Apparent and root causes of occupational accidents occurred during maintenance interventions

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Abstract: This paper introduces the results of a structured analysis of occupational accidents occurred during maintenance interventions in Italy, in the last decades. The investigation includes 49 occupational accidents occurred in Italy between 2002 and 2016, involving maintenance workers. Results show that the leading apparent cause of accidents was the voluntary adoption of an improper procedure, e.g. the bypass of a risk control measure, followed by distraction and error of judgment. The lack of training appeared to be the leading root cause of the investigated events. However, the investigation of root causes was difficult because of the lack of information on human factors and other intermediate causes that lead to the occupational accident. The findings of this analysis suggest that a structured methodology for accident registration is required. Such methodology should collect data supporting the identification of the root causes of occupational accidents and workers' reasonably foreseeable behaviors on which prevention strategies should focus.

Keywords: maintenance; occupational accidents; prevention strategies; occupational health and safety.

1. Introduction

Maintenance operations are widely performed in different sectors and all types of work environments. These activities influence the safety and health of maintenance workers who are required to restore the work system after a failure or for preventive purposes. As they perform a wide range of operations requiring the contact with various substances, maintenance workers are exposed to multiple hazards, e.g. physical hazards, chemical hazards and biological hazards. The characteristics of maintenance operations also determine the occurrence of psychosocial hazards, which may impact on the psychological health and on the mental wellbeing of maintenance workers.

The scientific literature categorizes maintenance actions in two main typologies: preventive and corrective maintenance operations (Ahmad and Kamaruddin, 2012; Duffuaa *et al.*, 2001; Hashemi *et al.*, 2020). The aim of preventive maintenance actions is to restore the system to better working conditions. These interventions are usually planned and scheduled, according to the management priorities. Corrective maintenance actions are performed on a failed system, aiming to restore the operating conditions. These interventions usually require the work system to reduce or to suspend its production processes until the intervention is concluded.

The need to solve complex problems in non-routine conditions, the time pressure and the urgency to resume the work system as soon as possible can put excessive stress and significant pressure on maintenance workers. This situation may result in excessive haste, reduced perception of the risks of the work tasks, poor communication and, ultimately, increased occurrence of occupational diseases and accidents. Statistics on Occupational Health and Safety (OHS) show that the risk of developing an occupational disease for industrial maintenance workers is up to 10 times greater than for the average population (Milczarek and Kosk-Bienko, 2010). The European Statistics on Accidents at Work (ESAW), i.e. the main data source for European statistics relating to OHS, reports that about the 20% of all the occupational accidents occurred in Belgium in 2005–2006 were related to maintenance operations. Similar data appeared in other European countries, e.g. in Finland (18–19%), in Spain (14–17%) and in Italy (10-14%) (Milczarek and Kosk-Bienko, 2010). The high incidence of procurement contracts for maintenance services is an additional factor that impacts on occupational accident rates. In 2005, maintenance services were the most subcontracted functions in the French industry. Statistics show that working with contractors can lead to communication problems and lack of coordination for health and safety procedures (Djamié, 2007; Manu *et al.*, 2013; Tamim *et al.*, 2017; Walter, 2017). In 2002, French maintenance workers were the second most frequent victims of accidents related to subcontracting, followed by construction employees (Grusenmeyer, 2005).

The scientific literature shows that most of the occupational accidents occurs during corrective maintenance interventions (Grusenmeyer, 2005). EUROSTAT data related to five European countries, i.e. Spain, Italy, Finland, Belgium and Austria, indicate that, in 2006, most maintenance-related accidents occured in

manufacturing and construction industry. Wounds and superficial injuries are the most frequent types of injuries from maintenance-related accidents, followed by dislocations, sprains and strains (Milczarek and Kosk-Bienko, 2010). Musculoskeletal disorders (MSDs) are one of the most frequent occupational diseases affecting industrial maintenance employees, together with respiratory diseases, hearing impairment, diseases of the peripheral nervous and the circulatory systems, skin diseases and inhalation of asbestos dust (AFIM, 2007).

A research published in 2006 revealed that fatal accidents among maintenance workers in construction industry mainly occur beacuse the workers are struck by heavy equipment or vehicles (McCann, 2006). The apparent causes of such accidents seem to be the failing to set brakes, leaving trucks in gear, or other failures to lock out the vehicles. No information about the root causes are provided in the accident reports. However, recent researches on the anlaysis of accident dynamics show that the investigation of accident root causes is usually difficult because of the lack of information on human factors and other intermediate causes that lead to the unfortunate events . However, the study of both apparent and root causes is fundamental for understanding the dynamics of occupational accidents and for identifing common patterns on which prevention strategies should put more attention (Botti *et al.*, 2020).

The European Union legislation promotes the adoption of OHS measures and procedures for improving workplace health and safety, and for encouraging the adoption of safe behaviors at work. The European Directive 89/391/EEC, published in 1989, requires the management of public and private organizations to ensure healthy and safety workplaces (European Council, 1989). The same document specifies the workers' obligation to adopt a safety-conscious behavior and to follow the employer's health and safety proceudres. Machine manufacturers also play a critical role in ensuring healthy and safety conditions at work. The European Directive 2006/42/EC recognizes the social and the economic cost of occupational accidents caused by the use of machinery. Manufacturers are invited to realize inherently safe machinery, ensuring OHS conditions of their products, from their construction, through to installation, utilisation and maintenance (European Parliament and The Council of the European Union, 2006). Despite the strong committment of manufacturers in complying with the requirements of safety regulations, previous studies showed that strong efforts are necessary to fully understand the dynamics of accidents at work and the main determinants for workers' behavior (Mosconi *et al.*, 2019). In 2020, Botti et al. proposed a structured methodology aimed at understanding the dynamics of occupational accidents and supporting the identification of the root causes of these events (Botti *et al.*, 2020). Such methodology invites the investigator to follow a hierarchical investigation process based on the Five Whys technique (Leino and Helfenstein, 2012). The authors concluded that the complexity and the reliability of the investigation process are related to the dynamics of each investigated accident and to the accuracy of the descriptions in the event reports.

Following the investigation methodology introduced in (Botti *et al.*, 2020)for the identification of the apparent and the root causes of occupational accidents, this paper introduces the results of the investigation of 49 accidents occurred between 2002 and 2016, in Italy, during maintenance interventions. The ultimate aim was to identify common patterns in accident dynamics on which prevention strategies for maintenance interventions should focus.

The remainder of this paper is as follows: Section 2 shows the materials and the methodology adopted during this research; Section 3 introduces the results of the investigation; finally, Section 4 and Section 5 discuss the results and provide directions for future research.

2. Materials and method

This research included the analysis of occupational accidents occurred in Italy between 2002 and 2016, during maintenance interventions. The analysis is limited to the events that caused a serious injury to the workers involved, i.e. serious accidents, also known as "non-fatal accidents". Specifically, serious accidents are those that result in serious injuries and a minimum number of four days of absence from work. Fatal accidents, i.e. accidents leading to the death of the worker involved within one year from its occurrence, are excluded from the present research. Data and information on each event are from the webtool InforMO, i.e. the database of the Italian National Institute for Insurance against Accidents at Work (INAIL) (INAIL, 2019). Each accident report in the InforMO database provides a short description of the event, the description of the activity that the injured worker was performing, and further details, as the accident year, the type of injury and a limited number of personal information about the worker and the company (Campo *et al.*, 2006). The collection of the accident information for the report is usually demanded to the safety inspectors or the occupational physicians who intervene in the place where the accident occurred. The accidents included in the analysis are 49 events occurred in different industries, including metal production, transport, storing and communication, manufacturing of metal components, industrial plants and machinery, and production of paper pulp, paper, cardboard and paper products.

The methodology adopted for the investigation of the causes of accidents is the hierarchical process described in Botti et al. (2020). Specifically, the hierarchical process supports the deep investigation of each event, aiming to identify the apparent and the root causes of the occupational accidents. In this study, apparent causes were derived from the event descriptions in the reports. Root causes were determined following a structured investigation process inspired by the approach proposed in Mosconi et al. (2019) and based on the Five Whys technique (Leino and Helfenstein, 2012).

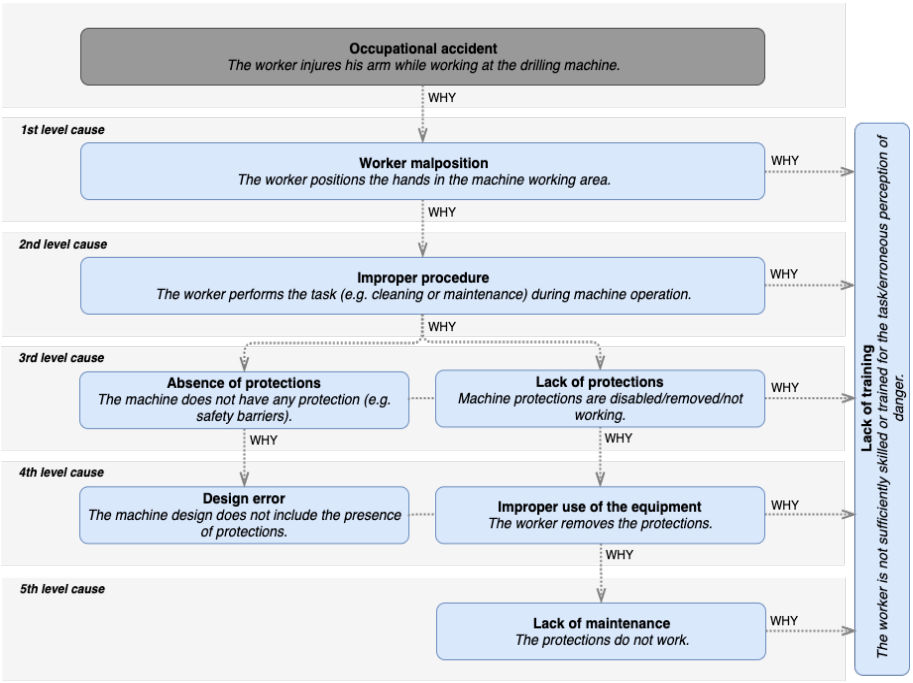

Figure 1. Causes-hierarchy investigation process adopted in this study (Botti et al., 2020).

The investigation process adopted in this study supports the identification of the temporal sequence of the events and the analysis of their interactions in a formal logical hierarchy. The result is the effective and rapid identification of common pathways and cause-effect relationships, which support the quantitative and qualitative analysis of the events (Rogith *et al.*, 2017). Figure 1 shows the causes-hierarchy investigation approach adopted for the analysis of the occupational accidents included in this study.

The investigators, i.e. a full-time professor and two researchers with multiple years of experience in occupational safety, retraced the succession of the events and workers' behaviors from the information in the accident reports.

3. Results

The occupational accidents included in this research were mainly due to the contact of the injured worker with the moving parts of machinery. Other common circumstances in which the accidents occurred include the sudden startup of machinery, the projection of solids, the uncoordinated movement of the injured worker, the contact with moving objects or machinery, and the presence of gas, smoke, aerosol and liquids leak.

Almost three quarters of the accidents occurred in presence of fixed machinery (76%). The second most frequent risk factor was the interaction with material handling systems, e.g. lifting and carrying equipment (16%). Other risk factors that were present during the investigated accidents are in Table 1.

Table 1: Distribution of the occupational accidents included in this analysis, by risk factor.

Type of accident	%
Fixed machinery	36 (73%)
Material handling equipment (e.g. for carrying and lifting)	8 (16%)
Work at height	1 (2%)
Manual material handling (lifting and carrying)	1 (2%)
Pressurized plants and equipment	1 (2%)
Above-ground combustion storage tank at atmospheric pressure	1 (2%)
Fixed thermal plants and equipment	1 (2%)
Total	49 (100%)

Table 2: Distribution of the occupational accidents due to the presence of fixed machinery, by industry.

Type of accident	%
Metal production	16 (44%)
Production of paper pulp, paper, cardboard and paper products	15 (42%)
Manufacturing of metal components, industrial plants and machinery	3 (8%)
Transport, storing and communication	2 (6%)
Total	36 (100%)

A deeper investigation was performed, aiming to understand the causes of occupational accidents determined by the contact with the fixed machinery (36 events, see in Table 1). Table 2 shows the distribution of such accidents by industry. Specifically, fixed machinery for

metal production and production of paper pulp, paper, cardboard and paper products determined most of the events. More details about the typologies of such machines are in Figure 2.

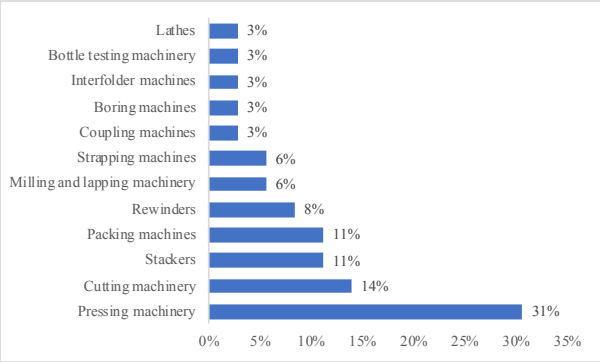

Figure 2: Distribution of the occupational accidents due to the presence of fixed machinery, by type of machinery.

The contact with pressing machinery, e.g. die cutters, punch presses and similar fixed machinery producing compression forces, determined almost one third of the occupational accidents involving the use of fixed machinery (31%). These machines, together with cutting machinery and stackers, caused more than half of the investigated accidents (56%). A further investigation revealed the apparent causes and the root causes of the occupational accidents determined by the contact of the injured worker with the fixed machinery. The results are in Figure 3 and Figure 4.

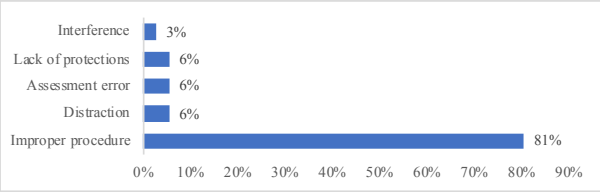

Figure 3: Apparent causes of occupational accidents involving the contact with fixed machinery reproducing compression forces during operation.

The results in Figure 3 show that the adoption of an improper procedure was the main apparent cause of the investigated events. A common example is the case of a worker who voluntarily bypassed a risk control measure, e.g. a safety barrier. Further apparent causes of occupational accidents due to the contact of the worker with fixed machinery are distraction, assessment error, lack of protections and interference with other operations. Figure 4 shows the root causes for the occupational accidents related to the apparent cause "Improper procedure".

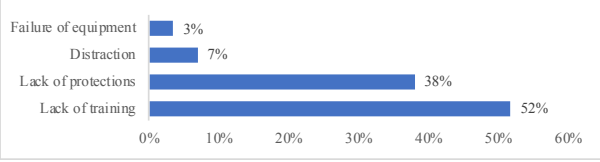

Figure 4: Root causes of occupational accidents related to the apparent cause "Improper procedure".

The leading root cause of these events was the lack of training (Figure 4). An example is the case of a maintenance worker who was performing an intervention at an operating pressing machine when he cut off his finger. The root causes of occupational accidents related to the other minor apparent causes are in Table 3. Particularly, the use of improper equipment and the failure of equipment are the leading root causes of occupational accidents related to the apparent cause "Distraction". Further root causes of the accidents were the lack of trainig, the use of improper equipment and the failure of the equipment adopted during the intervention.

Table 3: Root causes of occupational accidents related to the apparent causes "Distraction", "Assessment error", "Lack of protections" and "Interference".

Apparent cause	Root cause
Distraction	Improper equipment Failure of equipment
Assessment error	Lack of training
Lack of protections	Improper equipment
Interference	Failure of equipment

4. Discussion

The results of the present research are partially in line with the findings from the study published in 2020 about the causes of accidents occurred in the Italian manufacturing industry (Botti *et al.*, 2020). Such study revealed that more than four out of five occupational accidents occurred in metal production (81%) were determined by the contact of the worker with fixed machinery. The same risk factor was responsible for the 73% of the accidents occurred during maintenance interventions. A relevant percentage of such events was determined by the use of fixed machinery reproducing compression forces during operation (45% of the accidents occurred in metal production and 31% of the accidents occurred during maintenance operations). Boring machinery was the second most frequent type of equipment involved in the accidents occurred during the use of fixed machinery for metal production (12%). The present research does not confirm such data, i.e. the use of boring machinery was responsible for a limited number of occupational accidents occurred during maintenance interventions at fixed machinery (3%).

The analysis of the causes of accidents revealed the same leading apparent cause for the occupational accidents in both the studies, i.e. the adoption of an improper procedure. Such cause determined a significant percentage of the occupational accidents occurred during maintenance interventions (81% of the events). This may be due to the nature of maintenance work. The time pressure and the need to resume the work system as soon as possible determine a significant pressure on maintenance workers. These stressful work conditions may result in excessive haste, reduced perception of the present risks and, ultimately, increased adoption of improper procedures. However, no detailed information on such dynamics is available on the accident records. The reliability of the results of this study are related to the accuracy of the descriptions in the accident reports and to the complexity

of the event dynamics. Specifically, the analysis of root causes of accidents was difficult because of the lack of data in the accident records. Some investigations concluded after the analysis of few causes because of the lack of detailed information in the event descriptions.

The findings of this research suggest further considerations about the methodology adopted for the collection of accident data in the records. The leading apparent causes of the occupational accidents in this research are somehow related to workers' behavior, e.g. the voluntary adoption of an improper procedure, or distractions and assessment errors. It appears that the major objective of the descriptions in the reports is to assign responsibilities for the accidents, rather than describing the actual root causes of workers' behaviors. Other minor apparent causes are related to the lack of protection and the interference with other operations. Such causes may reveal poor risk perception at the time of the events.

5. Conclusion

The findings of this research reveal that the most frequent risk factors for non-fatal occupational accidents occurred during maintenance interventions was the use of fixed machinery. Previous studies revealed that the same risk factor determined a relevant proportion of all non-fatal injuries occurred in the Italian metal production industry. The adoption of an improper procedure was the leading apparent cause of such accidents. A common example is the case of a maintenance worker who got injured while performing a maintenance intervention at a running machinery, e.g. in active or stand-by mode, with no safety barriers. Lack of training appears to be the leading root cause of such event. However, the accident reports do not provide sufficient information to determine further causes for such improper behavior, e.g. the need to perform the intervention as quick as possible. The solution suggested on the accident reports for such apparent cause, i.e. the adoption of an improper procedure, is the application of an additional barrier between the risk factor, i.e. the fixed machinery, and the worker. This solution may result in higher complexity for the execution of the maintenance intervention. Though, an additional barrier may encourage further improper behaviors, rather than preventing their root causes. Hence, the focus of accident prevention strategies should be more on the analysis and the prevention of the root causes for accidents rather than on the consequences of workers' behavior.

The findings of this research suggest that additional investigations with subjective judgements and interpretations will be necessary for understanding and workers' reasonably foreseeable behaviors and the root causes of occupational accidents. The current structure of the accident reports and the accuracy level of information did not allow the investigators to make reliable conclusions on the accident dynamics and to determine the actual root causes of such unfortunate events. A further limitation of this research is related to the number of events included in the investigation. The data included in this study are related to all the occupational accidents occurred in Italy between 2002 and 2016 during maintenance interventions, which caused a serious injury to the maintenance workers involved. These data are from the INAIL database. For this reason, the analysis in this research was limited to 49 events. We are tracking the updates of INAIL database aiming to include more data in our future analysis.

These results also suggest that more efforts are necessary to understand the drivers of human behaviors, expecially in difficult and complex circumstances, such as during maintenance activities. In this context, participative approaches to OHS provide a reliable tool supporting the definition of common pathways for accident dynamics and for identifing cause-effect relationships. In this context, participative methodology propsed in Mosconi et al. (2019) supports researchers and safety professionals for the identification of critical risk factors in the workplace and for understanding the consequences and causes of unsafe behaviours. A further analysis will be necessary to further explore the company processes, aiming to identify potential connections between the safety gaps emerged from previous investigations and process inefficiencies. Future developments of this study will also include the analysis of common causes of accidents that lead to the fatal injury of the maintenance workers involved, aiming to identify new leading indicators for accident prevention.

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