OPTIMIZING RISK ASSESSMENT: THE CENTER POINT TO INCREASE MAINTENANCE WORKER SAFETY

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Abstract: Maintenance is associated with various management processes, such as safety, environmental and quality management. In terms of safety management and environmental impact in industry, the role of efficient and successful maintenance is important due to the increasing demands and expectations for achieving the intrinsic safety of a system. Reliability is also important for environmental safety, as errors and accidents in high-risk industries (e.g. mining, oil and gas, chemical industry) can cause a major impact on the environment. This reality sets high requirements for maintenance in such industries, due to the essential role it plays in supporting production management by ensuring trouble-free production. The main objective of this article is to systematically present the author's reflections on the binomial risk assessment-prevention of hazards associated with maintenance, in order to provide a core of good practice guidelines for all stakeholders in Romania, interested in and/or affected by the major incidence of undesirable events with significant negative consequences occurring in the field of industrial maintenance. We believe that an increase in the awareness and knowledge of specialists in the field of occupational health and safety is necessary, and this work provides a micro-compendium on a topic of primary interest in this spirit.

Keywords: risk assessment, industrial maintenance worker, accident at work, unsafe act, Lockout-Tagout Procedure.

1. INTRODUCTION

The sources of potential accidents can be explored in companies by interviewing workers, supervisors and management [1]. Risk assessment, interviews and observations complement each other as research methods [2]. Objective risk assessments and observations support interviews, which reflect the subjective opinions of workers and company representatives. Thus, it can be assumed that the risks within companies and the chosen tasks are reliably outlined [3].

Moreover, the analysis of accident types and sources can be based on the actual details contained in the official investigation files of work accidents [4].

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The purpose of the study of accidents in industrial maintenance is to prevent the recurrence of similar accidents and it must be taken into account that research files describe the accident episode with limited details regarding the information and contributing factors [5]. In addition to the descriptive text, the chain of events with basic information is sequentially modeled [6]. The use of such reports as sources for research materials has both advantages and disadvantages. Research files provide large amounts of information on accidents in different industries, providing valuable information on what actually happened. Thus, they can be considered as reliable sources of information [7]. The disadvantage is that the reports are not intended for use as research material [8]. Thus, the sources of the accidents, with contributing factors and other details, must be extracted from the text. This interpretation on the part of the researcher may leave some details unresolved. Extracting details from accident descriptions can lead to misinterpretation [9].

The basis of previous studies was the consideration that poor human performance poses a threat to post-maintenance reliability and several studies have examined the risks arising from human performance [10], [11]. However, it is also known that industrial maintenance operations involve major risks for maintenance workers [12], [13]. Such risks can result from technical failures in a system or result from human performance at any organizational level [14], [15], [16]. To deal with such risks, specific maintenance tools are needed to identify hazards and prevent accidents [17].

2. RISK ASSESSMENT: THE CHALLENGES OF INDUSTRIAL MAINTENANCE

The results of the risk assessment always highlight a majority proportion of local factors at the workplace, in contrast to organizational factors and unsafe acts, which have a lower proportion. This can be attributed to the risk assessment method that has been developed and applied, which is designed to identify hazards within a site and takes into account organizational dimensions or error-generating conditions [18].

Risks include real hazards (such as unsafe walking and work surfaces) and error-generating conditions (such as missing or unclear operational safety bulletins); these can contribute to unsafe acts and indirectly undermine safety in maintenance. Both factors can arise from the environment, from unsafe acts during planning and execution tasks, as well as from organizational factors, such as management and supervision. A detailed analysis shows that the ***preconditions that cause unsafe acts derive from organizational factors***, while ***real hazards*** (direct accident risks) ***derive from local factors*** at the workplace [19].

Time pressure can magnify the magnitude of hazards with respect to existing risks and even create new ones, as workers may resort to inappropriate methods when performing a task in a hurry. Thus, work planning and resource allocation play a crucial role in preventing accidents during maintenance and avoiding post-maintenance reliability problems [20].

In many locations, equipment failures and workplace design make it difficult for maintenance workers to reach the location or area of the system that needs repair. Factors that affect accessibility include structures within the work environment or the difficult location of the workstation that requires maintenance actions that require the worker to climb/climb. In addition, accessibility is often a challenge due to the lack of sufficient working space around the part of the system that needs to be repaired. In some locations, subsequent changes in the work environment, such as new machinery and/or piping, can lead to system maintainability problems [21]. These failures in the workplace and in the design of the maintainability system can contribute to accidents as local factors in the workplace.

Maintainability deficiencies manifest as physical ergonomics issues, which come from ***two main sources***:

1) from deficient machinery and workplace maintainability design and/or,

2) inadequate work methods and failure to use assistive equipment (e.g. lifting devices).

In addition to reduced accessibility, the first group of sources can lead to additional preparatory work phases, such as dismantling structures in the work environment before maintenance work begins. In the second group of sources there are organizational dimensions, when workers cannot identify the need to use assistive devices due to poor supervision or poor work instructions. Failure to use assistive devices can lead to conscious/unconscious risk taking, which can be identified in more than half of the risk assessment analyses. Such risk-taking usually involves errors in the use of personal protective equipment (PPE) and the adoption of inappropriate work methods. This behavior leads to ergonomic defects, such as poor working posture and risks in material handling [22].

The ***risk assessment*** should be completed with separate discussions involving only the workers. During the interviews, workers may report certain problems related to issues such as resource allocation and task planning. The observations can be organized into seven main groups (table 1). The specifications summarized in Table 1 present challenges, mostly related to organizational and local factors at the workplace. Local factors often refer to insufficient maintainability in the system or at the workplace, i.e. factors that prevent the execution of maintenance tasks. In addition, changing locations and various site-specific risks, together with the security requirements of the beneficiary, form a set of challenges, both for workers and for the maintenance organization.

Organizational factors are much more diverse. Cooperation with the beneficiary plays an important role in risk management at various sites. The risks associated with the wide variety of maintenance tasks may require information management between maintenance workers and the beneficiary's operating personnel. This type of information can be taken into account explicitly, while collecting implicit knowledge from qualified maintenance workers is another challenge for companies.

Table 1. **Specific details regarding maintenance challenges**

The group of problems	Details/specifications	The dominant type
Dysfunctions in collaboration with beneficiaries	• information flow between service provider and beneficiary; • reporting of unfinished tasks; • instructions on common practices; • scheduled maintenance operations (time pressure); • content and specifications of maintenance requests.	Organizational factor
Site-specific safety challenges	• risks associated with hazardous chemical agents; • working in hot or cold environments; • lack of maintenance workshops; • working in isolated conditions; • occupational hygiene requirements.	Local workplace factor
Dysfunctions in the work environment	• lack of sufficient space around the machines/process; • poor maintainability of machines and processes.	Local workplace factor
Aging of skilled maintenance workers	• increased demands for good ergonomics; • difficulty in replacing experienced team members.	Organizational factor
Working in changing locations	• site-specific practices; • various injury risks; • route accident risks; • incomplete or unclear work instructions.	Organizational factor / Local workplace factor
Dysfunctions related to maintenance attitudes	• failure to use personal protective equipment; • taking risks.	Unsafe acts
Wide variety of maintenance tasks	• high volume of tasks; • acquiring and maintaining skills and knowledge to perform various tasks; • risks and requirements specific to the activity performed.	Organizational factor

The risk assessment should be complemented by open-ended group interviews with maintenance workers, highlighting specific safety issues related to maintenance. Ergonomics issues in general were frequently highlighted as significant challenges in maintenance operations.

Most of these ergonomic issues are physical ergonomics, such as *working posture*. ***Cognitive overload***, caused by time pressure, was also mentioned. A specific safety issue may be related to lower limb injuries, which maintenance providers consider to be the most common type of maintenance-specific accident. The frequency of foot injuries and problems involving physical ergonomics are believed to be due to the *numerous work phases during disassembly and reassembly,* which involve handling objects. Other issues highlighted are issues related to *lack of time and resources*, especially the allocation of time and manpower. The risk assessment supports the findings from the on-site interviews. Thus, most of the risks identified are related to ergonomics, such as poor working posture, heavy lifting and improper working methods. Among other factors, *poor scheduling and time pressure* are considered risks at all organizational levels, both by managers and workers in industrial sites. Lack of time and adequate resources may not be significant risks in themselves, but they can nevertheless contribute to increasing the likelihood of other risks occurring. The risks observed reflect dysfunctions in the planning of maintenance operations and the work environment (including processes/machinery). Management in service companies perceive the same risks as maintenance workers. It has become evident that maintenance workers consider time pressure to be a serious concern.

In this context, risk analysis using the event tree method can provide specific information for the prevention of maintenance accidents. Case studies of work accidents reanalyzed in the form of an event tree, to model the chain of causes and consequences, certify the usefulness of Evante Tree Analysis (ETA) as a technique to build appropriate prevention strategies and measures. The objective will be to test whether and how data on real accidents on human victims can be examined through logical event modeling and whether such an analysis can provide detailed information on the root causes of accidents. The results of this testing indicated that possible root causes, within the limits set by the available data, can be identified at least to a large extent. The event tree model provides an effective tool for modeling accident scenarios for risk management and prevention. Real incidents and accidents that have already occurred can be analyzed using fault trees, which allow for more accurate identification of errors and accident origins. Because of this benefit, root cause identification and analysis could provide an effective tool in accident prevention [23], [24].

The results of an ***event tree analysis*** can be used in the process of learning from accidents and preventing their recurrence. The main advantage of event tree analysis is that it models events in a way that shows the root causes, the factors contributing to the causes and consequences, and their relationship within the chains of events that lead to accidents. In the case of accident prevention in industrial maintenance, an event tree analysis could provide more information than a sequential analysis [25]. Although the experiments on these cases are encouraging, this scenario requires further examination and validation within companies.

3. ACCIDENT PREVENTION: CONTROL OF HAZARDOUS ENERGIES - LOCKOUT / TAGOUT PROCEDURE

Implementing a Hazardous Energy Control Program - LOTO Lockout-Tagout Procedure in the company is the best method for ensuring the safety of workers performing maintenance work in confined spaces and in adjacent spaces [26].

No safety program for the control of hazardous energies is complete without the provision of specific devices for blocking, locking and tagging all energy isolation mechanisms that supply installations and equipment. When the enclosed space is connected to one or more energy sources (electrical, pneumatic, hydraulic, etc.), the latter must be isolated from the enclosed space. What does this isolation practically mean? Interruption of the connection between the energy source and the enclosed space, by physically blocking the path of the energy in question, physically blocking any mechanism that could reconnect the energy source and tagging this blocking. We will see in the following, briefly, what all this entails. The methods of blocking and tagging energy sources in the case of assembly/disassembly, repairs, and overhaul operations are analogous. So, how is a confined space isolated?

The sources of *electrical energy* are locked out and tagged, preferably by disconnecting the switches at a distance from the equipment. A *person authorized* for such isolations must check whether there is any stored energy of any type remaining in the system that could accidentally activate the equipment. Effective locking is ensured by locking devices, the key to which is only held by the person authorized to perform the isolation-de-isolation. Use:

a) ***electrical equipment locking devices*** (fig. 1: connection plugs, automatic fuses, switches, circuit breakers, etc);

Fig. 1. Electrical equipment lockouts

b) **locking devices for pneumatic** (fig. 2), **hydraulic, gas, steam and water equipment**: the pneumatic and hydraulic, gas, steam and water pipes, as appropriate, are purged, insulated and the locking system is labeled.

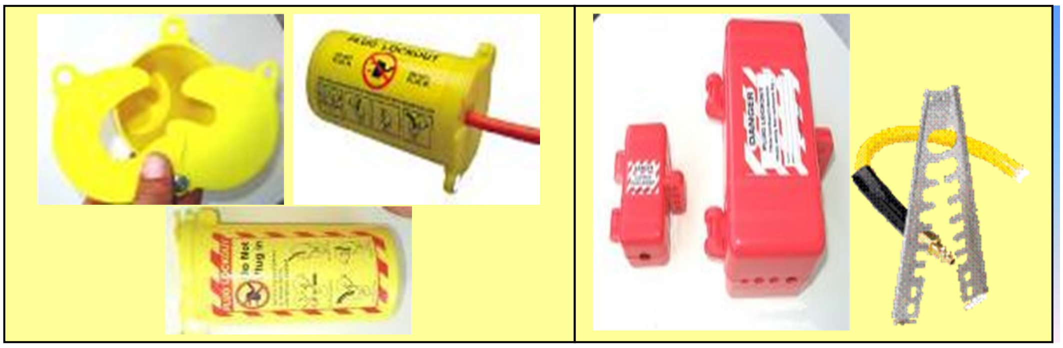

Fig. 2. Blocking of connection plugs / compressed air connection **-** systems used to prevent the connection of electrical connection plugs (220V / 380V) to the socket when they are not under the control of the person performing maintenance or service operations, as well as to block the connections of compressed air hoses to prevent their connection to the pressure source

c) ***Belts and chain drives, mechanical joints***, etc., which may be sources of kinetic energy (actuate a certain mechanism inside the space), or may activate another source of energy, are disconnected and tagged. Moving parts inside enclosed spaces are secured by stops, chains or other devices.

Isolation points should be recorded and visually or otherwise verified to ensure that the confined space is effectively isolated before a worker enters it. In general, details of the isolation of energy sources are recorded on the confined space entry permit, unless a separate form for isolation/de-isolation processes exists. The de-isolation and re-commissioning of energy sources will only be done after the work has been completed, all workers have left the enclosed space and the work site has been checked by the work supervisor and/or the person who authorized the isolation.

A few words about labeling/tagging (fig. 3) and why is it necessary? Any blocking of an energy source must be labeled, and this label must contain at least the following information: *when the blocking was done, who did it, the place where the work is being done, the estimated duration* of the blocking. Why is labeling necessary? Simple: so that it is known where, why and for how long that energy source is closed and who should be contacted for anything related to the stripping.

The tags are intended to ***warn workers of the hazards*** that arise if the machine or equipment in question is energized, indicating the person who made the lockout and the purpose. They are made of flexible plastic and can be attached to all lockout devices used, a padlock or a cable. They are resistant to chemical agents and UV.

Fig. 3. Information and warning tags

Potential hazards: workers in the petroleum and petrochemical industries face unique conditions and complex situations that expose them to a higher risk of injury and/or death. The magnitude of this risk is greater during the operation and maintenance of machinery, equipment or systems where there is the potential for accidental start-up or the release of hazardous energy.

Requirements and example solutions:

- The control of hazardous energies will be *planned and implemented through written programs* and procedures, using LOTO - Plus systems
- A *training hierarchy* adapted to the function of each worker will be established. The categories that indicate the level of involvement of each worker in the operationalization of the LOTO -plus system are as follows:
    - **Coordinator** – a worker designated by the employer to coordinate and supervise the application of LOTO, when multiple maintenance operations of equipment, machinery and systems are carried out simultaneously. The coordinator also completes the LOTO file.
    - **Lead Authorized Worker** - a worker designated by the employer who has responsibility for each group of authorized workers servicing the same equipment, machinery and systems during a LOTO-plus application. Specifically, this worker: determines the safety exposure level of each authorized worker in the group involved; obtains the approval of the operation coordinator; supervises maintenance or service operations, together with the coordinator.
    - **Authorized Worker** – a worker who carries out one or more of the following responsibilities:
        - installs a locking/tagging device;
        - maintains/services equipment, machinery and systems subject to the LOTO-plus application.
    - **Affected Worker** – worker who operates the equipment subject to the LOTO procedure in normal operation or who works in its area.
- All energy sources must be identified and isolated to render the equipment inoperable, before the authorized worker begins any intervention. Furthermore, verification of the de-energizing and isolation of all energy sources must be carried out, both initially and in a quasi-continuous (periodic) manner, by each *Authorized Worker* and/or by the *Lead Authorized Worker* of the LOTO application team.
- Each padlock and tag must be *uniquely identified* for the intended purpose of controlling hazardous energy and cannot be used for any other purpose. Padlocks and tags must also be: durable; standardized; strong; identifiable.
  The range of applicable devices includes:
- ***multi-lockout devices*** (fig. 4); the Multi-Lockout Safety Device (HASP) allows the use of multiple padlocks to lockout a lockout device/power source isolation mechanism. The device is inserted through the isolation point and each person

performing maintenance or service work applies their own padlock to it. This ensures the safety of each worker, as power to the installation cannot be restored until maintenance operations have been completed and each padlock has been removed..

- ***safety padlocks*** (fig. 5): steel, plastic, Keyed Different, Keyed Alike);
- ***industrial valve locking devices*** (fig. 6 and fig. 8): handwheel, lever, valve, ball, flap);
- ***cable locks*** (fig. 7): Cable locking of energy isolation mechanisms is a very versatile method, which makes it perfect for locking atypical mechanisms, handwheel valves or in case of multiple lockouts. The cables are made of steel, coated with plastic, being resistant to corrosion and extreme temperatures.

Fig. 4. Steel multi-lock devices — Lockout HASP Steel or Aluminum or Plastic

Fig. 5. Safety Padlocks

Fig. 6. Gas cylinder and valve locking device

Fig. 7. Locking cables

Fig. 8. Industrial valve locking devices

LOCKOUT devices (Fig. 9. Lockout stations; Fig. 10. Storage stations; Fig. 11. Multi-lockout box) are easy to use and are compatible with most isolation mechanisms of all types of energy.

Fig. 9. Lockoutstations

Fig. 10. Storage stations

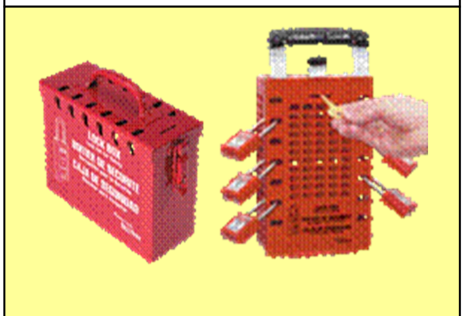

Fig. 11. Multi-locking box

Portable metal box. Ideal when lockout operations involve multiple workers and multiple energy sources. All energy isolation mechanisms are locked and padlocked by the lockout manager, then, ***after checking the effectiveness of the lockout,*** the keys to the respective locks are placed in the lockout box, with each worker involved in the maintenance activity attaching their personal padlock to the lockout box. Only after removing all padlocks from the box, can the padlocks and energy blocking devices be removed.

4. CONCLUSIONS

Industrial maintenance presents several challenges for accident prevention. In addition to the usual risks associated with any industrial work environment, maintenance operations involve several risks specific to it. These include working close to an ongoing process, using complicated machinery and time constraints. Unlike many other areas of technology and industry, direct contact between operators and machinery in maintenance activities cannot be substantially reduced. Isolating workers from work processes reduces the likelihood of human error and other chains of events that can lead to accidents. However, maintenance is and will likely remain an area where technology will be used and workers must be in direct contact with work processes.

The results of the studies showed that the number of work phases within the maintenance operations is also reflected in the number of accident risks. From the point of view of post-maintenance reliability it can be admitted that there is an increased risk of unsafe acts leading to work accidents or reliability problems, while technology-based errors are independent of the number and complexity of tasks.

Accident prevention approaches consider various ***latent conditions*** and ***organizational factors*** as possible contributors to unsafe acts. At the same time, technology-based errors are independent of direct human actions, although technical errors may arise indirectly from human action or its absence, such as the absence of maintenance. According to the literature, the following conclusions can be drawn::

- Accidents occur within the human-machine interface although the sources of accidents may be latent in the technological or organizational system;
- Accident sources can be grouped into errors (human or technology-based), which can occur in any part of a socio-technical system, i.e. independently of the human-machine interface and in the real hazardous conditions of the work environment;
- To prevent accidents, errors and hazardous conditions must be identified, evaluated and managed at the organizational interface and the human-machine interface;
- Accident prevention can be promoted by organizational and technical measures, which support the operation of the human-machine interface in safe conditions.

In order to manage accident sources in maintenance operations, they must be identified and assessed. Identification can be based on potential and actual accident sources and possible event chains. Relevant information can be collected through risk assessment, from accident or hazard information. In the case of ***risk assessment in industrial maintenance***, attention must be paid in a holistic way to variations in tasks, human performance and the work environment, including the system being maintained.

Unlike machine maintenance (after-sales services of technical equipment), in the case of industrial maintenance the workplace design is another important factor that must be taken into account in the design of maintainability and the prevention of undesirable events. Findings from companies have highlighted that the design of maintainability in the workplace was often deficient, due to structures and parts in the process that prevent access to areas requiring maintenance. The reduced accessibility often required considerable preparatory work before maintenance tasks could begin. This probably increases the number of work tasks and indirectly, the risk of errors and accidents during the disassembly and reassembly phases. Such maintenance-related factors must be taken into account in the design or renewal of production facilities, in order to maximize the safety and health of maintenance workers.

Maintainability of the workplace and of the machinery are key aspects in maintenance safety, although in many companies they seem to be somewhat neglected issues. Poor maintainability has several effects on maintenance work, such as affecting safety during work, prolonging the task and complicating the work, all of which can increase the risk of human error during work operations. Maintainability and ergonomics, in particular task fluency and working posture, are interdependent. Thus, good maintainability ensures a safer and easier to perform work task. This intrinsic prevention objective promotes both worker well-being and time- and cost-effective maintenance. Ergonomic design has major implications for workplace safety design.
Poor safety design can contribute to maintenance accidents, for example when workers are unable to identify or detect warning signs or safety markings on the system being maintained. On the other hand, good ergonomic design can prevent accidents when it is difficult or impossible to perform an incorrect or even dangerous maintenance task. Finally, maintainability is related to cognitive ergonomics. Minimizing the number of components to be replaced, connected, disconnected, etc. promotes both efficient task execution and a reduction in cognitive load during the task.

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