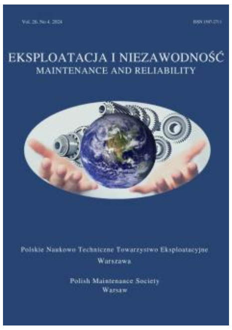

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Occupational safety management and human reliability testing during the operation of a plastic injection molding machine

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Michał Łukasz Pałęga[a], Dariusz Rydz[a], Mariusz Salwin[b], Konrad Lewczuk[c,*], Tomasz Chmielewski[d]

[a] Faculty of Production Engineering and Materials Technology, Czestochowa University of Technology, Poland
[b] Faculty of Mechanical and Industrial Engineering, Institute of Production Systems Organization, Warsaw University of Technology, Poland
[c] Faculty of Transport, Warsaw University of Technology, Poland
[d] Faculty of Mechanical and Industrial Engineering, Warsaw University of Technology, Poland

Highlights

- Occupational safety and the reliability of the plastic injection molding machine operator.
- Analyse of dangerous and burdensome factors for the identification of occupational hazards.
- Immersive technologies like VR for industrial safety improvements.
- JSA, TESEO and HEART methods for human reliability and safety assessment.

Abstract

Work safety is a key element in the design and maintenance of industrial workplaces and processes. This article examines occupational safety and the reliability of the human factor in the role of a plastic injection molding machine operator. Analyzing the work process and the dangerous, harmful, and burdensome factors present in the environment and workplace allowed for the identification of occupational hazards. Additionally, factors such as the frequency of threats, the likelihood of events, the possibility of avoiding and limiting damage, and the consequences of events were considered to conduct an occupational risk assessment according to the JSA (Job Safety Analysis) method. Following this, human reliability was assessed by determining the probability of operator errors using the TESEO and HEART methods. Finally, the possibility of using selected immersion techniques on the results of the research was discussed. The research methods and tools used in this study included a literature review and analysis, observation, interviews, and inference.

Keywords

operation of a plastic injection molding machine, human reliability, occupational safety management, occupational risk, TESEO method, HEART method

1. Introduction

The operation and reliability of industrial workplaces and workstations play a key role in ensuring occupational health and safety, constituting fundamental aspects of risk management and employee health protection. Reliable and well-maintained machines and devices minimize the risk of accidents and failures, contributing to the creation of a safe working environment. Moreover, the effective use of workstations translates into the optimization of production and service processes, which directly reduces employees' exposure to harmful and dangerous factors [1]. Regular maintenance, inspection of the technical condition of equipment, appropriate training of employees in the operation of machines and devices and ergonomic design are necessary to maintain a high level of reliability and safety at workstations. Therefore, effective

(*) Corresponding author.
E-mail addresses: M. Pałęga (ORCID: /0000-0002-2779-431X) michal.palega@pcz.pl, D. Rydz (ORCID: 0000-0002-9985-8036) dariusz.rydz@pcz.pl, M. Salwin (ORCID: 0000-0001-9325-8796) mariusz.salwin@pw.edu.pl, K. Lewczuk (ORCID: 0000-0002-0152-8531) konrad.lewczuk@pw.edu.pl, T. Chmielewski (ORCID: 0000-0003-0002-8751) tomasz.chmielewski@pw.edu.pl,

management of operations and maintaining the reliability of workplaces have a direct impact on improving working conditions, thereby increasing overall operational efficiency and creating the basis for a healthy and safe working environment.

The basic aspect of reliability in the operation of machines and devices is to provide operators with an appropriate level of safety. Safety can be defined as “freedom from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment” [2]. Safety assessment methods are developed for different areas of human technical activity, especially related to industry and manufacturing [3, 4] or transport (see [5, 6]) or logistics [7, 8, 9].

The safety of employees operating machines that pose direct threats due to moving parts, temperature, or radiation requires the recognition, quantification, and analysis of these threats. This analysis, in turn, enables decisions regarding the ergonomic and safe design of workstations and the organization of manufacturing processes to ensure the safety of employees and their surroundings. Employee well-being is not only a basic design and organizational premise but also a crucial factor in shaping labor and production costs. Ensuring employee safety requires investments in the implementation of passive and active safety measures at global (facility), local (workplace), and personal (clothes, personal equipment) levels. Additionally, it involves training employees in the use of devices and procedures for situations that threaten life or health and other crises.

Various methods are used to assess occupational safety, including the Job Safety Analysis method discussed in the article, which help improve workplaces by analyzing the risks associated with their use. The article mainly focuses on risk factors related to the operation of injection molding machines, specifically activities directly associated with injuries and accidents. However, to provide a complete picture, technical aspects of machine operation should be complemented by additional factors that may affect work safety in industrial plants. These factors include, among others [1]: local and corporate safety culture, local and corporate technical culture, dominant workloads, boredom and work routine, employee condition and fatigue, investments in safety systems and measures, legal safety conditions, pressure to achieve results, and the life and economic situation of employees (motivation). Including these factors would require a comprehensive analysis of the organization and its operating conditions. One way to incorporate these additional factors into assessing the safety and reliability of injection molding machine operators may be through the use of immersive technologies, such as Virtual Reality, during on-the-job and hazard training.

The article presents the application of the JSA (Job Safety Analysis) method, supported by the TESEO (Technica Empirica Stima Errori Operatori) and HEART (Human Error Assessment and Reduction Technique) methods, for assessing human reliability and determining the probability of molding machine operator errors. The research presented in the article is an extension of studies on the JSA method in various application areas, e.g., laser cutter operation [10]. It allows to obtain new comparative results.

From the point of view of preventing potential accidents and protecting employee health, actions resulting from a reliable assessment of occupational risk that eliminate or limit the threat are of key importance [3, 11].

The remainder of this paper is organized as follows: Section 2. introduces the safety standards in the European Union applied in this case. Section 3. discusses the assessment of occupational risk as a systemic process and scetches the use of immersive methods (VR) for safety improvement. Section 4. focuses on occupational risk assessment using the Job Safety Analysis (JSA) method and the application of the TESEO and HEART methods. Section 5. explores the general principles of operation of a plastic injection molding machine as the work environment and the machine operator's position. Section 6. presents the assessment of occupational safety during the operation of a plastic injection molding machine using the JSA method. Section 7. examines the operator’s reliability during machine operation using the TESEO and HEART methods. Finally, the last section discusses the findings and provides concluding remarks. The literature review is carried out successively in the following sections.

2. Safety standards in European Union

Ensuring proper occupational safety requires compliance with appropriate standards and principles described in the relevant

European Union directives and national (Polish) regulations. First of all, those relating to the construction and operation of machines and the relevant ones should be mentioned. One of the most important legal regulations at the European level is the Framework Directive 89/391/EEC [12]. This legal act establishes minimum standards for occupational health and safety and aims to harmonize the level of safety and health protection. Moreover, the said directive obliges employers to take actions aimed at improving working conditions. According to this regulation, employers are obliged to prevent, assess and eliminate threats at their source. It is extremely important to treat occupational health and safety as an integral part of the enterprise management process [12].

Moreover, the important role of two European regulations should be pointed out: Directive 2009/104/EC [13] and Directive 2006/42/EC [14]. Under these regulations, machinery is divided into two main categories: "old machinery" and "new machinery". Machinery that was placed on the market or put into service in the European Economic Area before 1 May 2004 is classified as "old machinery". In turn, "new machines" mean machines that were manufactured after this date [13, 14]. "Old machinery" must meet at least the minimum criteria of Directive 2009/104/EC, while "new machinery" is subject to the requirements of the Machinery Directive 2006/42/EC [15].

The European Union Directive 2009/104/EC [13~~12~~] sets out fundamental occupational health and safety requirements that workers should comply with when using work equipment. In accordance with the requirements of this directive, employers are obliged to implement appropriate measures aimed at adapting equipment to perform work safely, ensuring the protection of employees' health and life [13, 16, 17]. The selection of appropriate work equipment requires the employer to conduct an in-depth analysis of specific working conditions and potential threats, both at a given position and those related to the use of the equipment itself [18, 19, 20].

If the use of work equipment poses a risk to the employee, the employer is obliged to take action to minimize this risk. In the process of implementing minimum requirements, the employer should take into account ergonomic aspects [21], the positions adopted by employees when using the equipment, as well as the conditions at the workplace. These guidelines are aimed both at ensuring an adequate level of safety and health protection of workers and at enabling the free circulation of machines on the European market [22].

3. Assessment of occupational risk

3.1. Systemic process of occupational risk assessment

The assessment of occupational risk is a systematic process aimed at analyzing the risk and establishing its permissible level [17, 22, 23, 24]. This assessment enables employers to ascertain the adequacy of measures in place for mitigating or nullifying the adverse effects of work environment factors on human health [25, 26]. The outcomes of this risk assessment also provide guidance on the necessary actions to diminish the likelihood of accidents and health hazards [23]. For an effective occupational risk assessment, a meticulous and comprehensive evaluation of the workplace should be conducted, focusing on [10]:

- the presence of hazardous, harmful, and annoying factors in the workplace;
- potential incidents that could lead to accidents;
- health and safety conditions within the workplace and the broader work environment;
- ergonomic conditions at the workplace.

The primary objectives of conducting an occupational risk assessment, as outlined in the literature [27] include:

- confirming the identification of occupational hazards and the awareness of the associated risks;
- ensuring that the safety measures in place are commensurate with the identified and indicated risk factors;
- selecting appropriate materials, equipment, and methods for workplace organization;
- establishing priorities for actions aimed at eliminating or mitigating occupational risks;
- assessing whether the level of occupational risk is acceptable and, if not, verifying the implementation of adequate protective measures;
- demonstrating to employees, as well as supervisory and regulatory bodies, compliance with the obligation to assess and understand the occupational risks present in the workplace;
- facilitating the continuous enhancement of occupational health and safety conditions.

In accordance with the legal requirements in Poland, employers are mandated to conduct and document an assessment of occupational risks and to communicate the findings to all employees.

In addition to systematically carried out occupational risk assessment, attention should also be paid to issues related to human reliability, defined as the ability to meet requirements with a minimum probability of making an error, under specified conditions and within a specified period of time [28]. Among the dominant so-called operator errors (i.e. related to the operation of a specific technical object) the following types of operational errors can be distinguished [29, 30, 31, 32]:

- lack of correct operation after the signal appears,
- late activity,
- an action performed on time but not completed or performed instead of another,
- unnecessary activity, resulting from chaotic activity,
- premature action,
- spontaneous activity, without an external signal, instead of refraining from activity, premature participation in activity,
- action that is opposite to the desired action or inaccurate.

The presented classification shows that the dominant cause of errors in actions (execution) is inadequate time regulation of actions, including cases of premature, delayed, spontaneous actions, etc [33, 34]. Another factor is disruptions in spatial regulation, manifested in the execution of actions in the wrong direction (e.g. left instead of right, down instead of up) and errors resulting from the source of activity, both internal and external, including lack of internal initiative or lack of inhibitory impulse [35, 36].

By analyzing these three aspects of performance (space, time, and source of activity), further combinations of error causes can be deduced [37, 38]. Examples include activities that are performed on time but incorrectly, activities that are correct but performed late, activities that are inappropriate both in terms of time and space (e.g. spontaneous), and those that are partially performed on time and partially not (e.g. incomplete) [39, 40, 41, 42].

3.2. Immersive technologies as a tool improving safety in industrial conditions

Immersive technologies like Virtual Reality (VR) are a promising tool for industry, particularly for early-stage design of safe solutions, and training. When applied to industrial conditions, VR combined with simulation technologies appropriate for particular conditions can support testing the configurations of workstations and machines, implementing new technologies to increase safety, collecting statistical samples for research on the impact of specific solutions on safety, and training operators and other individuals involved in the molding process [1].

Holuša et al. [3] explore the application of VR for training and safety assessment within the raw materials industry. They investigate how VR training affects employees, demonstrating that it is an effective tool for education and training. Their research reveals that VR enhances the acquisition of practical skills, improves information retention, and supports the development of soft skills like communication, teamwork, and leadership.

Ji et al. [4] present a training method that integrates the evaluation of Diminished Quality of Life (DQL) risk with virtual reality (VR). This approach emphasizes VR-based training sessions designed to educate users on sequential operations, standard work procedures, and the assessment of short-term safety risks.

In addition to VR analysis, it is important to highlight that augmented reality (AR) greatly improves the production work environment by delivering essential information to operators. This enhancement boosts both the speed and quality of operations. Notably, the feasibility of AR implementation can be evaluated using VR.

Work Safety and Hygiene (OHS) is the area where VR finds important applications. VR offers realistic training scenarios on OHS to increase employee awareness of potential hazards and prepare operators for new situations, especially when working with an increased risk of accidents, such as with an injection molding machine. Meanwhile, AR can be applied not only to expand the scope of information provided to the employee with essential real-time communication, but to signal hazards at workstations [1].

Evangelista et al. [43] developed an augmented reality (AR) tool for assessing ergonomic risks in the workplace. Their tool enables real-time evaluation of ergonomic risks associated with employee postures at workstations, allowing for monitoring of employee operations and improvements in ergonomic conditions. Wetzel et al. [44] explored the application of virtual reality (VR) to enhance workplace safety, specifically in preventing accidents caused by slips, trips, and falls. This research demonstrates that VR can significantly increase employee awareness of potential hazards. Runji, Lee, and Chu [45] investigated AR applications in production maintenance, emphasizing the needs of operators. They proposed a general process that classifies maintenance operations into four stages and analyzed the classification results based on geographical location, type of maintenance, AR technical elements, and integrated external sensors.

The active use of VR for safety analysis will significantly impact key safety KPIs (as given in [46]). Implementing VR may enhance the Total Recordable Incident Rate (TRIR) and Lost Time Injury Frequency Rate (LTIFR) due to the increased focus on safety testing. The Near-Miss Frequency Rate can be lowered through continuous situational training in Virtual Reality, particularly by repeatedly training employees to handle near-miss scenarios. Moreover, VR, combined with a customized training policy, will improve the Safety Training Compliance Rate and boost Employee Safety Perception Survey scores by providing an engaging and immersive training experience.

As part of the organization's proactive measures, VR can enhance the Safety Suggestion Implementation Rate and the Corrective Action Completion Rate. VR will also help increase the Safety Audit Score by facilitating repeated testing of safety protocols and regulations in a virtual environment. Additionally, in the event of an accident, VR can improve Incident Investigation Completion Time by allowing the recreation of hazardous situations in a virtual setting.

The above discussion on the use of immersion technologies allows us to analyze the factors affecting the safety of injection molding machine operators from the perspective of possible improvement.

3.3. Fuzzy logic, predictive analytics, and machine learning for identifying emerging risks

Occupational safety management and human reliability testing are research subjects in various areas, including the possibility of using artificial intelligence techniques, machine learning and fuzzy modelling to assess and predict phenomena related to occupational safety and human behaviour. Due to the increasing possibilities of collecting and analyzing data, using computational intelligence methods is becoming possible and justified.

Caggianoa et. al. [47] propose a novel machine learning-based framework and associated methods to classify physiological data acquired using wearable sensors during manufacturing work, to be utilized in a fuzzy-based expert system. This approach is applicable to injection molding machine operators who work in a closed area that is relatively easy to monitor.

Özkan and Ulaş [48] develop a predictive framework using machine learning to identify the causes of fatalities and amputations in the metal industry based on occupational accident data. Authors investigate created prediction frameworks for lowering occupational accidents with random forest, k-nearest neighbour, gradient boosting method and recursive partitioning and regression trees. Karkula and Mazur [49] formulate a model supporting decision-making to order power capacity. They propose solution based on machine learning.

Fuzzy modelling is a tool that allows you to take into account factors with a wide range of values for which the correlation may not be clearly visible. In the case of injection molding machine operators, thanks to the use of fuzzy modeling, it is also possible to take into account factors that are difficult to measure, such as fatigue or the technical culture of the organization. Fuzzy modelling methods are widely used in occupational safety management. Govindan and Li [50] investigate ergonomic risks and propose a fuzzy logic-based decision support system considering physical, environmental, and sensory factors to assess the ergonomic performance of work systems. Xu et. al. [51] propose w an edge inference framework based on multi-layered fuzzy logic for safety of construction workers. Jahanvand et al. [52] use the fuzzy Delphi Method to gather experts opinion and judgment on occupational safety.

Applying fuzzy logic, predictive analytics, and machine learning to identify emerging risks in molding operator workstations offers a sophisticated approach to enhancing workplace safety. These technologies can analyze historical data and trends to anticipate potential hazards and improve decision-making processes and be a base for assessment methods as well as for simulation models supported with virtual reality.

Fuzzy logic is particularly useful in handling the uncertainty and imprecision inherent in risk assessment. Predictive analytics leverages historical data to identify patterns and predict future events while machine learning enhances these processes by continuously learning from new data.

4. Research methodology

4.1. Occupational risk assessment using the Job Safety Analysis method

Occupational risk assessment using the Work Safety Analysis (JSA) method involves estimating two parameters: the severity of the consequences of events and the probability of occurrence of these consequences (P). This relationship is described by the equation: [25]:

$$P = F + O + A \tag{1}$$

where:

F – means the frequency of occurrence of the hazard;

O – means probability of occurrence;

A – means the ability to prevent or mitigate damage.

The measures relating to the assessment of individual parameters are presented in Tables 1–3.

The described JSA methodology was a research tool for the work: [10]

Moreover, the values for individual occupational risk assessment criteria contained in Tables 1 - 5 result from the adopted research methodology (standardized data).

Table 1. Assessment of hazard frequency – *F* (JSA).

Value *F*	Characteristic
1	Less than once a year
2	Once a year
3	Once a month
4	Once a week
5	Daily

Source: [10, 23, 25]

Table 2. Assessment of event probability - *O* (JSA).

Value *O*	Characteristic
1	Irrelevant
2	Unlikely
3	Imaginable
4	Likely
5	Usually

Source: [23, 25]

Table 3. Assessment of the possibility of avoiding or reducing damage - *A* (JSA).

Value *A*	Characteristic
1	Obvious
2	Likely
3	Possible
4	Not possible
5	Impossible

Source: [23, 25]

In the method outlined, the consequences of an event (C) are categorized into four distinct classes, as detailed in Table 4.

Table 4. Event consequence classes - C

Class	**Description**	Characteristic
C1	Slight	Non-incapable of work
C2	Marginal	Short inability to work
C3	Serious	Prolonged inability to work
C4	Very serious	Death

Source: [23, 25]

Subsequent to the assessment of all risk parameters, the level of risk is to be ascertained from the matrix (refer to Table 5), following which its classification is to be determined, encompassing three potential categories: negligible risk, acceptable risk, and unacceptable risk [10, 23, 25, 53].

Table 5. Risk Valuation (JSA)

Class C	***P* – probability of consequences**				
	3-4	**5-7**	**8-10**	**11-13**	**14-15**
C1	1	2	3	4	5
C2	2	3	4	5	6
C3	3	4	5	6	7
C4	4	5	6	7	8

1-2	negligible risk
3-5	risk acceptable
6-8	risk not acceptable

Source: [10, 23]

4.2. Experimental method for assessing TESEO operator errors

TESEO method (Technica Empirica Stima Errori Operatori), that is, the Experimental Method for the Evaluation of Operator Errors, designed by Bello and Colombari in 1980, represents a somewhat empirically based approach. It was developed to estimate the probability of errors made by system operators [30, 32, 33, 35]. The key task of the operator is to perform a specific task, and the model takes into account five important factors, marked as K1 to K5, which may affect the risk of making an error by the operator [39, 40, 41, 42].

The values of the coefficients for individual factors, predicted by the creators of the method, are taken from tables prepared in detail by them. This model takes into account both internal and external factors that may affect the operator, indicating the complexity of the work environment and the variety of influences that may contribute to errors.

- K1 – type of task performed,
- K2 – time available to complete the task (preliminarily called stress factor here),
- K3 – characteristics of the person performing the function of a traffic dispatcher, in particular his preparation to perform the function entrusted to him, taking into account his education or habits,
- K4 – emotional state of the operator (called here the fear factor),
- K5 – environmental characteristics, including MMI (here called ergonomic factor).

Calculating the probability of human error involves multiplying the values of the coefficients taken for these five factors from tables developed by the authors of the method (tables 6-10). Moreover, the values included in tables 6-10 regarding the assessment of the probability of making an error by the operator result from the adopted research methodology (they constitute standardized data).

Table 6. Type of activity

Action type	K1
Simple, repeatable	0,001
Requires attention, repetitive	0,01
Unique	0,1

Source:[40, 42]

Table 7. Time stress

Time stress	K2
For repetitive activity Time available: <2 seconds 2-10 seconds 10-20 seconds	 10 1 0,5
For a unique activity Available time <3 seconds 3-30 seconds 30-35 seconds 45-60 seconds	 10 1 0,3 0,1

Source: [40, 42]

Table 8. Operator

Operator	K3
Careful selection, education	0,5
Average knowledge and training	1
Poor knowledge and poor training	3

Source: [40, 42]

Table 9. Threat stress

Threat stress	K4
Extreme danger	3
Potential threat	2
No threat	1

Source: [40, 42]

Table 10. Environmental factors and ergonomic conditions

Environmental factors and ergonomic conditions	K5
Excellent	0,7
Good	1
Medium	3
Weak	7
Badly	10

Source: [40, 42]

4.3. Human Error Assessment and Reduction Technique

The HEART method (Human Error Assessment and Reduction Technique), which was first presented by Williams in 1985 [54, 55, 56, 57], is a relatively quick and easy method for quantitatively assessing the risk of human error [58]. This method is based on the following several assumptions [59]:

- basic human reliability depends on the nature of the task to be performed,
- in ideal conditions, this level of reliability is achieved with the assumed nominal value of compliance within the limits of probability,
- because such nominal conditions do not exist under any circumstances, the predicted human reliability will

be worse as the value of the function determining the application of the identified error circumstances.

The creators of the method presented a table they had developed that included 9 Generic Task Types (GTT) with nominal human error probability values assigned to them. General types of tasks (GTT) and the corresponding human reliability (HEP) values according to the authors of the method are presented in Table 11, while Table 12 presents examples of conditions affecting the occurrence of errors [54, 56]. These are standardized data resulting from the adopted research methodology

Table 11. General task types (GTT) and corresponding human fallibility values.

General task types	Nominal values of the probability of making an error
An unknown task, performed in a hurry without awareness of its consequences	0,55
Restoring a state or causing a new state of a system without supervision or procedures	0,26
A complex task requiring complex reasoning or great dexterity	0,16
A simpler task, but performed quickly or with insufficient attention	0,09
A routine, well-mastered task that does not require much dexterity	0,02
Restoring or bringing about a new state of the system according to procedures or under supervision	0,003
A routine, well-mastered task performed by a well-trained person	0,0004
Reaction to a signal from the automatic supervision system with a detailed description of the system status	0,00002
Other tasks performed without knowing their description	0,03

Source: [54, 56]

Table 12. Conditions that have an adverse impact on human performance along with correction factors

Conditions that adversely affect human performance	Values of correction factors
Lack of time needed to detect the error or fix it	11
Lack of correspondence between the actual course of action and the designer's imagination	8
Incorrect technique	6
Ambiguity in required courses of action	5
Poor risk perception	4
Lack of operator experience	3
Inconsistency of short- and long-term goals	2,5
Conditions favoring the choice of the wrong procedure	2
High levels of stress resulting from the threat	1,3
Low employee morale	1,2
Age of the employee performing perceptual activities	1,02

Source: [54, 56]

5. General structure and principle of operation of a plastic injection molding machine

5.1. Molding machines

The injection molding machine, as a device dedicated to the mechanical processing of plastic objects, plays a key role in the injection molding process. Designed for shaping thermoplastic and thermosetting materials, the injection molding machine is a complex unit consisting of three main systems: plasticizing, tooling and drive and control, as well as four functional modules: drive, injection, forming and closing [55, 57, 58, 59]. The operation of the injection molding machine consists in plastic processing of the material and filling the mold with it, where it is concentrated and transformed into the final product [55, 59, 60].

The design of the injection molding machine includes three basic systems. The plasticizing system, whose central component is a screw or piston, is responsible for preparing the material for forming and then injecting it into the mold. The tooling system includes a mold that can take on various configurations (two-piece, single-cavity, multi-cavity) and a closing system, usually consisting of two centric actuators that keep the mold in the closed position when the pressure increases [57]. Injection molds are divided into hot and cold channel. The drive system, which may be hydraulic or electric, drives the screw to perform rotation and reciprocation. An integral element of the injection molding machine is also a tank for plastic granules, which are dosed into the cylinder, where the plasticization process takes place. The temperature in the cylinder is regulated by heating elements. In addition, injection molding machines are equipped with ejector mechanisms (hydraulic or mechanical) for separating the finished product from the mold, as well as two separate cooling systems (Figure 1) [55, 59, 60, 61].

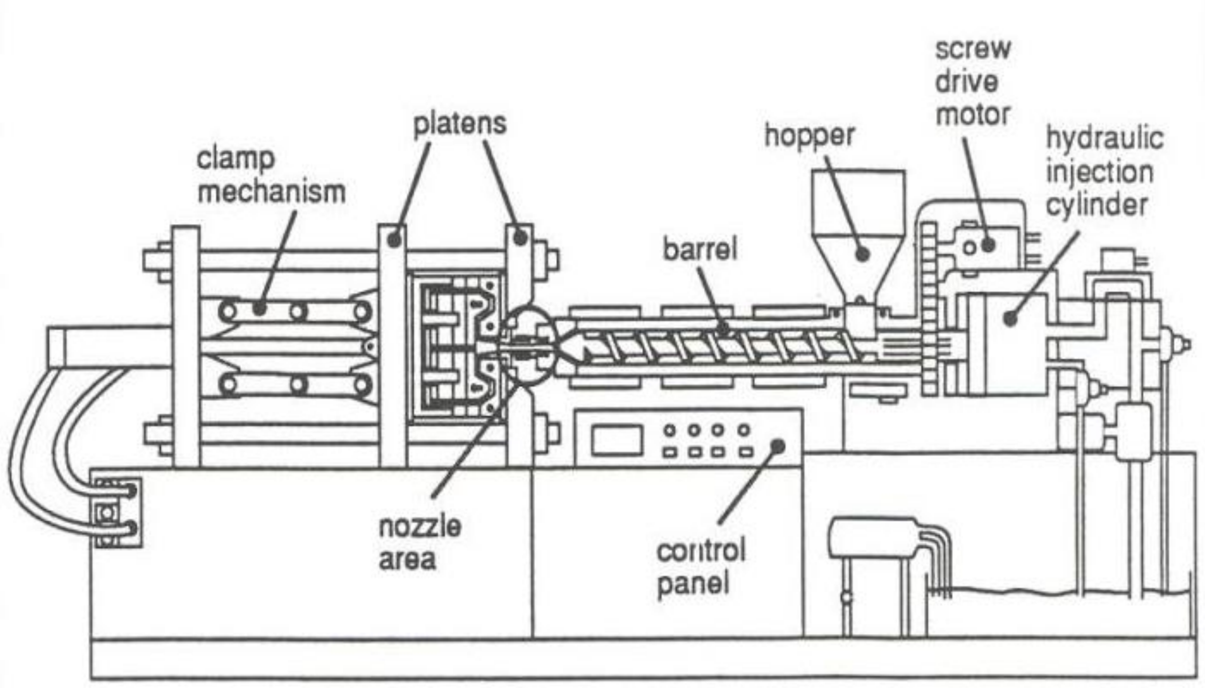

Figure 1. General structure of a plastic injection molding machine. Source: [55, 61].

The basic mechanism of operation of the injection molding machine is based on the sequential execution of cyclic work stages. In the initial phase, the mold is in the open state and the cylinder remains in the retracted state, with the screw placed in the rear position. In the next stage, the mold is closed and the screw is started in a reciprocating motion. This process allows the plasticized plastic to be injected into the mold, which takes place while increasing the internal pressure in the mold, which is crucial for effective filling of the mold cavity.

Then, the molded part is cooled and the screw, rotating, moves the material towards the injection nozzle. After reaching the final position of the screw, the last phase of the injection molding machine cycle occurs: the cylinder retracts, the mold opens again, which allows the molding to be removed. Once this process is complete, the entire cycle of the injection molding machine is ready to start again [55, 57, 59, 60].

The most important advantages of injection molding include [55, 59, 60, 62]:

- high quality and aesthetics of manufactured products,
- repeatability of shape and size,
- the ability to create even very complex shapes using one technical operation,
- possibility of mass production,
- low level of emissions of harmful substances,
- full process automation,
- no need for finishing processing,
- low production waste.

5.2. Characteristics of the plastic injection molding machine operator's position

The profession of an injection molding machine operator is characterized by specific duties of a production nature. This person is responsible for initiating the process and regulating the parameters of plastic injection molding. Additionally, the operator monitors the quality of manufactured products, sorts and labels them, acting in accordance with established technological instructions and operational procedures [63].

The role of the injection molding machine operator includes managing the production process of thermoplastic and thermosetting plastic products, while observing appropriate standards, instructions and procedures. As part of his duties, the operator introduces the necessary parameters to the injection process, operates production and auxiliary machines for feeding raw materials and receiving finished elements. He is also responsible for supervising the proper conduct of the entire production process [63].

If any irregularities occur in the process, the injection molding machine operator is obliged to take appropriate actions to eliminate the problems. The work process at this position may vary in terms of the degree of automation, ranging from partial to complete automation [63].

Depending on the production volume, the injection molding machine operator performs work manually or mechanically using appropriate tools and devices. His work consists of [63]:

- using an injection molding machine and auxiliary devices to perform the process of injecting plasticized plastic into molds,
- performing daily operation and maintenance of the injection molding machine and auxiliary equipment,
- transporting granules (or pieces) of material from which products (moldings) will be made from the warehouse to the workplace,
- preparing the injection molding machine for operation (e.g. assembling and disassembling injection molds),
- filling the hopper (feed hopper) of the injection molding machine with granulate or shredded plastic from which the products are made,
- checking the injection process and the quality of manufactured products,
- receiving, sorting, labeling, packing and storing manufactured products,
- completing production and quality documentation (including product identification cards),
- performing work in accordance with the principles and regulations of occupational health and safety, fire protection, environmental protection and ergonomics.

An employee operating an injection molding machine usually performs his duties in production spaces, isolated from the influence of atmospheric factors. These tasks take place in specialized production sections, often referred to as "injection shops", i.e. departments equipped with machines and devices for creating plastic products. Additionally, within these zones there are also warehouses for raw materials and finished products.

In his scope of duties, the injection molding machine operator uses a variety of equipment, tools and equipment, which includes [63]:

- evices for loading plastic pellets or slices into an injection molding machine,
- tools for assembling and disassembling injection molds, including trolleys, cranes and lifts,
- devices for transporting plastic granules and finished products from and to the warehouse,
- instruments for monitoring key parameters of the injection process, such as temperature and pressure,
- tools for removing products from molds,
- computer hardware and software supporting the performance of tasks,
- devices for labeling, quality control and storage of manufactured elements,
- individual and collective protective equipment used in professional work.

Depending on the size and characteristics of the enterprise, the operator may work in a single-shift or multi-shift system, with different working hours. These tasks can be performed individually or as part of a team, and the operator's work is supervised by foremen or managers.

6. Assessment of the level of occupational safety during operation of a plastic injection molding machine using the JSA method

The occupational risk assessment of plastic injection molding machine operators was performed using the advanced JSA matrix method. The research included an analysis of the workplace, an interview with employees and a review of the company's internal documentation. As a result, it allowed us to identify potential occupational hazards. Then, for each of them, individual risk parameters were assessed and the risk value and its category were determined.

The basis for determining specific values of individual risk parameters were the technical and organizational security measures existing in the company. The analysis showed that thanks to the use of innovative technical solutions, the injection molding machine achieves the highest safety standards. Examples include the use of advanced security systems, interlocks and protective covers that minimize the risk of accidental machine start-up. Moreover, the employer has protected each operator by equipping him with specialized glasses and protective clothing, which effectively protects the employee's eyes and skin against potential damage, for example in the event of a device failure.

It is necessary to emphasize that the key element in terms of occupational health and safety is the proper maintenance of technical infrastructure and compliance with safety rules. Any deficiency in these areas can lead to a significant increase in risk beyond acceptable limits.

The study of the level of occupational risk for plastic injection molding machine operators revealed that all identified occupational hazards are within tolerance limits. However, to maintain this status, it is necessary to constantly monitor the effectiveness of the implemented preventive measures and quickly respond to any anomalies.

In the process of detailed analysis of risk parameters, it was found that the frequency of occurrence of threats (F) for all identified risks was uniformly classified at level 5 - daily or 4 (once a week), reflecting the routine nature of these threats in the operations carried out. The probability of events (O) rating for each hazard was assigned at level 1 (unimportant), 2 (unlikely), or 3 (imaginable), which was justified, among others, by: no previous accidents in a given position, as well as confirmed interviews with employees indicating no history of accidents or occupational diseases.

The degree of possibility of avoiding or limiting damage was also considered (A), where the lowest values were assigned to individual threats: 1 - obvious or 2 - probable. Based on the aggregation of these three parameters, the probability of consequences (P) was estimated. Taking into account the C consequence classification, determined on the basis of the severity of possible injuries, the final risk value and its category were extracted from the risk matrix. Detailed risk assessment results are presented in tables 13 and 14.

The indicated occupational hazards and their causes and effects can be considered to be common in the work environment, including at work [10].

Table 13. Identification of hazards in the plastic injection molding machine operator's position.

Hazard symbol	**Hazard**	**Source of danger**	**Effects**
TH-1	Injuries caused by contact with sharp or abrasive edges and surfaces.	Risks associated with workpieces, waste mesh, and machine tables.	Incidences of contusions, lacerations, abrasions, cuts, and traumatic injuries to limbs and head.
TH-2	Compression or crushing injuries due to machinery.	Dangers resulting from the movement of the machine, tilting of the machine, and uncontrolled closing of the clamping jaws.	Significant injuries encompassing sprains, fractures, crush injuries to the head and spine, concussions, internal organ damage, leading to disability or death.
TH-3	Impact from objects dislodged and falling.	Potential for injury from objects stored on racks or from falling materials.	Contusions, head trauma, concussions.
TH-4	Incidents of slips and falls on the same level.	Dangers resulting from wet surfaces, improper cable placement, general mess at the workplace, blocked passages and inappropriate footwear.	Bruises, abrasions, sprains, injuries of the upper and lower limbs, head and spine.
TH-5	Falls from an elevated position to a lower level.	Risks associated with climbing roofs (e.g., for opening), climbing on pallets, machines, working with platforms and ladders	Injuries including bruises, abrasions, sprains, fractures, head and spinal trauma, internal organ damage, disability, and death.
TH-6	Exposure to excessive noise levels.	Noise coming from machines and devices in the production plant	Fatigue, headaches, concentration difficulties, general malaise, auditory damage.
TH-7	Risks of electric shock.	Dangers resulting from faulty electrical installation and improper use of electrically powered devices and tools	Skin irritation and burns, ocular damage.
TH-8	Unexpected closure of the mold	Design errors, errors in the injection molding machine control system, human error	Crushing of the upper limb

Hazard symbol	Hazard	Source of danger	Effects
TH-9	Contact with hot surfaces	Hot cylinder in the injection system	Thermal burns
TH-10	Contact with hot granulate	Moistened filling granulate for the injection molding machine	Thermal burns, eye injuries
TH-11	Contact with hot media (water, oil) thermostatting the mold	Damage to the mold thermostat cables	Thermal burns, corrosion of machines and equipment, electric shock
TH-12	Exposure to particulate matter.	Exposure to dust and particulates released during material transport and processing.	Various types of influenza and complications such as pneumonia.
TH-13	Exposure to influenza viruses (types A, B, C).	Direct contact with individuals infected with the flu.	Colds, flu, pneumonia.
TH-14	Variations in atmospheric conditions.	Hazards resulting from variable work inside and outside the building	Burns, soaking, disability, death, catastrophic events.
TH-15	Fire hazards.	Fire caused by smoking cigarettes, intentional actions (arson), short circuit of the electrical installation, improper storage of flammable materials.	Poisoning, health deterioration, respiratory tract damage, internal organ damage.
TH-16	Contact with hazardous chemicals (liquids, gases, dust)	Exposure to chemicals (e.g. oils, processing oils or polyethylene.	Allergic reactions, mucosal irritation of eyes, throat, larynx, headaches, malaise, intoxication.
TH-17	Potential for allergic reactions.	Exposure to sensitizing factors (viruses, fungi, bacteria)	Occurrence of allergic reactions of the skin, eyes, respiratory tract (rash, eye irritation, cough)
TH-18	Dynamic load on muscles and joints	Moving heavy loads, too many repetitions of the same activities	Pain, musculoskeletal disorders, varicose veins in the legs, spine disorders
TH-19	Static strain on the musculoskeletal system.	Risks related to deposition of materials on injection molding machine templates, operation of computers controlling the injection process.	Visual impairment, pain, burning, tearing, conjunctivitis.
TH-20	Visual strain.	Work requiring precision under poor lighting conditions.	Somatic symptoms (e.g. headaches and dizziness, pain in the gastrointestinal tract), sleep problems, anxiety and depression.
TH-21	Stress on the nervous system.	Interpersonal relations with superiors and colleagues, impacting the employee's work environment.	Risks of lacerations, limb amputations, and fatalities.

Source: own research.

Table 14. Results of occupational risk assessment as a plastic injection molding machine operator

Hazard symbol	Hazard	Preventive measures	Risk assessment					
			F	O	A	**P** [F+O+A]	**C**	**Risk**
TH-1	Injuries caused by contact with sharp or abrasive edges and surfaces.	Working in protective clothing, using gloves and other protective equipment	5	3	2	10	C2	4
							Short inability to work	risk acceptable
TH-2	Compression or crushing injuries due to machinery.	Using protection zones, following designated roads, and following safety rules	4	2	1	7	C4	5
							Death	risk acceptable
TH-3	Impact from objects dislodged and falling.	Securing objects against falling from a height, observing safety rules	5	2	2	9	C3	5
							Prolonged inability to work	risk acceptable

Hazard symbol	Hazard	Preventive measures	Risk assessment					
			F	O	A	**P** [F+O+A]	**C**	**Risk**
TH-4	Incidents of slips and falls on the same level.	Removing spilled liquids, equipping the hall with anti-slip mats, using protective footwear, observing safety rules	5	3	1	8	C3	5
							Prolonged inability to work	risk acceptable
TH-5	Falls from an elevated position to a lower level.	Ensuring cleanliness in the workplace, careful use of ladders and platforms, marking thresholds and possible unevenness	4	1	2	7	C4	5
							Death	risk acceptable
TH-6	Exposure to excessive noise levels.	Use of hearing protection, systematic maintenance of machines and devices that emit noise, cyclical noise measurement	4	2	1	7	C2	3
							Short inability to work	risk acceptable
TH-7	Risks of electric shock.	Observing caution and safety rules when using electrical devices, service and maintenance of electrical installations	4	2	1	7	C4	5
							Death	risk acceptable
TH-8	Unexpected closure of the mold	Inspection and maintenance of the injection molding machine, use of appropriate lubricant, reporting faults, behavior, compliance with safety rules	5	3	2	10	C3	5
							Prolonged inability to work	risk acceptable
TH-9	Contact with hot surfaces	Use of personal protective equipment (heat-resistant gloves, protective clothing), exercise caution	5	3	2	10	C2	4
							Short inability to work	risk acceptable
TH-10	Contact with hot granulate	Use of personal protective equipment (heat-resistant gloves, protective clothing), exercise caution	5	4	2	11	C2	5
							Short inability to work	risk acceptable
TH-11	Contact with hot media (water, oil) thermostatting the mold	Use of personal protective equipment (heat-resistant gloves, protective clothing), exercise caution,	5	4	2	11	C2	5
							Short inability to work	risk acceptable
TH-12	Exposure to particulate matter.	Ensuring adequate air ventilation	4	2	1	7	C2	3

Hazard symbol	Hazard	Preventive measures	Risk assessment					
			F	O	A	**P** [F+O+A]	**C**	**Risk**
							Short inability to work	risk acceptable
TH-13	Exposure to influenza viruses (types A, B, C).	Prevention, voluntary, vaccination	4	2	3	9	C2	4
							Short inability to work	risk acceptable
TH-14	Variations in atmospheric conditions.	Use of protective clothing appropriate to the weather	4	2	3	9	C2	4
							Short inability to work	risk acceptable
TH-15	Fire hazards.	Use of fire protection measures (e.g. class B and D fire extinguishers, fire protection systems), compliance with safety rules	4	2	1	7	C4	5
							Death	risk acceptable
TH-1.6	Contact with hazardous chemicals (liquids, gases, dust).	Ventilation of the production hall, airing of rooms, safe handling of chemicals, maintaining safety data sheets for chemical and hazardous substances	5	2	1	8	C3	5
							Prolonged inability to work	risk acceptable
TH-17	Potential for allergic reactions.	Ventilation of the production hall, airing of rooms	4	2	2	8	C2	4
							Short inability to work	risk acceptable
TH-18	Dynamic load on muscles and joints.	Maintaining ergonomic conditions when lifting and moving loads, ensuring ergonomic working conditions at a computer station	5	3	1	8	C2	4
							Short inability to work	risk acceptable
TH-19	Static strain on the musculoskeletal system.	Adopting the correct body posture while working, resting and rotating employees, observing the principles of egronomics	5	3	1	8	C2	4
							Short inability to work	risk acceptable
TH-20	Visual strain.	Ensuring proper lighting, replacing worn out light bulbs, measuring illumination intensity	5	2	1	7	C2	3
							Short inability to work	risk acceptable

Hazard symbol	Hazard	Preventive measures	Risk assessment					
			F	O	A	**P** [F+O+A]	**C**	**Risk**
TH-21	Stress on the nervous system.	Responding to conflict situations, leisure	5	2	2	9	C2	4
							Short inability to work	risk acceptable

Source: own research.

7. Testing human reliability during the operation of a plastic injection molding machine using the TESEO and HEART methods

7.1. General remarks

Human reliability analysis (also – human error analysis) is an important element in identifying and assessing the causes of events caused by human activity. It mainly involves determining the impact of the human factor (operator) on the implementation and functioning of individual processes, systems and machines. Human reliability analysis allows for the identification of factors that influence the behavior of employees and the safety of facilities, taking into account the characteristics of staff, the working environment, scope of duties and responsibilities in terms of behavior and performance of tasks under stress and emergency situations [42, 54].

Human reliability analysis is therefore used to assess the risk resulting from potential human errors in order to minimize the susceptibility of systems to failure [56, 57]. Human reliability analysis methods assume that analyzing human errors and determining the probabilities of their occurrence can significantly reduce the risk of failure [64, 65, 66, 67].

This publication examines the reliability of a plastic injection molding machine operator using two commonly used methods: the TESCO and HEART methods. The assumptions for the research and the results of the conducted research are presented below.

7.2. TESEO method – assumption and research results

The human reliability test involved determining the probability of human error. The TESEO model assumes that the probability of operator error depends on five factors, the value of which is quantified based on the data contained in tables 15 – 16.

The probability of human error P(B) was determined based on the formula [34, 42, 57, 67]:

$$P(B) = K1 \cdot K2 \cdot K3 \cdot K4 \cdot K5 \quad (2)$$

The results of the research are presented in table 15.

Tabela 15. Results of assessing the reliability of a plastic injection molding machine operator using the TESEO method.

No.	Operator activity/task	Characteristic	Probability of human error
1.	Transporting plastic pellets or chips from the warehouse to the workstation	The activity requires attention, is repetitive Time to take action/reaction: 2-10 s. Average qualifications and no experience Potential threat Average ergonomic conditions	K1 = 0,01 K2 = 1 K3 = 1 K4 = 2 K5 = 3 **P(E) = 0,06**
2.	Preparing the injection molding machine for operation (e.g. mounting and disassembling injection molds)	The activity is not very repeatable Time to take action/reaction: 30-35 s. Average qualifications and no experience Potential threat Average ergonomic conditions	K1 = 0,1 K2 = 1 K3 = 1 K4 = 2 K5 = 3 **P(E) = 0,6**
3.	Filling the charging hopper (feed hopper) of the injection molding machine with granulate or plastic chips	A simple, repeatable activity Time to take action/reaction: over 20 s. Average qualifications and no experience Potential threat Average ergonomic conditions	K1 = 0,001 K2 = 0,5 K3 = 1 K4 = 2 K5 = 3 **P(E) = 0,003**

No.	Operator activity/task	Characteristic	Probability of human error
4.	Checking the injection process and the quality of manufactured products,	The activity is not very repeatable Time to take action/reaction: 30-35 s. Average qualifications and no experience Potential threat Average ergonomic conditions	K1 = 0,1 K2 = 1 K3 = 1 K4 = 2 K5 = 3 **P(E) = 0,6**
5.	Receiving, sorting, labeling, packing and storing manufactured products	The activity is not very repeatable Time to take action/reaction: over 60 s. Average qualifications and no experience Potential threat Average ergonomic conditions	K1 = 0,1 K2 = 0,1 K3 = 1 K4 = 2 K5 = 3 **P(E) = 0,06**
6.	Completing production and quality documentation (including product identification cards)	The activity requires attention, is repetitive Time to take action/reaction: over 20 s. Average qualifications and no experience Potential threat Good ergonomic conditions	K1 = 0,01 K2 = 0,5 K3 = 1 K4 = 2 K5 = 1 **P(E) =0,01**

Source: own research.

The assessment shows that the greatest probability of making a mistake by a plastic injection molding machine operator concerns two activities performed by them, i.e.: preparing the injection molding machine for operation, e.g. assembling and disassembling injection molds (task 2) and checking the injection process and the quality of manufactured products (task 4) and is 0.6. The main factors contributing to the increase in the P(E) value are the fact that these are non-repeatable activities that require non-standard actions in a relatively short time (up to 30 seconds).

In turn, the lowest probability of making an error concerns filling the injection molding machine's hopper with granulate or plastic chips. It is a simple, repeatable activity that is not time-limited.

7.3. HEART method – assumption and research results

In order to determine the operator's reliability, the probability of human error during the implementation of tasks related to the operation of the plastic injection molding machine was estimated. The research assumed that these are routine, well-practiced, fast tasks requiring a relatively low level of dexterity. In the analyzed situation, the factors contributing to human error will be: incorrect technique, poor risk perception and lack of experience of the operator.

Using the HEART approach, at the beginning a task type was selected (Table 11) corresponding to a specific reliability value. In this case it is the type of task (E - Routine, well-practiced, fast tasks requiring a relatively low level of dexterity) and the corresponding human unreliability (0.02). Then, appropriate correction factors were assigned to the above-mentioned conditions conducive to making an error, based on the principles described in table 11:

- incorrect technique (6,0)
- poor risk perception (4,0)
- lack of experience of the operator (3,0)

The next step is to determine the relative importance of the conditions for each task (by taking a value from 0 to 1). Based on the above data, the values of impact coefficients for individual factors were calculated [54]. The test results are presented in table 16.

Table 16. Table. Results of assessing the reliability of a plastic injection molding machine operator using the HEART method

No.	Operator activity/task	Nominal probability value	Factors	Relative importance of factors(0 to 1)		
1.	Transporting plastic pellets or chips from the warehouse to the workstation	0,02	Incorrect technique	0,6	$WP_1 = (6 – 1) x 0,6 + 1 = 4,0$	$WWZ_1 = 4/8,5 = 0,47 =$ 47%
			Poor risk perception	0,5	$WP_2 = (4 – 1) x 0,5 + 1 = 2,5$	$WWZ_2 = 2,5/8,5 = 0,29 =$ 29%
			Inexperience	0,5	$WP_1 = (3 – 1) x 0,5 + 1 = 2,0$	$WWZ_3 = 2/8,5 = 0,24 =$

No.	Operator activity/task	Nominal probability value	Factors	Relative importance of factors(0 to 1)		
						24%
	Probability of error				**P(E) = 0,02 x 4,0 x 2,5 x 2,0 = 0,4 = 40%**	
2.	Preparing the injection molding machine for operation (e.g. mounting and disassembling injection molds)	0,02	Incorrect technique	0,9	WP_1 = (6 – 1) x 0,9 + 1 = 5,5	WWZ_1 = 5,5/10,7 = 0,52 = 52%
			Poor risk perception	0,6	WP_2 = (4 – 1) x 0,6 + 1 = 2,8	WWZ_2 = 2,8/10,7 = 0,26 = 26%
			Inexperience	0,7	WP_3 = (3 – 1) x 0,7 + 1 = 2,4	WWZ_3 = 2,4/10,7 = 0,22 = 22%
	Probability of error				**P(E) = 0,02 x 5,5 x 2,8 x 2,4 = 0,74 = 74%**	
3.	Filling the charging hopper (feed hopper) of the injection molding machine with granulate or plastic chips	0,02	Incorrect technique	0,4	WP_1 = (6 – 1) x 0,4 + 1 = 3	WWZ_1 = 3/6,7 = 0,45 = 45%
			Poor risk perception	0,3	WP_2 = (4 – 1) x 0,3 + 1 = 1,9	WWZ_2 = 1,9/6,7 = 0,28 = 28%
			Inexperience	0,4	WP_3 = (3 – 1) x 0,4 + 1 = 1,8	WWZ_3 = 1,8/6,7 = 0,27 = 27%
	Probability of error				**P(E) = 0,02 × 3 x 1,9 x 1,8 = 0,205=20%**	
4.	Checking the injection process and the quality of manufactured products	0,02	Incorrect technique	0,8	WP_1 = (6 – 1) x 0,8 + 1 = 5,0	WWZ_1 = 5/10,6 = 0,47 = 47%
			Poor risk perception	0,8	WP_2 = (4 – 1) x 0,8 + 1 = 3,4	WWZ_2 = 3,4/10,6 = 0,32 = 32%
			Inexperience	0,6	WP_3 = (3 – 1) x 0,6 + 1 = 2,2	WWZ_3 = 2,2/10,6 = 0,21 = 21%
	Probability of error				**P(E) = 0,02 × 5,0 x 3,4 x 2,2 = 0,75 = 75%**	
5.	Receiving, sorting, labeling, packing and storing manufactured products	0,02	Incorrect technique	0,4	WP_1 = (6 – 1) x 0,4 + 1 = 3,0	WWZ_1 = 3/7,2 = 0,42 = 42%
			Poor risk perception	0,4	WP_2 = (4 – 1) x 0,4 + 1 = 2,2	WWZ_2 = 2,2/7,2 = 0,30= 30%
			Inexperience	0,5	WP_3 = (3 – 1) x 0,5 + 1 = 2,0	WWZ_3 = 2/7,2 = 0,28 = 28%
	Probability of error				**P(E) = 0,02 × 3,0 x 2,2 x 2,0 = 0,26 = 26%**	
6.	Completing production and quality documentation (including product identification cards)	0,02	Incorrect technique	0,3	WP_1 = (6 – 1) x 0,3 + 1 = 2,5	WWZ_1 = 2,5/7,4 = 0,34 = 34%
			Poor risk perception	0,5	WP_2 = (4 – 1) x 0,5 + 1 = 2,5	WWZ_2 = 2,5/7,4 = 0,34 = 34%
			Inexperience	0,7	WP_3 = (3 – 1) x 0,7 + 1 = 2,4	WWZ_3 = 2,4/7,4 = 0,32 = 32%
	Probability of error				**P(E) = 0,02 × 2,5 x 2,5 2,4 = 0,3 = 30%**	

Source: own research.

The results of the assessment of the probability of error using the HERAT method indicate that during the operation of a plastic injection molding machine, the greatest level of risk related to operator reliability occurs in the case of two activities, i.e. preparing the injection molding machine for operation (task 2) and checking the injection process and the quality of manufactured products (task 4). High values of the P(E) coefficient are determined by the high level of relative importance of the assessment factors (incorrect technique, poor risk perception and lack of experience).

In the case of activities related to preparing the injection molding machine for operation, it was found that incorrect technique (0.9) has the greatest impact on the probability of making an error by the operator, followed by lack of experience (0.7) and poor risk perception (6). Similarly, these factors were assessed in the case of the task related to the control of the injection process and the quality of manufactured products. The relative importance of these factors is as follows: incorrect technique (0.8), poor risk perception (0.8), lack of experience (0.6).

In turn, the lowest level of error probability is characterized by work related to filling the injection molding machine's hopper with plastic granules or chips and receiving, sorting, labeling, packaging and storing manufactured products.

It is also worth emphasizing that the analysis of the probability of making an error using the TESEO method showed comparable results.

The above-mentioned tasks number 2 and number 4 are related to the direct operation of the injection molding machine, which involves their proper use, carrying out activities according to precisely defined sequences and procedures, as well as their systematic diagnostics and maintenance. The correct risk perception is also important, i.e. the employee's awareness, appropriate to the situation, that he may make a mistake, which requires him to exercise an appropriate level of caution. Professional experience is also important for operating this type of equipment.

8. Conclusions

The analysis of the injection molding machine operator's workplace and the factors influencing occupational safety, as well as the analysis of the obtained numerical results, allow for the following conclusions regarding the topic of the article:

1. Occupational risk assessment is crucial to ensuring that employers maintain a safe and healthy working environment. This process, by identifying factors in the work environment, allows for the correct operation of machines and devices, and also improves human unreliability (tendency to make mistakes). In addition, it provides key information enabling planning interventions aimed at improving working conditions and reducing the probability of failures or errors made by employees (operators).
2. When assessing occupational risk, it is essential to take into account all potential or existing factors that are dangerous, harmful to health or cause discomfort. In addition, particular attention should be paid to the unique vulnerability of specific groups of workers, including older workers and workers with no experience. These are groups of professionals who are more prone to making mistakes and are therefore more unreliable.
3. The identification of hazards forms the cornerstone of occupational risk assessment. This necessitates the collection of comprehensive information pertaining to both the workplace and the broader organizational context. Equally crucial is the analysis of job requirements and the range of activities performed by employees.
4. To ascertain potential hazards, a comprehensive study was conducted, encompassing workplace observation (utilizing a checklist), interviews with the employer, employees, and a health and safety expert. Additionally, an analysis of the following organizational documents was performed: records of illnesses, accident reports, measurements of harmful environmental factors, workplace guidelines, manufacturers' instructions for machinery and equipment, and safety data sheets.
5. Given the diverse range of risk factors present in the work environment, there is no single, universally applicable risk assessment method applicable to all scenarios. Moreover, Polish legal regulations do not impose the choice of a specific assessment method. In this work, the Occupational Safety Analysis (JSA)

matrix method was used to assess the occupational risk of plastic injection molding machine operators.

6. The occupational risk assessment showed that the examined job position of the plastic injection molding machine operator is characterized by an acceptable level of occupational risk. However, maintaining this state of affairs requires continuous monitoring of technical and organizational security measures. In this context, it is also important to increase employee awareness and remain vigilant in special situations. In this area, immersive techniques, such as virtual reality for employee training and testing of technical concepts of positions by their users, may be beneficial. Failure or neglect of preventive measures identified in the risk assessment documentation may increase the likelihood of work-related accidents or illnesses, potentially raising the risk category to an unacceptable level.
7. The fundamental stage of the research, apart from the occupational risk analysis, was to determine the reliability of the human factor. Human reliability is identified with the characteristic of resistance to disturbances occurring during work. Due to the consequences of human errors made during work (including during the operation of machines and devices), it is necessary to study them and determine the conditions for the operator's reliable work. In practice, various indicators and quantitative methods are widely used for this purpose.
8. Many different methods for assessing human reliability have been described in the literature. Commonly used methods are HRA (human reliability analysis method), which focus on estimating the probabilities of potential human errors. These methods are based on expert opinions and data presented in qualitative and quantitative form. In this work, the authors used two commonly used methods for their own research: TESEO and HERAT.
9. The research results indicated that the greatest probability of making a mistake by a plastic injection molding machine operator involves two activities: preparing the injection molding machine for operation (including assembly and disassembly of injection molds) and supervising the injection process and the quality of manufactured products. The analysis of the work process in accordance with the TESEO methodology shows that these are activities that require optimal attention (caution) and quick action. Additionally, the influence on the operator's error probability level results from his or her average knowledge and training. The analysis of the work environment also showed that it is characterized by the presence of potential threats and an average level of ergonomic conditions.
10. Taking into account the HEART methodology for assessing the probability of error, it should be noted that during the operation of the injection molding machine, tasks related to its preparation for operation (including assembly and disassembly of injection molds) and supervision of the injection process and the quality of manufactured products are characterized by a relatively high importance of the examined factors. i.e. incorrect technique, poor risk perception and lack of experience.
11. As a result of the occupational risk assessment and human reliability assessment studies, it should be concluded that the injection molding machine operator's workplace requires monitoring of dangerous, harmful and burdensome factors in the work environment, the effectiveness and efficiency of the implemented security measures, and attention should also be paid to counteracting risks related to work reliability. operator. For this purpose, it is required to comply with the adopted safety standards and procedures and to maintain the proper technical condition of the device. An important element of prevention is also raising employees' awareness of potential threats and the possibility of employee making mistakes, as well as increasing the level of their knowledge and training. Only such an approach to managing the work process can guarantee maintaining an appropriate level of safety.

As part of the development of the research topic and further work, the authors plan to continue studying the reliability of the operator's performance as a function of their training level for specific conditions using VR technology. They intend to formalize potential or existing hazardous factors for inclusion in the assessment and compare the results obtained using the Human Reliability Assessment (HRA) method with those obtained using other methods, including expert opinions. Additionally, authors plan to incorporate methods utilizing fuzzy logic to mitigate the impact of potential information gaps on the assessment results.

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