of work order and similar access systems, use of serviceable tools.
2.1.7 Ore from the walls of vibratory feeders. (30; Middle)	2.2.7 Injuries due to falling and dislodging large pieces of ore	2.3.7 Conducting of safety training, monitoring the use of PPE and compliance with movement routes. Use of work order and similar access systems, use of serviceable tools.

Continuation of the Table 4

2.1.8 Macroorganisms (plants and animals). (16; Middle)	2.2.8 Attack or appearance of insects, animals, exposure to pollen, phytoncides and other substances released by plants	2.3.8 Conducting of safety training, controlling routes of movement, use of overalls. Conducting of safety training, controlling routes of movement, use of overalls, first aid training.
2.1.9 Ore from the slopes of the plate feeders. (15; Middle)	2.2.9 Injuries due to falling and dislodging large pieces of ore	2.3.9 Conducting of safety training, monitoring the use of PPE and compliance with movement routes. Use of work order and similar access systems, use of serviceable tools
2.1.10 Passage of movement routes in the vicinity of Process channels, pits, manholes. (15; Middle)	2.2.10 Getting into unclosed process channels, pits, hatches	2.3.10 Conducting of safety training, maintaining transport routes in good condition, preventing theft. Monitoring the availability of fences and hatch covers, as well as ensuring that repair sites are made safe
2.1.11 Overhanging ore on the walls of the of the unloading trolley. (3; Middle)	2.2.11 Injuries due to falling and dislodging large pieces of ore	2.3.11 Conducting of safety training, monitoring the use of PPE and compliance with movement routes. Use of work order and similar access systems, use of serviceable tools
2.1.12 Overhanging ore on the walls of intermediate hoppers. (3; Middle)	2.2.12 Ore fallout from slopes	2.3.12 Use of work order and similar access systems, use of serviceable tools. Conducting of safety training, monitoring the use of PPE and compliance with movement routes
2.1.13 Foreign objects. (3; Middle)	2.2.13 Presence of foreign objects in the way of movement	2.3.13 Conducting of safety training, maintaining routes of movement in good condition. Overseeing the safe condition of work sites, storage of materials in specially designated areas, and timely removal of garbage.
2.1.14 Increased noise levels in the workplace. (3; Middle)	2.2.14 Constant noise of operating equipment	2.3.14 Monitoring the use of PPE, conducting mandatory medical examinations, and introducing regulated additional breaks. Visualising the hazard, eliminating the causes of noise, using soundproofing, and implementing measures to reduce noise levels, grouping premises with high noise levels
2.1.15 Movement on the stairs. (3; Middle)	2.2.15 Loss of balance, falling	2.3.15 The responsible person must maintain the stairs and railings in good condition and respond immediately to any hazards on the stairs.
Low risk		
2.1.16 Air temperature of the working area. (1.5; Low)	2.2.16 Effect of low ambient air temperature	2.3.16 Conducting of safety training, controlling the use of PPE, conducting medical examinations. Training in first aid in case of frostbite, At air temperatures of -15 and below, set additional breaks of 10 minutes for every hour of work.
3. Equipment		
Medium risk		
1 Problem	2 Cause	3 Solution
3.1.1 Tool (scraper, crowbar). (50; Middle)	3.2.1 Impact actions	3.3.1 Conducting of safety training, specialised training and knowledge testing. Monitoring of safe work performance, use of PPE, timely inspection and repair of equipment and tools.

Continuation of the Table 4

3.1.2 Parts of the material to be drilled. (50; Middle)	3.2.2 Parts of the drilling material coming into contact with unprotected areas of the body	3.3.2 Conducting of safety training, special training and knowledge control, monitoring compliance with routes. Control over the safe performance of work, the use of PPE and the use of serviceable tools, and the prevention of unauthorised persons in the work area
3.1.3 Pneumatic tools. (50; Middle)	3.2.3 Injury when working with pneumatic tools	3.3.3 Conducting of safety training, specialised training and knowledge control. Control over the route of movement, ensuring timely diagnostics and repair of equipment, control over the safe performance of work, use of PPE
3.1.4 Machines and mechanisms that move. (15; Middle)	3.2.4 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.4 Conducting of safety training, monitoring compliance with routes, correct use of PPE. Use of protective fences, remote control, automation, use of automatic shutdowns, as well as work order and similar access systems for repair work.
3.1.5 Compressed air. (50; Middle)	3.2.5 Rupture of the air pressure hose	3.3.5 Conducting of safety training, specialised training and knowledge control. Control over the route of movement, ensuring timely diagnostics and repair of equipment, control over the safe performance of work, use of PPE.
3.1.6 Products, workpieces, materials, that are moved and transported. (15; Middle)	3.2.6 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.6 Conducting of safety training, monitoring compliance with routes, correct use of PPE. Use of protective fences, remote control, automation, use of automatic shutdowns, as well as work order and similar access systems for repair work.
3.1.7 Moving parts of production equipment. (15; Middle)	3.2.7 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.7 Conducting of safety training, monitoring compliance with routes, correct use of PPE. Use of protective fences, remote control, automation, use of automatic shutdowns, as well as work order and similar access systems for repair work.
Low risk		
3.1.8 Crushers, belt conveyors. (1.3; Low)	3.2.8 Pulling (hair, clothing, body parts) into moving parts of the mechanism when approaching a dangerous distance	3.3.8 Conducting of safety training, monitoring compliance with routes, correct use of PPE. Use of the work order system and similar access systems during repair work, use of serviceable tools, do not leave the water hose under pressure unattended during hydro-cleaning, do not allow water to get onto electrical equipment and the non-operational area of the conveyor

4. Conclusion

The studies were carried out to assess the impact of dangerous and harmful factors on employees of the main job positions at the mining and processing enterprises. The grouping and ranking of factors affecting the safety of mill operators, conveyor operators and flotation machine operators by calculating the priority risk number proved the need to improve safety management for workers at mining and processing enterprises by taking into account all factors affecting the value of occupational risk. Also, the analysis of the use of cause-and-effect diagrams has shown that this method should not be used as an independent method of analysing risks and hazards. Therefore, the authors recommend using it in combination with other risk analysis methods or as a supplement to workplace risk maps.

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СТВОРЕННЯ БАЛЬНО-МОДИФІКОВАНОЇ ПРИЧИННО-НАСЛІДКОВОЇ ДІАГРАМИ ІСІКАВИ ДЛЯ ГІРНИЧО-ЗБАГАЧУВАЛЬНИХ ПІДПРИЄМСТВ

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Анотація. Дана стаття ставить перед собою завдання вивчення та вирішення проблеми аналізу ризиків на гірничо-збагачувальних підприємствах. Гірнича промисловість в Україні і багатьох інших країнах є ключовою для національної економіки, але вона також включає в себе значні небезпеки та шкідливі впливи на працівників та довкілля. Тому ефективний аналіз ризиків є важливим кроком для забезпечення безпеки працівників та зменшення негативних впливів на навколишнє середовище. Автори статті перш за все виявляють недоліки традиційного методу аналізу ризиків, який базується на створенні причинно-наслідкових діаграм Ісікави. Серед цих недоліків можна відзначити складність визначення пріоритетності ризиків та відсутність візуальних елементів у цьому методі. Однак цей метод часто використовується на підприємствах гірничої промисловості через його загальноприйнятість. Автори пропонують використовувати бально-модифіковану версію діаграми Ісікави як сучасний ін-

струмент для аналізу ризиків на гірничо-збагачувальних підприємствах. Ця модифікація включає в себе додавання візуальних елементів, які роблять аналіз більш зрозумілим та інформативним. Окрім того, до модифікованої діаграми додається шкала пріоритетного числа ризику, яка дозволяє визначити пріоритетність ризиків як в межах груп, так і окремих ризиків. Стаття також пропонує алгоритм для створення модифікованих причинно-наслідкових діаграм та надає приклад його застосування на практиці. За допомогою цього алгоритму автори вивчають шкідливі чинники для трьох робітничих професій на дробильній фабриці одного з гірничо-збагачувальних підприємств України. Результатом застосування модифікованої причинно-наслідкової діаграми є візуалізація даних щодо ризиків та їхніх можливих наслідків. Це дозволяє приймати управлінські рішення щодо безпеки та гігієни праці, спрямовані на зменшення впливу небезпечних і шкідливих факторів на працівників та довкілля. Використання модифікованої діаграми сприяє систематизації та аналізу даних, що робить її цінним інструментом для управління ризиками на гірничо-збагачувальних підприємствах. Загалом, дана стаття вносить важливий внесок в область аналізу ризиків у гірничо-збагачувальній промисловості та надає новий підхід для забезпечення безпеки працівників та довкілля на цих підприємствах. Модифікована діаграма Ісікави стає потужним інструментом для управління ризиками та може знайти застосування не лише в гірничій галузі, але й в інших сферах, де важлива безпека та управління ризиками.

Ключові слова: безпека праці; гігієна праці; візуалізація даних.