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# VISUAL SOLUTIONS AS A WAY TO IMPROVE WORK SAFETY WHEN USING MACHINES – SELECTED ASPECTS OF VM

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**Abstract:**
The issue of ensuring work safety during the use of machines plays a key role due to the recorded accident events, the source of which are the machines in use. In the scope of reducing the risk associated with machines, particular attention should be paid to the threats, as well as solutions allowing to limit their negative impact on the operator. The study presents the possibility of using visual management (VM) as a form of information transfer that allows to meet the requirements set out in legal regulations, as well as reduce the risk of accidents. The machines in question were assessed for the possibility of using various forms of visual management to reduce the risk of accidents. The investigations were also supplemented with an analysis of accident statistics to present the importance of using visual management in improving the safety of machine operators' work. The conducted analyzes allowed to determine the direction of activities in the use of various forms of visual management aimed at improving the safety of machine operators.

***Key words:*** *visual management, usage machinery, accident at work, forecasting, risk reduction*

## INTRODUCTION

Enterprises are looking for various solutions to improve work safety. The methods and tools used in the Lean Manufacturing concept can improve safety in the work environment. The article presents one of the methods of the LM concept, which allows to reduce the risks associated with the use of machines. The perception of information through the organ of vision becomes a key element in both every day and professional life. The information provided should be simple, understandable for the recipient and not mislead him. Various forms of visual management (vertical and horizontal signs, pictograms, LOTO system) can be used to reduce accidents at work and potentially accidental incidents in production companies, allowing for their reduction or even elimination.

The aim of this study is to assess the possibility of implementing visual management as a method of improving the safety of machine operators and enabling the fulfillment of legal requirements. Effective use of various forms of visual management has a significant impact on improving work safety and ergonomics, as well as increasing employee awareness in this regard. Thus, the use of visual solutions can be effective in terms of improving work safety and shaping safe behavior of employees in the field of machine exploitation.

## LITERATURE REVIEW

Visual management (VM) is one of Lean Manufacturing tools and forms part of lean production [1]. It has been an inseparable component of the Toyota production system and its derivatives since its very beginning [2, 3]. It is a universal form of effective communication, discipline and motivation [4]. It allows for the transfer of information in a simple and easy manner [5, 6]. Visual management has an impact on worker autonomy, fosters the elimination of waste, enables the exchange of information, reveals noncompliances [7, 8]. Visual information is received in the work environment by human senses, that is: sight, touch, hearing, smell and taste [7, 9]. Information received by the senses of sight, hearing and touch (machinery control devices) will play a significant role in the field of machinery safety, which is the subject-matter of this study. Visual and auditory stimuli make it possible to receive information and are, as a rule, available to all workers [10]. The information is also provided at the right place and time. It is essential because it ensures clarity, but most of all, it has an impact on accident risk reduction [5]. Previous studies on visual management point to its use in various areas of life – road signs (vertical and horizontal) [2], branches and sectors of the economy: production [2], construction [5, 9, 11], rail market [4] automotive [12],

higher education [13], banking services market [14], health care [15], petrochemical industry [16], as well as in areas connected with: waste identification [17], tools suitable for the 4.0 industry affecting the human-computer interaction [18], boosting supply chain efficiency [19], or the identification of materials in a workshop of the maintenance department [20]. The broad use of visual management did not bypass the area connected with work safety and ergonomics. Prior research points to a significant role of visual management also with regard to that area [16, 21].

Work safety in using technological machinery is essential for enterprises. Moreover, machinery industry is an important part of the European Union economy [22]. The concept of ensuring safety connected with machinery is based on two pillars related to minimum and essential requirements. As regards the minimum requirements, the employer is responsible for the adaptation and maintenance of machinery in conformity with legal requirements [23, 24], whereas as regards the essential requirements, the responsibility remains with the manufacturer [22, 25]. Cooperation between employers and manufacturers is important to secure safety for machine operators.

## MATERIAL AND METHOD

In order to achieve the intended aim of the study, a three-step own methodology was adopted.

In **the first step**, a control list was prepared on the basis of the applicable legal regulations [22, 23, 24, 25] and harmonized standards [26, 27, 28, 29, 30, 31], which made it possible to assess the use of visual management for risk reduction. Then, non-compliances were detected as regards the legal requirements and standards in relation to areas where it is possible to apply visual management to machinery operation as a form of reduction in residual risk (the risk remaining after the application of manufacturer's and user's solutions). As regards the use of visual management as a form of risk reduction, technological machinery, such as bench drill, mechanical press and rubber machine, were subjected to analysis. The causes of the occurrence of non-compliances were also determined.

**The second step** addressed the essence of the problem on the basis of the detected causes of accidents occurring when machinery is operated. The causes of accidents were compared with the data published by Statistics Poland. The compared Statistics Poland [32] figures also underwent a prediction process in order to assess the trend in the occurrence of the causes of accidents under analysis (increase, decrease). The following models were used in the forecasting process: Holt's model with a multiplicative trend (forecast value presented in Fig. 1), and Holt's model with additive trend (forecast value presented in Fig 2) [33, 34]. The prediction process has not been completed by making forecasts. For the purposes of the study, the following assumptions were made [33, 34, 35, 36]:

- the mean error Ψ cannot exceed 10% ($\Psi < 10\%$);
- the value of the Rot Mean Square Error of the ex post RMSE forecasts should be less than or equal to the standard deviation of the $S_e$ model residuals (RMSE ≤ $S_e$).

In **the third step**, on the basis of performed analyses including an assessment of machinery and causes of accidents occurring during its operation, a list comprising various forms of solutions falling within visual management and allowing for risk reduction and fulfilment of legal requirements was prepared.

## RESULTS

### Assessment of the application of visual management in terms of risk reduction

In this study, the following machines were subjected to an own assessment: bench drill, mechanical press and rubber machine. An initial analysis made it possible to specify the type of legal requirements that were dedicated to the machines in question. Then, on the basis of applicable legal acts and harmonized standards, a list of areas in which visual management can be used as a form of residual risk reduction was made. The first part specifies legal acts [22, 23] (machinery and equipment directives) and harmonized standards [26, 27, 28, 29, 30, 31] (Table 1), which formulate good practices on machinery safety. In addition, harmonized standards point to areas directly referring to the need to apply various forms of visual management. The following part consisted of an identification of selected areas connected with safety and referring to various forms of the implemented solutions from visual management. The analysis included selected areas connected with [26, 27, 28, 29, 30, 31]:

- control devices – the assessment included such aspects connected with visual management as the reception of control devices by more than one sense (sight, touch), visualization, i.e., color, description of control devices – their simplicity, clear and unambiguous interpretation, compliance with the provisions in the documentation file and instructions for machinery, durability of descriptions;
- emergency stop – the assessment covered such aspects connected with visual management as (yellow) background and form of control device, typically a (red) mushroom. The background should be outside the control device. Attention was also drawn to: the reception of the emergency stop device (sight, touch), compliance with the provisions in the documentation file and instructions for machinery, durability of description;
- the occurrence of risks related to, among others, moving parts of machinery, hot surfaces, electrical hazards, noise, where attention was drawn to the arrangement and location of visual solutions in the operator's field of view and in a place where a direct hazard exists (mandatory, prohibition and information signs);
- application of protective measures – the assessment referred to visual information on the need to apply protective measures and the individual protection used by workers;

- machinery maintenance – in this regard attention was drawn to solutions used by workers in the field of maintenance work, visual protection against accidental starting of the machine by third persons.

For each machine, the assessment process included the implementation of visual solutions that permit the fulfilment of legal requirements and aim to improve the safety and efficiency of performed production tasks. In the case of the machines in question, i.e. bench drill, mechanical press and rubber machine, the following non-compliances directly related to the application of various forms of visual management were recorded (Table 1):

- a lack of the proper color of control devices, a lack of their description that allows the identification of the performed function, gaps in the instructions and documentation file for machinery;
- as regards the emergency stop, a lack of emergency stop switch was recorded (bench drill). In the case of mechanical press and rubber machine, the yellow background was missing. That element was also not described;
- as regards warning, mandatory and prohibition signs, there were no pictograms giving information on the other residual risk related to, inter alia, moving parts of machinery, the duty to become familiar with the instructions for machinery, hot surfaces, or the need to use a movable guard during the performance of production tasks. The absence of pictograms resulted in a failure to use personal protection;
- in the case of mechanical press and rubber machine, no visual solutions were used that would allow for an unambiguous identification of machine downtime due to repair, overhaul or maintenance.
- The detected non-compliances were mainly due to inappropriate organization of work and inappropriate organization of workstation, which also resulted in a failure to use personal protection.

***Table 1***

***Assessment of residual risk reduction by visual solutions***

| Requirements of harmonized standards in the scope of the applicability of visual management | Subject of assessment | | | | | |
|---|---|---|---|---|---|---|
| | Bench drill | | Mechanical press | | Rubber machine | |
| | Meeting legal requirements | | | | | |
| | Yes | No | Yes | No | Yes | No |
| **Area being the subject of analysis: Control devices** | | | | | | |
| Legal requirement: Controls devices (on/off) should be clearly visible, recognizable, enable their safe use and be easily identifiable | | | | | | |
| perception of control devices with more than one sense | x | | x | | x | |
| visualization – color of control devices (red, green) | | x | | x | | x |
| description of the control devices (Start/Stop) | | x | | x | | x |
| compliance with documentation, instructions | | x | | x | | x |
| persistence of descriptions | | x | | x | | x |
| Cause of non-compliance: inappropriate organization of workstation | | | | | | |
| **Area being the subject of analysis: emergency stop** | | | | | | |
| Legal requirement: The machinery must be fitted with an emergency stop devices that is clearly recognizable and visible | | | | | | |
| perception of control devices with more than one sense | | x | x | | x | |
| visualization – color – red mushroom on a yellow background | | x | | x | | x |
| control devices description – emergency stop switch | | x | | x | | x |
| compliance with documentation, instructions | | x | | x | | x |
| persistence of descriptions | | x | | x | | x |
| Cause of non-compliance: inappropriate organization of workstation | | | | | | |
| **Area being the subject of analysis: warning signs, mandatory and prohibition signs** | | | | | | |
| Legal requirement: Measures must be taken to communicate the remaining risks from the hazards | | | | | | |
| information about the remaining residual risk | | x | | x | | x |
| location within the operator's field of vision | | x | | x | | x |
| unambiguity, simplicity of understending | | x | | x | | x |
| persistence of descriptions | | x | | x | | x |
| Cause of non-compliance used: inappropriate organization of workstation, not using protective equipment | | | | | | |
| **Area being the subject of analysis: machine maintenance** | | | | | | |
| Legal requirement: Maintenance should take place outside the danger zones and when the machine is at a standstill. The devices enabling the disconnection of the energy source should be clearly marked, it should be possible to block them | | | | | | |
| used visual protection during repairs, maintenance and adjustment of machines | Not applicable | | | x | | x |
| durability of markings | | | | x | | x |
| Cause of non-compliance: inappropriate organization of work, not using protective equipment | | | | | | |
| **Area being the subject of analysis: protective equipment** | | | | | | |
| Legal requirements: Provide protective measures, provide instructions for safe work (adjustment, maintenance, operation) | | | | | | |
| the availability of visual information on the necessity to use protection | | x | | x | | x |
| availability of instructions | | x | | x | | x |
| Cause of non-compliance: inappropriate organization of work, inappropriate organization of the workstation, not using protective equipment | | | | | | |

**Analysis of accidents at work and their causes**

For the purposes of this study, an analysis covered statistical data from Statistics Poland [32] on the number of persons injured in accidents at work who were operating a machine at the time of accident. The analysis included events recorded in the years 2011-2020 (a period of ten years). The analysis of statistical data (Fig. 1) states that the highest number of persons injured in accidents at work during machine operation was recorded in 2011. Since 2011, fluctuations (rise, fall) in the number of persons injured were recorded. In 2020, a significant fall in the number of injured persons was recorded. Besides, forecasts for the years 2021-2022 were made to assess the trend. The forecasts of persons injured during machine operation were, respectively:

$$y^*_{2021} = 5484,$$
$$y^*_{2022} = 4827.$$

These figures were obtained using smoothing parameters $\alpha$ = 0.83 and $\beta$ = 0.59. The forecasts were deemed as admissible because the values of the estimated ex post forecast errors were, respectively:

$$\Psi = 6.3\%,$$
$$RMSE = 664{,}7,$$
$$S_e = 753.7.$$

The forecasts were deemed as admissible in accordance with the assumptions defined in the own methodology.

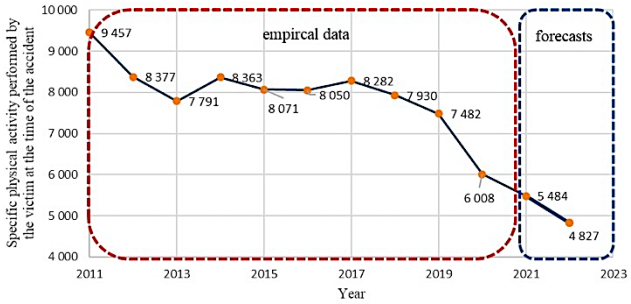


***Fig. 1 Numbers of people injured in accidents while operating machinery, together with event forecasts***

The determined forecast values provide positive information for enterprises in which primarily machine operators are victims of accidents. In connection with the above, the performed analyses were supplemented by the causes of accidents suffered by machine operators. For the purposes of this study, the analysis covered only the causes identified in the first part of the study, i.e. inappropriate organization of work, inappropriate organization of workstation, failure to use protective equipment. The performed analyses state that these causes account for approximately 30% (period of analyses – years 2011-2020) of all causes of accidents recorded in Poland. Fig. 2 shows a summary table for the number of persons injured in accidents at work resulting from the causes under analysis. From 2012 to 2016, there is a significant decline in the number of persons injured in accidents resulting from causes related to inappropriate organization of work, inappropriate organization of workstation and a failure to use protective measures. In 2017, there was an increase, to be subsequently followed by a downward trend. Moreover, for the purposes of this study, ex ante forecasts were determined for the years 2021-2022. The determined forecast values also fit into the downward trend and are, respectively:

$$y^*_{2021} = 1720,$$
$$y^*_{2022} = 1610.$$

These values were obtained using smoothing parameters α = 0.71 and β = 0.42. The forecasts were deemed as admissible because the values of estimated ex post forecast errors were, respectively:

$$\Psi = 8.1\%,$$
$$RMSE = 249.5,$$
$$S_e = 278.8.$$

The forecasts were deemed as admissible in accordance with the assumptions defined in the own methodology.

The downward trend in the number of persons injured in accidents during machine operation and in the main causes under analysis needs to be maintained. However, it is necessary to take actions aimed at reducing accidents at work and their causes. It is therefore important to implement effectively protective measures that fall within the scope of various forms of visual communication.

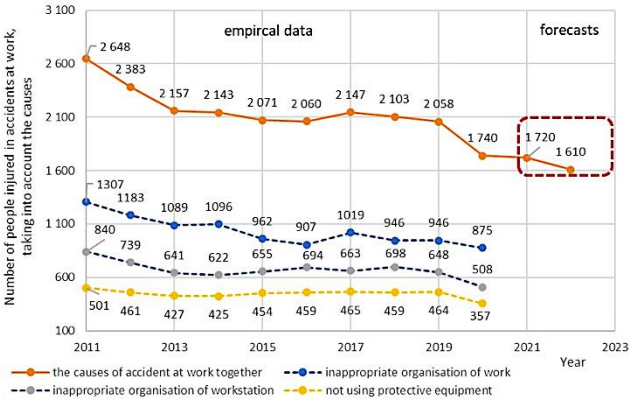


***Fig. 2 Number of people injured in accidents at work, taking into account the causes***

**FORMS OF VISUAL MANAGEMENT IN THE AREA OF RISK REDUCTION**

The lack of visual information placed on machinery and at workstations is an obstacle in the performance of works and causes accidents at work. Within the scope of performed analyses, non-compliances were detected in the use of various forms of visual management, which are received by the organ of sight, touch. As regards **control devices**, it is proposed that control devices that differ in color are introduced (Stop – red, Start – green), in addition to the description of control devices that clearly defines their function (Start, Stop) – height of the wording 30 mm. It is also important to ensure the durability of introduced solutions and to transfer the introduced changes to the machinery documentation file and instructions at the workstation.

As regards the **emergency stop**, it is proposed for the machinery in question that a device taking the form of a red mushroom on a yellow background is used, along with a description: emergency switch. The height of the wording should be 30 mm and all the wordings should be resistant to the external environment. The introduced changes

should be included in the documentation file and instructions for machinery.

Information in the form of **pictograms** is an essential part of visual management. The recommendation for the machinery in question is the use of standardized signs: mandatory signs (see the instructions for machinery, use guards, use protective measures), prohibition signs (moving machine parts, prohibition to start), warning signs (general warning sign, beware of moving parts, electric shock warning). Durability is also required of this form of risk reducing solutions from the scope of visual management. All pictograms situated on machinery should also be described in the documentation file and instructions. In the case of mandatory signs, it should be remembered that the employer is obliged to provide workers with protective equipment free of charge.

In order to ensure safety of workers carrying out **machinery maintenance and repair**, the LOTO (Lockout – Tagout) system, which takes the form of locks and tags, could be implemented. The locks are adapted to identified energy sources, preventing the accidental turning-on of a dangerous energy source. In addition, the lock is closed with a padlock. Padlocks can vary in color depending on a group of workers carrying out machinery repair and maintenance. The last element is the tag, which allows for the identification of the worker who attached it. The LOTO system can effectively improve work safety and it also fits into the concept of visual management.

The application of solutions representing various forms of visualization and information transfer for workers can be seen as a significant solution in the area of residual risk reduction.

## DISCUSSION OF THE RESULTS

The issue of ensuring work safety when using machines is an important topic for production companies. It becomes important to look for methods and solutions to improve work safety and meet the requirements set out in legal regulations. Effective implementation of visual management as a form of limiting the risk associated with the use of machines may translate into the improvement of working conditions, i.e. reduction of accidents at work, potentially accidental events. The study refers to the narrow area of operation of enterprises, i.e. machine parks. However, it is possible to use visual management more widely in terms of improving work safety, but also work organization. Within the Lean Manufacturing concept, other methods and tools can be distinguished, the impact of which on the improvement of working conditions is possible. The methods and tools include: the 5S (6S) method, SMED, One Point Lesson, Kaizen [3].

## CONCLUSIONS

The conducted own research has shown the important role of visual management in terms of improving work safety when using machines. The machines in question did not meet the requirements of legal regulations and standards. Registered non-conformities were mainly related to the marking of control devices, the lack of markings, including pictograms informing about the remaining residual risk, or the lack of solutions ensuring safe repair and maintenance of machines. Meeting the requirements was possible through the use of various forms of visual management (pictograms, descriptions, LOTO system). Each of the presented solutions effectively improves the working conditions of machine operators, as well as repair and maintenance workers. The issue of accidents at work of machine operators, where the main causes are inappropriate organization of work, inappropriate organization of workstation, failure to use protective measures, requires the implementation of solutions aimed at increasing awareness and improving safety. Compiled statistical data of the Statistic Poland [32] and the designated (ex ante) forecasts for 2021-2022 indicate a downward trend, which is good news for enterprises. However, special attention should be paid to simple forms of visualization that allow employers to meet legal requirements and facilitate the performance of production tasks by employees and improve communication.

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