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ANALYSIS OF MECHANICAL RISKS IN THE USE OF MACHINERY AND EQUIPMENT AS A FACTOR IN OCCUPATIONAL INJURIES AND ACCIDENTS AND THEIR PREVENTION

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Abstract: On a global scale, we witness daily occurrences of workers being injured in the workplace. These injuries and accidents are most commonly associated with the use of machinery and equipment or stem from mechanical risks. Consequently, a significant number of these accidents result in serious health implications for employees, leading to permanent changes in their personal and professional lives. The ultimate consequence of such accidents is a diminished quality of life within society. Occupational accidents impact both the employees and the organizations they work for. They place a significant burden on the socio–healthcare system and have broader negative effects on the national economy. Despite the existence of labor laws, regulatory frameworks, and machine safety standards, the level of harm remains high. This risk must be approached with extreme caution, prioritizing the continuous improvement of machine safety standards and investing heavily in the prevention of accidents and unwanted injuries. The analysis of mechanical risks is crucial for identifying key factors in the occurrence of accidents and proposing effective measures for improvement and prevention. All gathered data and facts should be viewed as a vital source of knowledge and information—an opportunity for organizational learning, development, and the advancement of protection against accidents where mechanical hazards are the primary risk.

Keywords: occupational safety, workplace injuries, mechanical injury risks, mechanical risk analysis, machine safety and standards, prevention

INTRODUCTION

Utilizing relevant globally available statistical data, this paper highlights and analyzes the most significant mechanical risks associated with industrial accidents, as well as the most prevalent patterns of worker injuries resulting from the use of machinery and equipment. The study investigates the diverse etiologies of machinery-induced accidents while simultaneously proposing methodologies for their mitigation. A critical analysis is conducted to address accidents stemming from inherent mechanical hazards; based on these findings, appropriate corrective measures and strategic frameworks are proposed to minimize occurrence rates. Special emphasis is placed on international machinery safety standards specifically pertaining to mechanical risk factors. It is anticipated that the statistical outcomes of this study will provide substantial benefits for employees, employers, and state occupational safety and health (OSH) institutions. Workplace accidents do not merely affect individual health but also lead to significant economic losses at the national level. According to the International Labour Organization (ILO, 2019), the costs associated with compensation for occupational accidents and diseases are estimated to range between 1% and 6% of a country's Gross Domestic Product (GDP) [1].

GLOBAL AND REGIONAL STATISTICS ON MACHINERY-RELATED INJURIES AND ACCIDENTS

Fatal occupational injuries continue to represent a significant global health concern, exerting a profound negative impact on industrial sectors, national economies, and the broader social fabric. Machinery (including transport and material-handling equipment) consistently ranks among the primary causes of accidents resulting in severe and fatal workplace injuries.

2.1 European Occupational Accident Statistics (2023)

According to 2023 data provided by the Statistical Office of the European Union (EUROSTAT), Europe recorded approximately 2.82 million non-fatal workplace accidents (defined as resulting in 4 or more days of absence) and 3,298 fatal accidents [2]. In 2023, Europe documented a standardized incidence rate of 1,393 non-fatal accidents per 100,000 employees (Source: Eurostat hsw_n2_02) [3]. Across the European Union as a whole, the average incidence rates were recorded at 2.07 fatal accidents and 1,500 non-fatal accidents per 100,000 workers [4].

Regarding the demographic context of the labor market in 2023, the working-age population (ages 20-64) in the EU totaled 259.9 million. Within this cohort, the active labor force comprised 207.8 million individuals, while 52.0 million remained outside the labor force (economically inactive).

The total number of employed persons within this age range in the EU reached 195.7 million in 2023 [5].

Key worker injury data in Europe for 2023:

- 2023: 2,800,000 non-fatal injuries (totaling 2,823,298 accidents); non-fatal injury rate of 1,500 / 100,000 employees; fatalities (fatal injuries): 3,298; rate of 2.07 / 100,000.

Average annual rate (2023):

- Annual probability calculation for a single worker: (rate / 100,000).
- Injuries (non-fatal/visible incident): 1,500 per 100,000 employees → annual probability for 1 worker = 0.015 = 1.5%.
- Fatal outcome: 2.07 per 100,000 employees → probability for 1 worker = 0.0000207 = 0.00207%.
- Accident incidence rate calculation: 2,823,298 / 197,700,000 x 100 = 0.01428 x 100 = 1.428
- Mortality rate: 3,298 / 197,700,000 x 100,000 = 1.6881
- Ratio: 856 non-fatal accidents for every fatal incident.

Key statistical terms, such as accident incidence rates, mortality rates, and accident frequency rates, were standardized at the 16th International Conference of Labour Statisticians in Geneva to provide a common language (standard) for occupational accident statistics [6]. The following equations and their respective meanings and definitions are provided:

$$\text{Incidence Rates} = \frac{\text{Total number of occupation in injuries}}{\text{Total number of workers}} \text{ x } 100$$

The number of injuries per 100 workers employed in the relevant sector is utilized to determine accident incidence rates.

$$\text{Mortality rates} = \frac{\text{Total number of fatal occupation injuries per year}}{\text{Total number of workers}} \text{ x } 100$$

The number of fatal accidents per 100,000 workers employed in the relevant sector is utilized to determine mortality rates.

The accident frequency rate is defined as the number of workplace accidents per one million working hours per year. To calculate the accident frequency rate, it is necessary to determine the total number of accidents and the aggregate number of working hours within the corresponding year.

$$\text{Accident Frequency rate} = \frac{\text{Number of occupational accidents per year}}{\text{Total working hours in year}} \text{ x } 1{,}000{,}000$$

Given that the majority of non-fatal and fatal workplace accidents in 2023 were caused by the loss of control over machinery, tools, or transport and handling equipment, approximately 27% of all non-fatal workplace accidents in the EU distribution sector in 2023 can be attributed to these factors; the proportion was notably higher for fatal workplace accidents, reaching 37.8% [7].The loss of control over machinery, tools, or transport and handling equipment in 2023 was one of the leading causes of fatal and non-fatal workplace accidents in the European Union (EU) and a significant factor in international safety reports. Regarding fatal accidents in the EU (2023), the loss of control over machinery, tools, or transport and handling equipment was a primary cause of workplace fatalities, accounting for 27.1% of all workplace deaths [8]. Furthermore, this category was the leading cause of non-fatal workplace accidents in the EU, representing 21.7% of the total number of incidents.

2.2Occupational Injury and Accident Statistics in the United States (USA)

Private sector employers in the United States reported 2.6 million non-fatal workplace injuries and illnesses in 2023 [9]. The primary high-risk sectors include transportation, construction, manufacturing, and healthcare. The U.S. Bureau of Labor Statistics (BLS) implemented more detailed statistical methodologies after 2023 following revisions to the Occupational Injury and Illness Classification System (OIICS).Fatal Injuriesin 2023: there was a total of 5,283 fatal workplace injuries. “Contact with objects and equipment” accounted for a significant portion, totaling 779 fatalities [10] in the US, representing a leading cause of workplace incidents.

According to 2023 statistics regarding machinery-related injuries and fatalities—based on data from the BLS, OSHA, and NIOSH—the leading causes included “contact with objects and equipment,” alongside slips, trips, falls, and overexertion.

In 2023, the total number of employed persons in the United States reached an annual average of approximately 161 million (specifically 161.04 million) [11].

Key worker injury data in the United States (USA) for 2023:

- 2023: 2,600,000 non-fatal injuries (totaling 2,605,283 accidents); non-fatal injury rate: 1,614 per100,000 employees; fatalities (fatal injuries): 5,283; rate: 3.28 per 100,000.

Average annual rate (2023) USA:

- Annual probability calculation for a single worker: (rate / 100,000).
- Injuries (non-fatal/visible incident): 1,614 per 100,000 employees → annual probability for 1 worker = 0.01614 = 1.614%.

- Fatal outcome: 3.28 per 100,000 employees → probability for 1 worker = 0.0000328 = 0.00328%.
- Accident incidence rate calculation: 2,605,283 / 161,400,000 x 100 = 0.01614 x 100 = 1.6141
- Mortality rate: 5,283 / 161,400,000 x 100,000 = 3.273

According to data from NIOSH (National Institute for Occupational Safety and Health) and the CDC for 2024, which are not yet finalized, machinery and equipment remain significant sources of severe workplace injuries. CDC data indicate that contact with objects and equipment accounts for over 12% of fatalities.The manufacturing sector continues to face numerous hazards, such as musculoskeletal disorders and incidents involving workers being "caught-in" or "struck-by" machinery, while the mining industry is particularly affected by mechanical accidents. Reports suggest that machinery, related risks specifically "caught-in" or "struck-by" events, remain a critical focus for prevention research. Machinery-related fatalities: Generally, data from the CDC (Centers for Disease Control and Prevention) highlight that fatalities resulting from contact with objects and equipment constitute a significant portion (approximately 12.6%) of total workplace deaths [12].

Based on preliminary data from the U.S. Bureau of Labor Statistics (BLS) for 2023-2024, "contact incidents", which include contact with objects and equipment, such as machinery-ranked as the second leading cause of non-fatal cases involving days away from work (DAFW), as well as days of restricted work activity or job transfer (DART) [13].

U.S. Non-fatal Contact Injury Statistics:

Total "Contact Incidents" (2023-2024): Approximately 860,050 cases were associated with contact incidents (including objects, machinery, and equipment) during this biennial period.Leading Cause: Contact with objects and equipment is consistently identified as the third leading cause of DAFW (Days Away From Work) cases and the second leading cause of DART (Days of Restricted Work Activity or Job Transfer) cases, surpassed only by "overexertion, repetitive motion, and bodily conditions.

INDIVIDUAL ANALYSIS OF MECHANICAL RISKS AS A FACTOR IN THE OCCURRENCE OF OCCUPATIONAL INJURIES AND ACCIDENTS

According to international, global, and world statistics, worker injuries resulting from contact with machinery and equipment occupy a significant position within total injury figures. In Europe for 2023, these incidents accounted for 27.1% of all workplace fatalities. During the same period, this category was the leading cause of non-fatal workplace accidents in the EU, representing 21.7% of the total number of injuries. Specifically, this indicates that out of the total 2,800,000 non-fatal injuries, 21.7% (or 607,600 cases) resulted from contact with machinery and equipment. Furthermore, out of the total 5,283 fatal injuries, 1,431 were the result of accidents associated with mechanical contact.

Conditions in the United States were similar; for the 2023-2024 period, machinery and equipment remained significant sources of severe workplace injuries. Contact with objects/equipment caused over 12% of fatalities, while serving as a leading factor in the occurrence of non-fatal injuries. It should be noted that the categorization of accident and injury types in the US differs from that used in Europe.

Based on global practice and statistics from NIOSH, OSHA, EU-ESAW, the International Labor Organization (ILO) [14], and ISO 12100, the most frequent cases of worker injuries involving machinery and equipment are the result of the following mechanical risks:

- Entrapment / Entanglement in moving parts
- Cutting and Puncturing
- Crushing and Compression
- Impact from moving or rotating parts
- Ejected parts / Projectiles
- Slips and Falls in the vicinity of machinery
- Electrical injuries / Electrocution

The protection and prevention of workplace injuries for workers depend significantly on a thorough and comprehensive analysis of the injuries and the underlying factors that cause these accidents and incidents.According to data from EU-OSHA, EUROSTAT's European Statistics on Accidents at Work (ESAW), and the risk principles established in EN ISO 12100.

Entrapment / Entanglement in moving parts

According to data from EU-OSHA, EUROSTAT's European Statistics on Accidents at Work (ESAW), and the risk principles established in EN ISO 12100 the impact on industry, particularly the manufacturing sector, is significant, as contact with moving machinery (including entanglement in rotating parts) causes approximately 19% of fatal injuries and 12% of non-fatal injuries.

The following are identified as high-risk industries regarding mechanical hazards from rotating parts, as well as entrapment and entanglement injuries: agriculture recognized as a primary source of non-fatal injuries due to machinery entanglement (e.g., PTO shafts, conveyors).

Then in the manufacturing sector, the primary sources of non-fatal injuries involve entanglement in rotating shafts, gears, rollers, and belt drives. In construction industry accidents involve heavy machinery (e.g., excavators, rollovers), which serve as a primary factor in severe incidents. Machine assemblies and components generate hazardous mechanical motions: rotating parts, such as gears and rollers, can entangle hair and clothing, drawing limbs into danger zones and causing serious injuries. Nip points (or pinch points) occur where two components move together [16],for instance, between a belt and a roller, posing a risk of trapping body parts. Furthermore, reciprocating motions in machine components are found in presses and shapers; these hazardous back-and-forth mechanical movements can entrap and injure body parts. Transverse motions involve the continuous movement of materials that can entangle or pull in nearby objects, including human limbs.

Cutting and Puncturing

In 2023, within the EU, out of 2.825 million non-fatal accidents, contact with sharp/pointed or rough/coarse objects (including tools and machinery such as presses, saws, knives, and cutters) caused 15.2% of these incidents [17].The industries most affected by cutting injuries include manufacturing (machine operators), which recorded the highest number of non-fatal accidents (522,000, or 18.5% of the total) in 2023. Approximately 32% of all non-fatal accidents in 2023 occurred at industrial sites.

The primary causes of knife-related injuries in the industry are slips during cutting or trimming (84% of cases), which frequently result in lacerations and amputations of the hands, fingers, and limbs. Amputations, lacerations, and wounds from work-related machinery and tools are severe, often permanent, and primarily affect the manufacturing and service industries.

Furthermore, machinery such as saws and cutting discs perform sharp cuts that pose serious risks to the safety and health of workers. Shearing machines, which apply force to cut materials like metal, require rigorous safeguarding measures to prevent amputation risks.

Crushing and Compression

Crushing and compression injuries represent a significant portion of fatal and severe workplace accidents, particularly in construction, agriculture, manufacturing, heavy industry, mining, and the transportation sector, involving entrapment or entanglement in machinery and equipment. According to OSHA data, these risks and injuries are among the “Focus Four” leading causes of fatalities. They are frequently classified as “caught-in/between” or “struck-by” incidents involving machinery and equipment.

Statistics regarding crushing and compression injuries, specifically those resulting in legal claims, account for approximately 26% of all workplace injury cases reported to workers' compensation attorneys. In 2023, these incidents accounted for 5.4% of all construction fatalities (143 deaths). The mortality rate from crushing injuries causes the death of 7.2% of all construction workers in the U.S. annually. Primary Causes: “Caught-in/between” and “struck-by” are identified as the two leading causes of work-related crushing injuries, with shares of 27.1% and 21.7% respectively, according to OSHA. Based on available OSHA information, fatalities from “caught-in-between” hazards, which include squeezing, crushing, or pinching between objects, comprise approximately 2% of all workplace deaths.Incidence Volume: Each year, workers in the United States suffer approximately 125,000 “caught-in” or “crushed-by” injuries.Amputation Rates: Nearly 60% of all amputations in industrial settings involve a worker's fingers or hand becoming entrapped or compressed by machinery.Regional Data (Michigan 2023): According to a study summarizing 916 work-related crushing injuries, 45.5% occurred within the manufacturing sector, and 72% of these injuries affected the upper extremities.

Fatal injuries in the EU according to Eurostat and ESAW analysesin 2023, whole body injuries (which often include crushing) accounted for 33.1% of all fatal accidents at work. Construction, agriculture, and heavy industry are identified as high-risk industries for these hazards. These sectors are the most vulnerable, with high rates of crushing injuries due to heavy machinery, structural collapse, and falling objects.The most common causes of crush/compression injuries include machinery accidents, such as getting trapped between moving parts (e.g., conveyors, presses, or robots); being caught between a moving and a fixed part [18]; being crushed between a crane and its load; or getting trapped between a press and a tool. Vehicle incidents involving trucks, heavy machinery, forklifts, and other industrial vehicles can cause pinching or run-over injuries. Material handling and falling objects, such as poorly stacked materials in warehouses or on construction sites, also pose significant risks. Finally, structural collapses, including trench cave-ins or the collapse of walls and structures, are frequent causes.

The majority of these injuries are associated with non-routine work, such as maintenance, cleaning, or machine repair, accounting for over 56% of entrapment/crush accidents.

Injuries from being struck by moving or rotating machine parts

Injuries from being struck by moving machine parts are common when a worker is within the operating zone of a mechanism. Contact or impact with moving machinery parts causes approximately 10-20% of all workplace injuries, with a higher percentage in specific manufacturing and construction sectors according to the ILO Encyclopedia of Occupational Health and Safety.Contact with a moving part of a machine' has been reported as the primary injury event in just over 10% of workplace accidents since this category was introduced into Swedish occupational injury statistics in 1979 [19].

Dangerous mechanical movements created by machine parts during operation, when coupled with inadequate safety preventive measures, result in worker injuries. Reciprocating motions (the back-and-forth or up-and-down movement of parts found in presses and shapers) can strike or trap body parts. Transverse motions involve the continuous, straight-line movement of materials that can draw in nearby objects, including body parts, into pinch or shear points.

Hazardous actions at the point of operation punching presses create holes in materials through a downward motion that can be dangerous for operators and cause injuries. Bending operations, where machines bend metal or other materials, can create pinch points and other hazards. Typical injuries from these risks to workers are most commonly fractures, head injuries, internal injuries, lacerations, amputations, etc.

Injuries from ejected parts / projectiles

Workers injured by objects thrown, ejected, or fallen from machinery are a significant component of "struck-by" injuries, which represent one of the leading causes of workplace fatalities and injuries in the United States and internationally. Based on data from NIOSH and the BLS (Bureau of Labor Statistics), injuries from thrown or flying machine parts fall under the broader category of "struck-by" accidents or "contact with objects and equipment."

Also based on recent European statistics and safety studies, machine-related injuries—including those caused by ejected or thrown parts, account for a large share of workplace accidents. In manufacturing and industrial settings, contact with moving machinery, which includes being struck by ejected material or thrown parts, constitutes approximately 12% of non-fatal injuries and 19% of fatal injuries. In 2023, the most common modes of contact for non-fatal workplace accidents across the EU included physical injuries from being struck by a moving object at 13%[20]; however, this group also includes other categories.

The most affected industries are manufacturing, construction, agriculture, and others. Injuries occur as a result of ejected fragments, debris, tools, or machine parts and materials moving at high speeds. Examples include tool breakage, the ejection of metal pieces,broken metal fragments from rotating parts due to material fatigue or material defects, the shattering of a disc, blade, or gear, flying metal shavings from a grinder, and more.

The most common injuries that occur are eye injuries, injuries to the face and head, injuries to the hands and body, puncture wounds, and fractures, among others.

Injuries as a result of slipping and falling around machinery

Injuries to workers from slips, trips, and falls around work machinery are a significant cause of serious workplace accidents, often resulting in concussions, spinal damage, severe musculoskeletal disorders, and broken bones, as well as cuts and wounds from falling onto the machines. Based on data from the European Statistics on Accidents at Work (ESAW), slips, trips, and falls (STF) are a major cause of non-fatal injuries in the EU, particularly when working near machinery, on industrial sites, or in manufacturing environments.

The second most common cause of workplace injury is the danger of tripping or slipping leading to a fall; 20-30% of workplace falls result in moderate or severe injuries such as deep bruising, broken bones, or concussions. In fact, according to OSHA, slips, trips, and falls cause nearly 700 workplace deaths annually, accounting for 15% of all workplace fatalities [21].

Non-fatal injuries from slipping, tripping, or falling in 2023, according to Eurostat data, amounted to 20.0%, while slipping, tripping, or falling accounted for 15.4% [22] of fatal injuries. The data does not distinguish between falls on the same level and falls from a height, but it must be assumed that most fatal accidents fall into the category of falls from height. There is no exact data on the percentage of non-fatal injuries to workers from slipping, tripping, and falling around work machinery, but it is estimated that they amount to up to 10% based on synthesized data from European and international occupational safety sources such as OSHA, EU-ESAW, and the ILO (2024-2025).

According to NIOSH and the Bureau of Labor Statistics (BLS), slips, trips, and falls (STF) account for approximately 18% to 27% of non-fatal injuries involving days away from work in U.S. industries. In the construction industry, these incidents cause nearly one-third of reported injuries and approximately 38% to 40% of deaths. STF is the second leading cause of non-fatal injuries overall, after transportation, with over 240,000 to 260,000 cases annually.

These incidents often occur due to wet, greasy, or uneven industrial surfaces, the presence of cables on the floor in walking zones, and more. Causes for falls around machinery include slippery surfaces from spilled oil, lubricants, or water on factory floors, as well as hazardous access points, uneven stairs and platforms, or improper climbing onto machines. Additionally, an unsafe work environment, poor lighting, and clutter contribute to the occurrence of these accidents.

Electric shock occurs when a part of the human body comes into contact with any source of electrical energy that produces sufficient current through the skin, muscles, or hair. The term is typically used to describe harmful exposure to electricity,the pathophysiological effect of an electric current passing through the human body.

Electrical injuries among workers caused by machines and devices

Electric shock occurs when a part of the human body comes into contact with any source of electrical energy that produces sufficient current through the skin, muscles, or hair. The term is typically used to describe harmful exposure to electricity, the patho-physiological effect of an electric current passing through the human body.

Numerous data points, such as international occupational safety reports including analyses from the Electrical Safety Foundation International (ESFI) and ILO-related studies, show that the percentage of worker injuries from electric shocks (arc flash, short circuits, uninsulated wires) and machinery, as well as fatal electrical incidents, is significant.

"Contact with electric current from a machine, tool, appliance, or light fixture" accounts for approximately 17% of all fatal electrical injuries in the workplace. Regarding machine-related activities, approximately 22% to 23% of fatal electrical injuries occur while "using or operating tools and machinery." According to an ESFI study and analysis for the period from 2003 to 2010, fatal accidents resulting from electrical injuries were highest in construction at 52% of all fatalities, while in manufacturing (machine use), this figure stood at 8%[23].

Data from Eurostat (2021) show that nearly 4% of workplace accidents fall into the "shock" category as a type of injury. When considering only the group of fatal workplace accidents, the share is approximately 2%.[24]

Also in 2025, the Electrical Safety Foundation International (ESFI) compiled data from the U.S. Bureau of Labor Statistics (BLS) and the Occupational Safety and Health Administration (OSHA) regarding fatal accidents resulting from electrical injuries for the period from 2011 to 2023, which determined that 5.6% of all workplace fatalities were caused by contact with electricity. The analysis also found that 74% of workplace electrical-related deaths occurred in non-electrical occupations according to OSHA.

The results of the analysis further established that 91% of all causes of fatal injuries occur by the following percentages:

- contact with overhead power lines 48.2%,
- unexpected contact with electricity 19.3%,
- contact with nearby energized equipment 12.7%,
- working on energized parts 4.1%,
- grounding 4.0%, and
- damaged wires or equipment 3.1% [25].

In this analysis, three main categories emerge as causes of fatal accidents resulting from electrical injuries. The first is contact with overhead power lines, the second is contact with wires, transformers, or other electrical components, and the third category for fatal accidents resulting from electrical injuries is contact with electric current from a machine, tool, appliance, or light fixture.

According to Eurostat, the percentage of worker accidents involving contact with electricity across the entire EU is not directly described in detail in the latest reports. Electrical accidents account for a low percentage of total workplace accidents, representing less than 1% of all non-fatal injuries; however, they are often serious and represent high-severity events with life-threatening and fatal consequences.

The most common injuries and consequences for workers as a result of contact with electrical energy include: severe burns, most commonly involving burns to the head, hands, and upper extremities, long-term disability, and fatalities.

ANALYSIS OF MECHANICAL RISKS.

The most common injuries and consequences for workers as a result of contact with electrical energy include: severe burns, most commonly involving burns to the head, hands, and upper extremities, long-term disability, and fatalities.

The analysis of accidents and incidents is a key and essential component of effective occupational safety management, primarily focused on prevention as well as the avoidance of future recurrences of accidents and incidents. It is aimed at the systematic improvement of the overall safety performance of companies, with the goal of protecting employees.

The analysis of accidents and incidents is a critical component of safety management within organizational operations. This paper provides an analysis of injuries where mechanical risks arising from the nature of machines and devices are identified as the cause.

According to the analysis of trends in the European Union and the USA, it was observed that mechanical risks are a significant factor in the occurrence of workplace accidents and injuries involving contact with machines and devices.

In the European Union in 2023, they accounted for 27.1% of all workplace fatalities and were also the leading cause of non-fatal workplace accidents in the EU, representing 21.7% of the total number of injuries.

Table 1

2023 year	Fatal injuries / Fatalities	Non–fatal injuries
Share of injuries from contact with machines and devices	27,10%	21,70%

Table2

no.	Type of risk/injury from contact with machines and devices	share in reported injuries %
1	Entrapment / Entanglement in moving parts	19%
2	Cutting and Puncturing	15%
3	Crushing and Compression	26%
4	Impact from moving or rotating parts	10%
5	Ejected parts / Projectiles	12%
6	Slips and Falls in the vicinity of machinery	10%
7	Electrical injuries / Electrocution	8%

The percentage distribution of the involvement of mechanical risks was obtained based on data cited in the paper (such as Eurostat ESAW, EU-OSHA, ILO, NIOSH, etc.), as well as through the synthesis of international statistics and papers, with some portions integrated from relevant safety sources and industrial analyses.

MACHINE SAFETY AND STANDARDS

Machinery involves hazards of various natures, and exposure to these hazards can result in injury or death. A machine is defined as an assembly equipped with or intended to be equipped with a drive system consisting of linked parts or components, at least one of which moves, and which are joined together for a specific purpose. Machines contain hazards of various types, and exposure to these hazards can lead to injuries or fatalities. Machine safety considers the ability of a machine to perform its intended function throughout its life cycle while the risk is appropriately reduced. The principles of machine safety, risk assessment, and risk reduction are covered in international standards, national standards, regulations, and other literature. The International Organization for Standardization (ISO) is a worldwide federation of national standards bodies (ISO member bodies): International standards provide design principles for machine safety. The primary goal of this international standard, ISO 12100 [26], is to provide designers with a general framework, guidance, and principles for decision-making during machine development, enabling them to design machinery that is safe for its intended use.

This international standard serves as the foundation for a set of standards categorized by the following structure and division:

- Type-A standards (basic safety standards) which provide basic concepts, design principles, and general aspects that can be applied to all machinery;
- Type-B standards (generic safety standards) which deal with one safety aspect or one type of safeguard that can be used across a wide range of machinery:
- Type-B1 standards for specific safety aspects (e.g., safety distances, surface temperature, noise);
- Type-B2 standards for safeguards (e.g., two-hand controls, interlocking devices, pressure-sensitive devices, guards);
- Type-C standards (machine safety standards) which deal with detailed safety requirements for a particular machine or group of machines.

Important standards concerning mechanical risks during the occurrence of injuries from contact with machines and devices:

- ISO 12100: Safety of machinery,General principles for design,Risk assessment and risk reduction. This is a type-A standard that provides the fundamental methodology for achieving safety in machine design. It mandates a three-step process: inherently safe design measures, safeguarding (using guards and protective devices), and providing information for use. All other machine safety standards are based on ISO 12100's risk assessment principles.
- ISO 14120: Safety of machinery, Guards, General requirements for the design and construction of fixed and movable guards This type-B2 standard specifies the general requirements for guards provided to protect from mechanical hazards, including rotating parts. It addresses design aspects like robust construction, secure fastening, prevention of new hazards, visibility of the process, and containment of ejected parts.
- ISO 13857: Safety of machinery, Safety distances to prevent hazard zones being reached by upper and lower limbs This type-B1 standard establishes values for safety distances in industrial and non-industrial environments. It is crucial for determining the minimum distance required between a guard opening and a hazardous rotating part to prevent human limbs from reaching the danger zone.
- ISO 13849-1: Safety of machinery, Safety-related parts of control systems This standard provides safety requirements and guidance on the design and integration of safety-related parts of control systems (SRP/CS). It specifies performance levels (PL) for safety functions, which are vital for interlocked guards that automatically stop the machine when opened.
- ISO 14119: Safety of machinery, Interlocking devices associated with guards, Principles for design and selection This standard covers the principles for designing and

selecting interlocking devices used with movable guards.
- ISO 13850: Safety of machinery, Emergency stop function, Principles for design. This standard sets out functional principles for the design and operation of emergency stop systems.
- ISO 13854:2017: Safety of machinery, Minimum gaps to avoid crushing of parts of the human body A Type-B1 standard that focuses on minimum gaps to avoid crushing hazards.
- IEC 60204-1: Safety of machinery,Electrical equipment of machines, Part 1: General requirements

The primary international standard for protection against electric shock in machinery. It covers electrical safety requirements, including protection against direct and indirect contact, grounding, and insulation.

- Key ISO/IEC standards for protection against electric shock include:
- IEC 60204-1: General requirements for electrical equipment in all machinery.
- IEC 60364-4-41: Low-voltage electrical installations — Part 4-41: Protection for safety Protection against electric shock. Basic principles for protection against electric shock.

PREVENTION AND PROTECTION AGAINST INJURIES CAUSED BY MECHANICAL RISKS

Prevention and protection against mechanical injuries is a combination of engineering controls, such as machine guarding, and administrative measures, including training and the proper use of personal protective equipment (PPE). Prevention involves and implies maintaining safe, protected, and inspected machinery, wearing appropriate clothing and PPE (gloves, goggles, etc.), and adhering to safe work procedures, as well as training employees regarding occupational safety and hazards.

Prevention of Risk from Entrapment / Entanglement in Moving Machine Parts

Operating machinery in industry, especially in the manufacturing sector and agriculture, involves contact with moving parts (including entanglement in rotating components) which causes a significant number of fatal and non-fatal injuries.

Rotating parts, such as gears and rollers, can snag hair or clothing, pulling hands into dangerous positions and causing serious injuries.

Description of injury occurrence:

Entrapment/entanglement of a hand, clothing, glove, or hair in moving machine parts:
- rollers / cylinders
- belts and pulleys
- conveyors
- gears / pinions
- shafts / spindles
- presses and forming machines

Most common injuries:
- Severe body crushing
- Amputations of fingers and hands
- Fractures of the extremities
- Fatal injuries

The causes of injuries resulting from entrapment/ entanglement in moving machine parts are divided into several categories:
- Organizational Factors: Improper operator training, non-compliance with lockout procedures, poor maintenance, and a lack of controls and inspections.
- Technical Factors: Absence of guards or protective fencing on machines and devices, lack of lockout/tagout (LOTO) systems during maintenance, bypassed or disabled safety devices, poor control of control systems, failure of machine safety mechanisms, and insufficient visibility or ergonomics.
- Human Factors: Inappropriate or unadjusted clothing, inattention and human error, insufficient experience, fatigue, and the improper use of machines and tools.

Prevention of worker injuries from the risk of Entrapment/Entanglement in moving machine parts, and the first phase of accident prevention, is achieved through inherently safe machine design [27]. All machinery must comply with the requirements of the Supply of Machinery (Safety) Regulations (SMSR) and adhere to ISO machine safety standards, including ISO 14120, ISO 13857, ISO 13849-1, ISO 14119 [28] (interlocking safety standards), ISO 13850, and ISO 13854 (minimum distance standards) [29], among others. Preventing injuries from jamming and pulling requires a multi-layered approach that prioritizes physical shielding and safety distances [30], safe operating procedures, and rigorous maintenance to eliminate or control access to moving parts. Of great importance is the installation of presence-sensing safety devices (light curtains, pressure mats) that detect if a person is in the danger zone and immediately stop the machine.

Furthermore, the second phase of prevention involves engineering controls, inspections of protective guards, and machine safety devices. Additionally, every employee must be cautious and take measures for their own personal protection, such as not wearing loose clothing, dangling jewelry, rings, or necklaces, and keeping hair neatly tied back. Adherence to safe working procedures and administrative controls is essential. Lockout/Tagout (LOTO) procedures must be strictly enforced to deactivate machines during maintenance, cleaning, or when clearing jams. Strict disciplinary actions should be taken against employees who bypass protective guards, maintaining a rigorous policy against the removal or bypassing of any guard or fence, even if it makes the work more difficult. Training and employee competence are vital for familiarity with procedures and safety hazards. The lack of safety device engineering in machine protective measures, when based on human factors—plays a role in worker injuries, even when human factors may initially seem insignificant[31].

Prevention of Cutting and Puncture Risks

A large number of non-fatal accidents result from contact with sharp/pointed or rough/coarse objects (including tools and machinery, presses, saws, knives, and cutters).

Description of injury occurrence:

- The primary causes of knife-related injuries in the industry are slips during cutting or trimming, which often result in injuries.

High-risk machinery:

- presses
- guillotines
- metal/wood cutting machines
- rotary knives
- cutting discs

Most common injuries:

- cuts/lacerations
- deep incisions
- amputations of fingers and hands
- severe bleeding (hemorrhage)

Causes of injuries resulting from the risk of cutting and puncturing by machine parts are increasingly and most commonly due to the absence of two-hand controls, the lack of lockout procedures, improper operator training, inattention or human error, insufficient experience, fatigue, and incorrect operator work during the manual positioning of material, as well as poor positioning of blades and other factors.

The primary prevention of this risk is the implementation of safety standards during the design and manufacturing of the machine. Key ISO standards for the protection of cutting tools include ISO 14120 [32](Guards): which specifies requirements for fixed and movable guards designed to prevent access to cutting tools and protect against ejected materials.

ISO 13857 [33](Safety Distances): establishes safe distances to prevent the upper and lower limbs from reaching danger zones (e.g., rotating cutting blades), along with other safety standards. It should be noted here that machine design must take into account the ergonomics of the human body and the length of the limbs [34]. Furthermore, during machine design, attention should be paid to the ergonomic evaluation of the location of two-hand controls [35], especially in operations with hazardous machinery where both hands must be in control of the machine.

Prevention or avoidance of worker injuries from the risk of cutting and puncturing by sharp machine parts, tools, blades, and other components requires a combination of safe work practices, the application of machine guarding, and the use of appropriate personal protective equipment (PPE), such as cut-resistant gloves and eye protection. Preventive measures include regular tool maintenance, safe storage, employee training in safe handling, proper tool usage, hazard recognition, and the management of distractions. Personal Protective Equipment (PPE) hand protection by wearing cut-resistant or chainmail gloves to protect the hand holding the material. Protective gloves designed for metal cutting must adhere to specific international standards to ensure safety against high-level cutting risks [36]. The primary standards for these applications are EN ISO 13997 [37] (cut resistance) and EN ISO 21420 (general requirements).Eye protection, safety glasses or face shields must be worn to protect against blade breakage or flying debris. Body protection, aprons or protective sleeves should be used in high-risk areas.

Prevention of Crushing and Compression Risks

Crushing and compression injuries represent a significant portion of fatal and severe workplace accidents involving squeezing, crushing, or trapping between objects.

Where it occurs:

- between a moving and a fixed part
- between a crane and a load
- between a press and a tool
- vehicle incidents: forklifts, trucks, work machinery, and other industrial vehicles causing trapping or run-over injuries

Most common injuries:

- fractures of the extremities
- amputations
- severe bleeding (hemorrhage)
- fatal injuries

Most of these injuries are related to non-routine work, such as maintenance, cleaning, or machine repair. The causes of injuries resulting from entrapment or entanglement in moving machine parts are due to organizational failures such as improper training, non-compliance with lockout procedures and other safety protocols, poor maintenance, and a lack of controls and inspections. Furthermore, the failure to meet technical requirements, such as inadequate guarding, the absence of guards or protective fencing on machines and devices intended to prevent physical contact with any part of the worker's body, the lack of Lockout/Tagout (LOTO) systems during maintenance, disabled safety devices, poor control of control systems, failure of machine safety mechanisms, and insufficient visibility or ergonomics, all contribute to these risks. The human factor also plays a role in the occurrence of injuries through inappropriate or unadjusted clothing, inattention and human error, insufficient experience, fatigue, decreased concentration, and the improper use of machines and tools.

Prevention of Injuries from Moving Machine Parts

The first phase of preventing accidents caused by moving machine parts is through sound machine design. All machinery must comply with the requirements of the Supply of Machinery (Safety) Regulations 2008 (SMSR), which establishes “essential health and safety requirements” to ensure that machines can be operated without risk to health and safety.

The manufacturer or supplier must generate a technical file containing evidence of how they designed the equipment to minimize the residual risks associated with it. Preventive measures include compliance with occupational safety regulations, regular machine maintenance, maintaining a safe distance from danger zones, employee training in safe handling, hazard recognition, and the management of distractions.

Prevention of injuries caused by ejected parts / projectiles from machinery

A large number of workers are injured by objects associated with kinetic energy that are thrown, ejected, or fallen from machines; these represent a significant component of workplace injuries occurring as a consequence of mechanical risks.

Examples of ejected parts or materials:

- tool breakage
- material processing during rotary or other tool movements
- shattering of a disc or blade
- ejection of metal pieces from scrap parts
- worn-out tools

Most common injuries that occur:

- eye injuries
- injuries to the face and head
- puncture wounds
- injuries to the hands and body
- bleeding and scars

Prevention and protection against injuries from this mechanical risk require a multi-layered approach focused on engineering controls, administrative procedures, and Personal Protective Equipment (PPE). The prevention of worker injuries from the risk of ejected parts / projectiles from machinery includes meeting safety standards during the design and construction of machines through inherently safe machine design. All machinery must comply with the requirements of the Supply of Machinery (Safety) Regulations (SMSR) and adhere to ISO machine safety standards[38], including the Machinery Directive (2006/42/EC), the European standard that requires protective measures, including guards, to prevent the ejection of parts such as shavings, tools, and fragments. Preventing injuries from ejected parts/projectiles also involves protection against objects falling into the moving parts of the machine, which could be thrown at high speeds and cause injuries.

Engineering Controls (Primary Prevention) through fixed safeguarding mechanisms on installed physical barriers (e.g., steel, polycarbonate panels) to enclose hazardous parts. Verification of interlocking guards followed by the use of safety mechanisms that prevent the machine from starting if the guard is open and trigger an immediate stop if it is opened during operation. Distance, location, and positioning of hazardous parts far enough away to ensure that ejected material cannot reach the operators.

- Containment Protection: Using polycarbonate vision shields strong enough to withstand impact, especially on CNC machines.
- Automated systems: Implementing automatic loading/unloading to keep operators away from the point of operation.
- Operational and administrative controls: Ensuring that work pieces are properly clamped and that clamps are in good condition to prevent the material itself from being thrown. Proper tooling/speed, using appropriate tools and selecting the correct speeds and feeds for the material.

Preventative maintenance, regular checking and inspection of machines for broken, worn, or unsecured components that could become projectiles. Ongoing employee training with an emphasis on workplace hazards and adherence to safety regulations.

Prevention of slips and falls around machinery

Injuries to workers from slips, trips, and falls (STF) around work machinery are very common causes of serious workplace accidents, often resulting in severe injuries.

Most common injuries that occur:

- severe musculoskeletal disorders
- strains and sprains
- fractures
- bruises and hematomas
- concussions
- cuts

Most frequent causes of injuries:

- unclean floors - spilled oils and lubricants
- cables on the floor
- untidy work zones

- wet or icy floors

Contaminants such as oil, grease, coolant, and lubricants leaking from machinery create slipping hazards. Additionally, cables, waste material, tools, and work pieces left in walkways cause trips. Safety standards involve a combination of proper machine guarding and maintenance of the work environment and floors. Safety and standards, machine design, and maintenance include ensuring that fluids do not leak. Compliance with international European standards regarding machine control, as well as EU Directive 89/391/EEC[39], requires employers to assess risks and prevent slips and falls in the context of surface irregularities. Employers are required to maintain a safe, dry, and unobstructed work environment.

Proactive measures include implementing strict safety protocols, ensuring regular maintenance to prevent leaks, installing appropriate flooring, providing adequate training, and making the use of proper Personal Protective Equipment (PPE) mandatory. Prevention also includes wearing slip-resistant safety footwear suitable for the work surface, as well as timely cleaning and maintenance to keep the floor dry and clean. Environmental factors such as insufficient lighting, uneven floors, and condensation or ice, especially in cold storage rooms, cause trips, falls, and injuries. Signage indicating slip hazards is part of the preventive measures.

Prevention of electrical injuries

These injuries arise from and are the result of the worker's body coming into contact with live parts, insulation defects and malfunctions, as well as improper maintenance of machines, equipment, and devices.

Causes of worker injuries from electrical voltage:

- damaged cables/insulation
- inadequate grounding and protection
- working on a machine without de-energizing it
- moisture and faulty insulation

Injuries resulting from electrical voltage:

- electric shock
- fatal consequences
- burns
- cardiac arrest
- disability

Machine safety standards focus on mitigating these risks through proper grounding, protection, insulation, and strict lockout and tagout procedures during maintenance. Electrical injuries in industrial settings are primarily prevented through a hierarchy of international safety standards during design and execution, with IEC 60204 and ISO 13849-1[40] being the most important for machine design and worker protection. Basic Electrical and Safety Standards for Machinery

IEC 60204[41] is the central standard for the electrical equipment of machines. It covers requirements for electrical power supply, protection against electric shock, and the safe operation of control circuits. The implementation of other standards during machine design is used to prevent electrical accidents. ISO 13850 [42] establishes design principles for the emergency stop function, ensuring that machines can be quickly disconnected from power or stopped.

IEC 62061[43] establishes functional safety requirements for electrical, electronic, and programmable electronic control systems. The application of IEC 60364[44], [45] is also essential, as it is the fundamental international standard for low-voltage electrical installations, providing the global framework for electrical safety and design. Furthermore, the NFPA 70E standard for electrical safety in the workplace is frequently used in conjunction with ISO standards to manage hazards related to electric arc flash and shock. Prevention includes technical measures (safety of the device itself), further isolation, and enclosures; specifically, all live parts must be insulated or enclosed in protective housings with an appropriate IP (Ingress Protection) rating to prevent direct contact. Furthermore, earthing provides a low-resistance path for fault currents to the ground, which triggers protective devices such as fuses. The inclusion of protective devices (RCD/GFCI) involves installing residual current devices that cut off the power supply in milliseconds if they detect current leakage. Safety Voltage using Extra-Low Voltage (SELV/PELV) for handheld tools and work in damp environments.

Implementation of organizational measures (work procedures):

- LOTO Procedure (Lockout-Tagout): The most critical measure during machine service—it must be physically disconnected from the power supply, locked with a padlock, and tagged to indicate that work is in progress (ISO 14118).
- Regular inspections and maintenance: Periodic testing of installations and portable tools (PAT testing) to detect damaged cables or faulty insulation.

Protection against electric shock also mandates compulsory employee training: every worker must be trained to recognize danger signs (burning smell, sparking) and know how to react in emergencies.

Personal Protective Equipment (PPE) is a vital element of prevention. When technical measures are insufficient, specialized equipment is used: dielectric gloves and boots made of non-conductive rubber. The work environment must be safe, providing sufficient space around electrical panels for secure access, maintaining a dry workspace, and preventing the accumulation of moisture or water near electrical devices. Additionally, there must be signage with clear high-voltage symbols and warning plates according to ISO 7010.

CONCLUSIONS

Through the analysis of mechanical risks in accident occurrences, the key factors causing accidents and injuries have been identified, and measures for improvement and prevention have been proposed. The main causes of injuries resulting from mechanical risks on machines and devices are: easy access to moving machine parts, lack of protection, absence of lockout procedures, worker inexperience, bypassing of safety measures, lack of risk assessment, lack of supervision, poor machine design, unsafe working methods, poor and untimely maintenance of machines and devices, an unsafe work environment, a lack of clear instructions for workers on how to safely intervene on machinery, as well as modifications made to machines and control systems. In other words, organizational, technical, or human failures have been made, resulting in worker injuries.

Within the framework of the study, data on accidents that occurred in 2023 in Europe and the USA, as well as synthesized data, were analyzed using internationally accepted parameters; it was observed and determined that mechanical risks in workplace accidents and injuries involving contact with machines and devices account for 27.1% of all fatal cases in the workplace, while they constitute 21.7% of the total number of non-fatal injuries in the European Union in 2023.

Prevention of injuries and improvement of worker safety entails: the implementation of sound and safe machine design in accordance with the ISO 12100 standard, which provides the methodology for designing safe machinery, the application of risk assessments, and the hierarchical use of risk reduction measures. Furthermore, it involves the application of the ILO Code of Practice on safety and health in the use of machinery, which covers planning, machine selection, risk assessment, and systemic management. Finally, it requires the establishment of ISO 45001 occupational health and safety management systems as part of broader safety frameworks that integrate mechanical risks.

Implementation of administrative and safety systems and procedures within work organizations. Furthermore, to avoid injuries, periodic engineering inspections of machines and devices are mandatory. Engineering controls are the most effective way to prevent contact with hazardous parts; it is also worth noting pre-operational inspections: daily checks for worn parts, leaks, or faulty safety switches before the shift begins. Continuous training of employees to increase their competence in terms of occupational safety and the proper use of machines and devices. Personal prevention and personal protective equipment (PPE),the last line of defense, include personal behavior and protective gear. Maintenance and the work environment, providing a well-lit work area and using mirrors or cameras to eliminate blind spots in the room, while ensuring large mobile equipment is constantly maintained in a safe, dry, and unobstructed work environment. Effective communication between employees, safety officers, and company management is essential for timely awareness, prevention, and the elimination of workplace hazards. In addition to technical, organizational, and human factors, it is necessary to strengthen regulatory controls (inspections) within organizations. These should be targeted at high-risk industries prone to mechanical risks where frequent injuries and hazards have been recorded. Punitive measures and warnings, along with their analysis, provide statistical data on the causes of injuries, thereby influencing prevention.

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