MODELING SAFETY INTERVENTIONS IN MAINTENANCE OPERATIONS

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Abstract: Maintenance work and service provision in the field are becoming increasingly important both for service providers and for equipment manufacturers, as after-sales services. At the same time, maintenance encounters safety-related problems, which require a specific holistic maintenance approach. In order to successfully prevent work accidents, a detailed analysis of the causes of accidents is necessary, as well as the identification of methods for modeling and systematically managing the causes within companies. This article proposes to Romanian experts in the field of occupational safety and health a structural and structured model of operational analysis of the genesis of work accidents in industrial maintenance, based on contributing factors and determining variables, a model capable of substantiating the steps to minimize the probability and severity of undesirable consequences occurring in industrial maintenance.

Keywords: safety intervention, industrial maintenance, accident at work, cause – effect duality, generic safety model of maintenance.

1. INTRODUCTION

According to various authors, accidents can be initiated by technical or human errors, which can result from various factors in the organizational and work environment or from variation in human performance [1], [2]. According to such approaches, the complexity of the socio-technical system can increase the probability of errors, as the number of parts and units increases, and the correlations between them become increasingly complicated [3]. At the same time, the variation in human performance sets increasing requirements for intrinsic security, adaptation and fault tolerance within the system [4]. Human activity can fail at any stage in an organization, or in any part of a system, although accident chains accumulate at the human-machine interface [5].

Accident prevention is a multidisciplinary field, which must consider all components of work and apply different sciences, such as *organizational, engineering*

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and humanities sciences [6]. In the case of *industrial maintenance*, accident prevention faces multiple challenges generated by factors specific to the work system. Theories of work accidents emphasize the role of the organization in preventing accidents, instead of attributing blame to the victim in the event of an accident [7]. This approach is supported by the fact that a significant number of major accidents originate in technical and management structures. Such causal factors include *inadequate supervision and training, the establishment of unsafe work practices, and poor workplace design*. These factors generally existed long before an accident occurred. However, in the event of an accident, a local trigger such as human error will increase the risk of potential accidents. Studying accidents with a view to preventing their recurrence should target the entire organization. However, learning from accidents and using information about them appears to be a complicated issue. [8].

Maintenance is a good example of work that is performed under exceptional conditions, such as the time of day in relation to the ***Yerkes-Dodson chart*** [9], especially when repairs with a high level of risk and complexity are involved [10]. The increasing practice of subcontracting maintenance services may encounter new challenges, given that the locations and tasks involved may vary depending on the customer. In addition, maintenance operations usually include both disassembly and reassembly, which can be considered as factors that can lead to increased risk of injury. In addition, the numerous work phases during disassembly and reassembly can give rise to the occurrence of human error. Such errors include replacing the wrong part or assembling the right parts in the wrong order. Due to human errors, maintenance activities can reduce the reliability of a technical system, and on the other hand have characteristics that make them risky for maintenance workers.

Simplifying Reason's theory, human errors can be either organizational factors or unsafe actions, while hazardous situations/conditions refer to local workplace factors (error-generating conditions) [11].

The ***hazardous situation/condition*** includes the local factors of the workplace, which correspond to the supplies and materials, design and environment of *Perrow's Normal Accident Theory* [12]. Similarly, human errors refer to human performance at different levels of the organization. Thus, they include workers and organizational factors, such as management and supervision. Finally, technology-based errors refer to technical failures and breakdowns, which can be reasons for maintenance, but can also be the cause of accidents during maintenance operations..

A system can be defined in various ways, depending on the focus of interest. For example, Kirchsteiger, 1999 [13], defines a system as "*an assembly of elements (components) that operate together to achieve a common goal (a plan)*". According to Perrow, "*... accidents in a system, like all accidents, begin with a failure of a component, most commonly the failure of a part, such as a valve, or due to human error*". The concept of "***socio-technical system***" refers to the technical system that has human operators. Taking Perrow's point of view into account, the concept of error includes deviations in a system, both those caused by humans and/or technology, and which can lead to undesirable consequences. The system refers to the object of maintenance, which can be a machine, a process or a part of a process. And finally, root causes are the factors that initiate the chain of events that lead to an undesirable result [14].

2. CAUSE – EFFECT DUALITY IN MAINTENANCE OPERATIONS

In a company, maintenance activities can be analyzed through three main elements, as follows: *the technical part, the human part, as well as the economic conditions and consequences of maintenance*.

Maintenance and plant safety are closely linked, since successful maintenance has been shown to promote plant safety and productivity. To meet the requirements, maintenance processes must be integrated with other internal processes, such as safety, quality and environmental management, which are governed by laws and regulations. To ensure this type of integration, specific information is required regarding the safety aspects of the system that may be affected by maintenance. Maintenance operations can be examined in various ways. For example, Tsang et al. used two main groups for maintenance operations, namely corrective and preventive maintenance [15]. Luxhøj et al., in 1997, grouped operations according to the motivation behind maintenance [16]. Thus, maintenance operations can involve *corrective, preventive* and *predictive* operations. According to Reason [17], maintenance operations include the following:

- ***unscheduled operations***, including corrective maintenance and operations to prevent failures and errors (opportunity-based maintenance);
- ***scheduled operations*** to prevent failures and errors;
- ***inspections;***
- ***calibration and testing***.

Maintenance operations are composed of two elements, namely:

- development of the need for maintenance (pre-maintenance conditions);
- the maintenance operation itself.

The first element or chain of events, mainly concerns the reliability of components and the system, as a result of a need to change, inspect or repair certain components, in order to maintain or restore the normal functioning of a system. In the second chain of events, i.e. the maintenance operation, human activity helps in determining the progress of events. From an analytical point of view, the development of the need for maintenance is the *cause* of its initiation, while the maintenance operation itself is the *consequence* of this need. ***From a safety point of view***, pre-maintenance conditions can generate certain hazards, which can cause risks during the actual maintenance operations. Such hazards include leaks and emissions, which must be identified and controlled before entering the work area. Malfunctioning of equipment presents another risk, due to irregular and unsafe operation. Identifying faults and controlling these risks are ***essential*** before the maintenance task can be carried out safely.

Within ***the cause-effect scheme***, the development of the need for maintenance can be examined using fault tree analysis (FTA), providing information on the source and evolution of a system failure/malfunction. FTA analysis can also provide quantitative data on the reliability of different parts and components in a system. Such information can be accumulated and used in the management and planning of maintenance operations, since the probability and frequency of the occurrence of defects can be estimated or calculated. An FTA analysis is also applied in cases of accident, since it contributes to highlighting the events that preceded the accident, establishing the existing interconnections. On the other hand, if the starting point is the observation/identification of the failure, the possible consequences and results of a maintenance operation can be expressed by an event tree model (ETA).

The ETA model starts from the top event, which is the *Observation and Identification of Failure*. The ETA model helps to model different chains of events, so that it can lead to desired consequences (successful maintenance) or undesired consequences (accidents/system reliability problems) [18].

From the maintenance worker's point of view, a maintenance operation can be divided into ***four main stages*:**

i. *Identifying the need for maintenance;*
ii. *Preparatory work phases;*
iii. *Repairs and service;*
iv. *Establishing the normal state.*

In the ***first phase***, the need for maintenance is identified and can be based on faults, time or opportunity, depending on the trigger that leads to the need for maintenance.

The ***second phase*** consists of the preparatory work phases, which are necessary before the actual maintenance work begins.

The ***third phase*** is the actual maintenance work.

The ***fourth phase*** involves restoring the normal state or restoring functionality. During this final phase, the process/part of the process/machine under maintenance is restored to normal operation and the work area is cleaned. These four phases follow a situational maintenance model, which was designed specifically for maintenance management, containing proposals for a generic industrial maintenance operating model. Maintenance operations have also been modeled to manage the economic dimensions of maintenance. However, conventional models focus on maintenance management in general and provide little detailed information about human activity during maintenance, which could be applied in hazard identification and accident prevention [19].

3. GENERIC MAINTENANCE OPERATION MODEL FROM A SAFETY PERSPECTIVE

Pre-maintenance conditions can significantly affect safety, along with unforeseen events and hazardous conditions during any phase of the actual maintenance operation. Thus, it could be beneficial to determine the origin of the various sources of accidents, their causes and consequences, along with the factors contributing to the causes and consequences. Evaluating the relationship between the various sources of accidents and the contributing/favoring factors is also important in identifying the sources of work accidents (fig. 1).

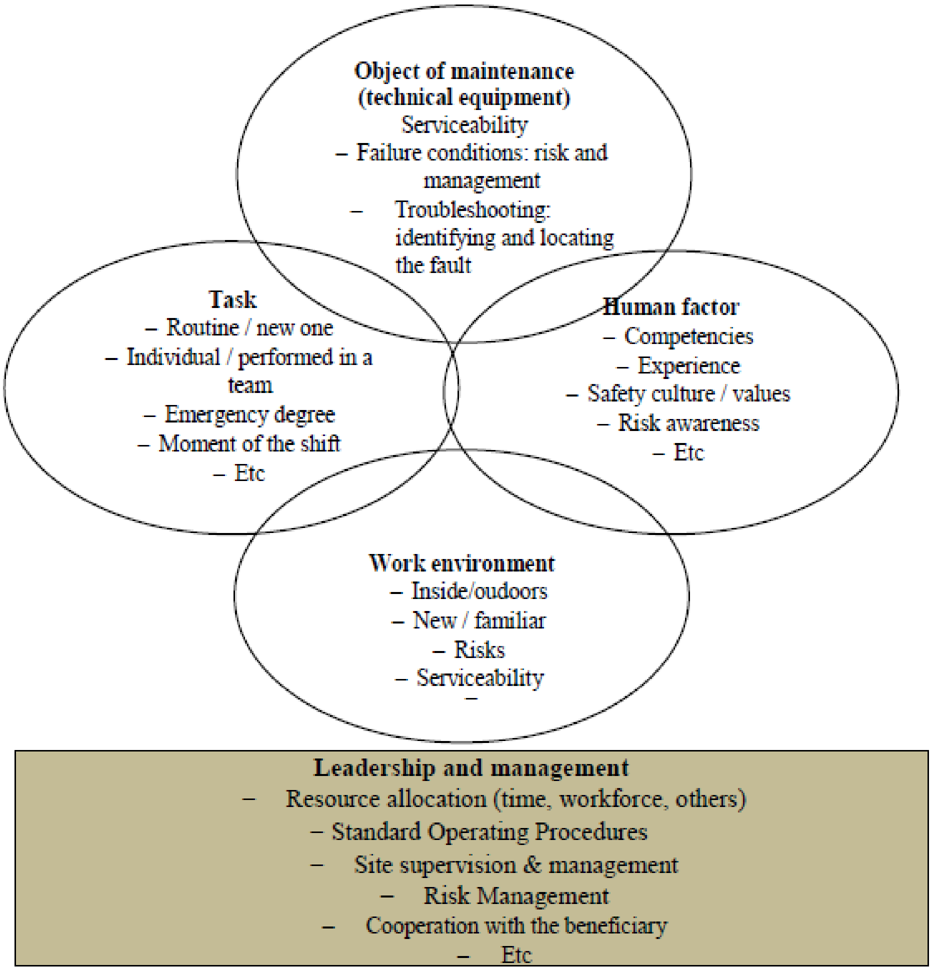


Fig. 1. Contributing factors and determining variables in industrial maintenance safety

Figure 2 illustrates the block diagram of the operational analysis process of the genesis of work accidents in industrial maintenance, proposed as a basis for the development of the generic model of the maintenance operation from a safety perspective.

A preventive approach can be based on the generic model of the industrial maintenance operation (fig. 3).

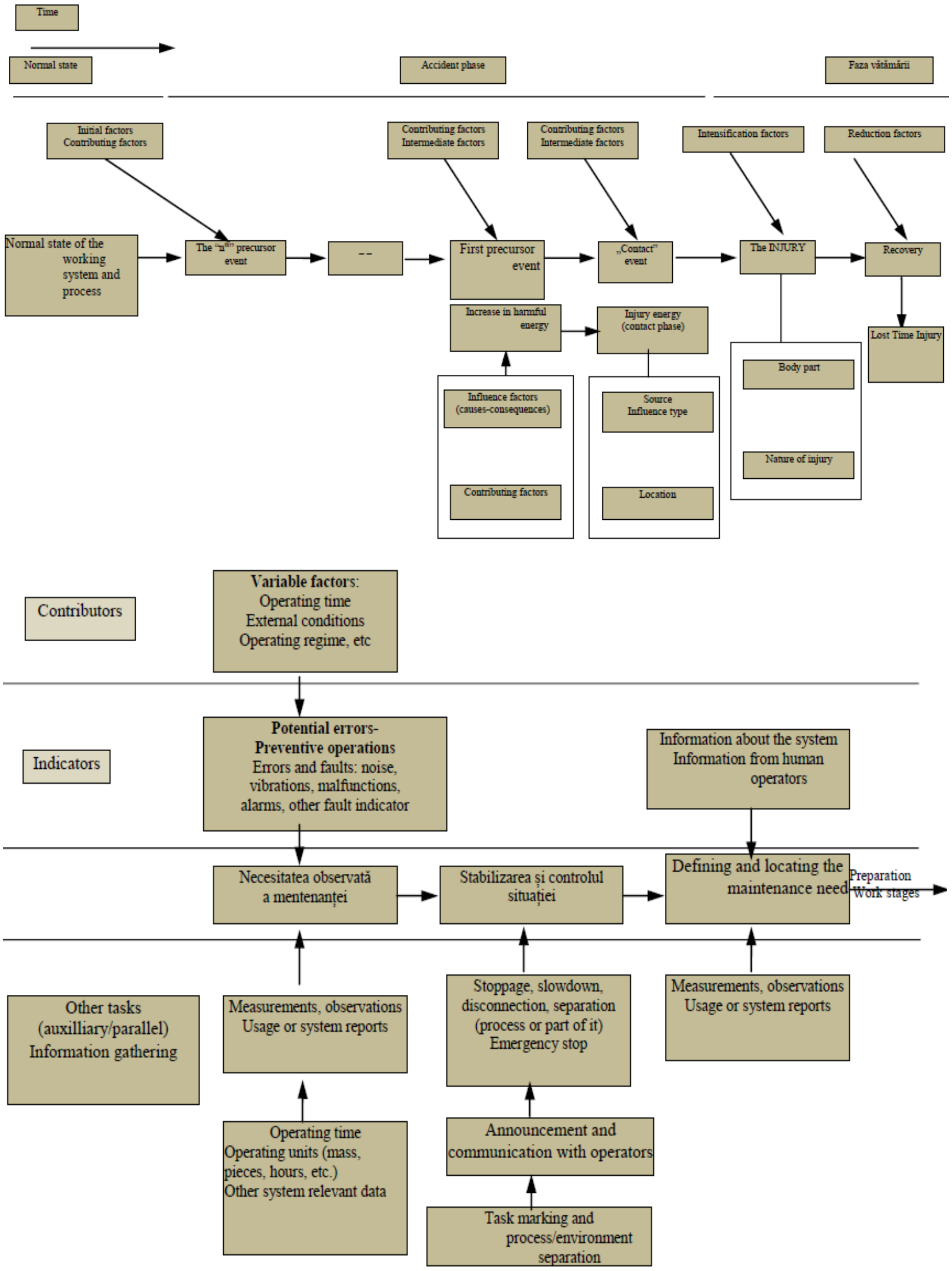
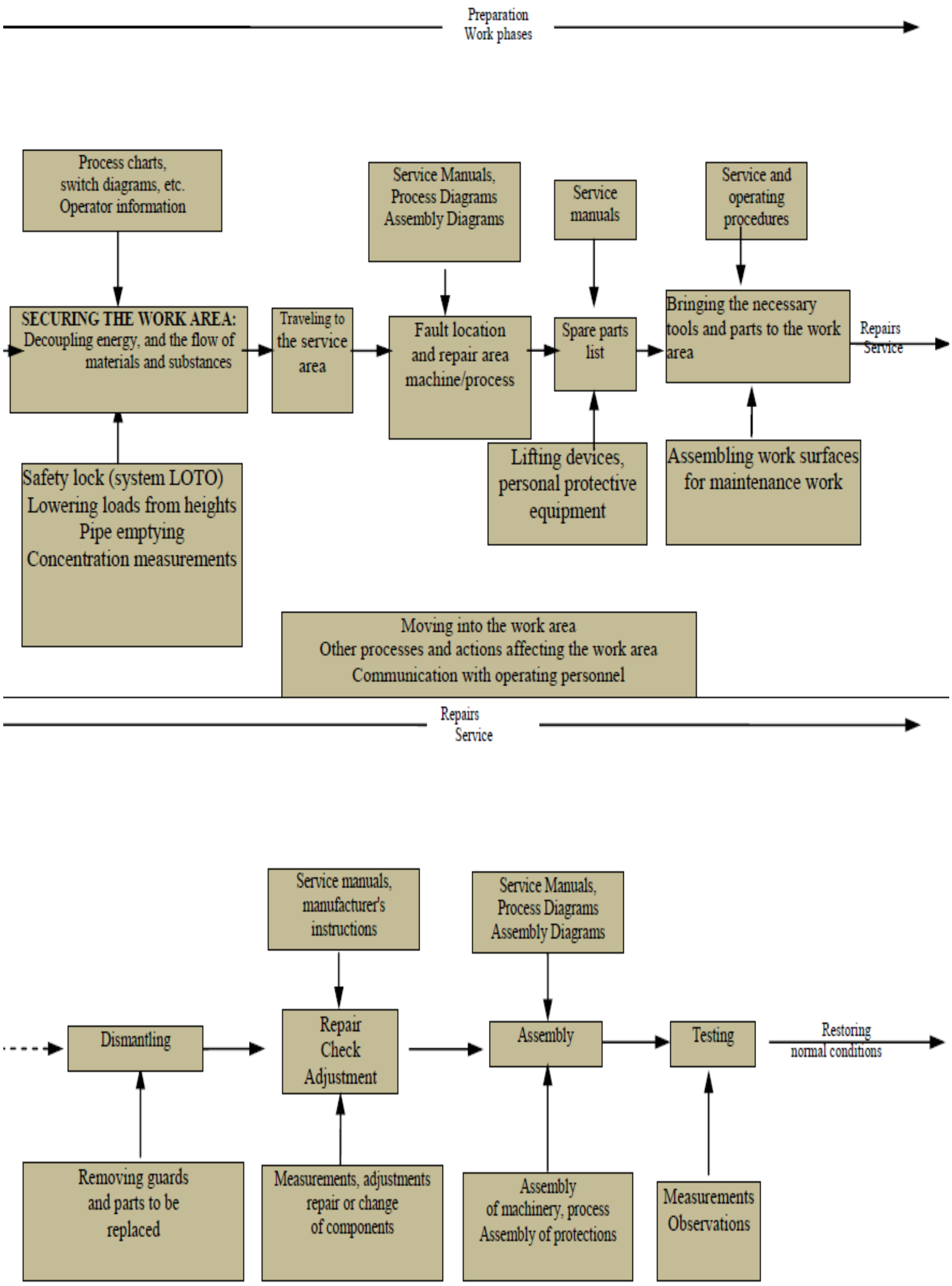


Fig. 2. Block diagram of the operational analysis process of the genesis of work accidents in industrial maintenance


Preparation
Work phases
Process charts, switch diagrams, etc. Operator information
Service Manuals, Process Diagrams Assembly Diagrams
Service manuals
Service and operating procedures
SECURING THE WORK AREA: Decoupling energy, and the flow of materials and substances
Traveling to the service area
Fault location and repair area machine/process
Spare parts list
Bringing the necessary tools and parts to the work area
Repairs Service
Safety lock (system LOTO) Lowering loads from heights Pipe emptying Concentration measurements
Lifting devices, personal protective equipment
Assembling work surfaces for maintenance work
Moving into the work area
Other processes and actions affecting the work area
Communication with operating personnel
Repairs
Service
Service manuals, manufacturer's instructions
Service Manuals, Process Diagrams Assembly Diagrams
Dismantling
Repair Check Adjustment
Assembly
Testing
Restoring normal conditions
Removing guards and parts to be replaced
Measurements, adjustments repair or change of components
Assembly of machinery, process Assembly of protections
Measurements Observations

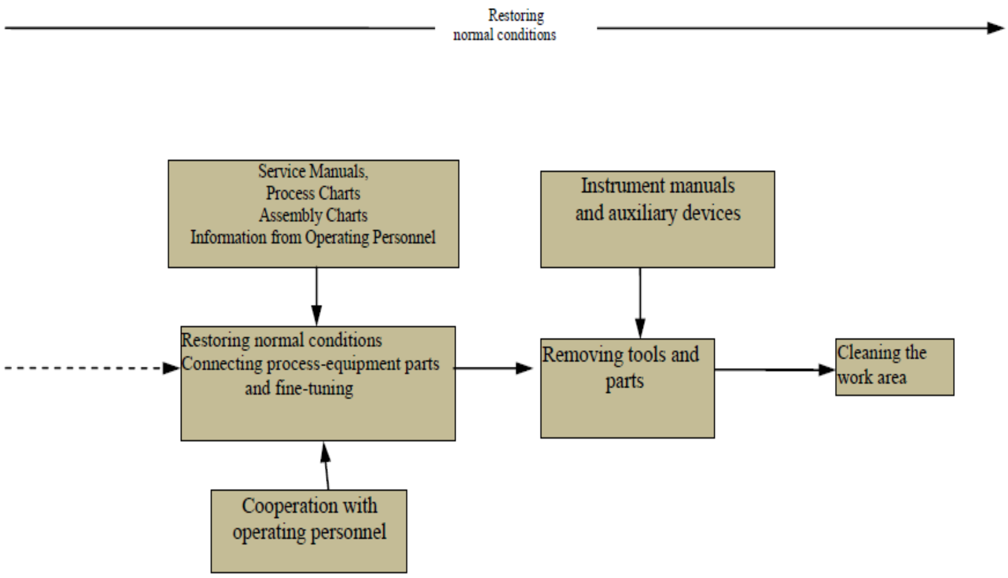


Fig. 3. The generic model of the maintenance operation from a safety perspective

4. CONCLUSIONS

In an industrial company, maintenance has ***direct*** and ***indirect objectives*** to support production and management processes. Examples of such objectives are ***promoting economic efficiency*** by freely using equipment in processes and minimizing downtime. Indirect economic efficiency is achieved by rehabilitating the process and product quality. Maintenance also ***improves the safety*** of the entire production, for example by preventing production interruptions and by providing assistance in controlling the impact on the environment, so that the components and parts of the technical system maintain their normal performance. An error in the maintenance operation can jeopardize all these benefits and can become a source of injury, dangerous to human health, production and/or the environment..

Safety in maintenance can be significantly affected by pre-maintenance incidents, this grouping being supplemented by technology-based errors, i.e. system failures and defects that can make the system and the working environment unsafe. Technology-based errors are independent of human action. This grouping provides an overview of the different factors that affect safety in maintenance of the human-machine interface and also supports the view of accident theories, according to which accidents are the sum total of several errors within a socio-technical system, which includes people at different levels of organization and technology.

To successfully integrate reliability and safety management functions, an important role will be played by the use of internal and external accident data in the development of maintenance functions, which can be used together to increase work safety, management efficiency and system reliability. Pre-maintenance events together with actions and conditions during actual maintenance operations can affect maintenance safety. Internal and external accident data can provide important information for accident prevention and safety management within a company. External accident information can reinforce internal information, which may otherwise be limited. In the case of industrial maintenance, this data could provide new information on issues such as: cooperation with beneficiaries, establishment of safety practices specific to the activity carried out, safe design of the workplace and equipment.

Maintenance management and planning can be approached from different perspectives, such as managing and reducing the economic impact of maintenance and ***promoting worker safety and system reliability through maintenance***. At the same time, the bi-directional maintenance-occupational safety link must also explore post-maintenance conditions, especially reliability that can be undermined by human errors during maintenance. Workplace safety management during maintenance has so far had a lower importance, although it has been widely recognized that maintenance operations include a variety of safety risks. A block diagram of the operational analysis process of the genesis of work accidents occurring during maintenance operations has been developed, proposed as a basis for the development of a generic model of maintenance operations from a safety perspective. Thus, the results of the studies can be grouped according to organizational factors, local workplace conditions and unsafe acts.

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