Safety Science 145 (2022) 105475

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Learn from the past and act for the future: A holistic and participative approach for improving occupational health and safety in industry

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A R T I C L E I N F O

Keywords:
Participatory intervention
Focus groups
Fault tree analysis
Safety management

A B S T R A C T

The European working population is significantly ageing. This trend is expected to increase in the next years. In this context, occupational health and safety strategies need to evolve, developing return-to-work procedures and workplace modifications to avoid long-term sickness absence and early retirement. Safety management strategies should consider age related factors, so that every worker, regardless of age, feels safe and committed to reach personal and corporate goals.

This study proposes a holistic approach based on a participatory methodology to identify the causes of workplace hazards and to improve occupational health and safety in industry. The first step supports the identification of the root causes of accidents and injuries. The second step involves the participation of the workers in the analysis of the consequences and the causes of safety issues in their workplace. The last step investigates the process deficiencies that may impact on the safety performances of the work system. The participatory technique adopted in this paper is the focus group with the workers, based on the fault tree analysis method. The findings suggest that the causes of unsafe work conditions may be the result of inefficiencies and deficits in the work process. The proposed approach allows multiple benefits, including an increased commitment of the workers and an improved safety culture within the organization. Such improvements are critical, especially when a relevant part of the workforce includes aged workers with multiple years of experience with the investigated tasks and, consequently, prolonged time of exposure to the same risk factors.

1. Introduction

In the recent decades, the European population has aged significantly. This marked demographic change is due to an increased life expectancy and declined birth rates (Ilmarinen, 2012). The European Agency for Safety and Health at Work (EU-OSHA) is expecting this trend to continue and intensify in the coming years (Belin et al., 2016). By 2050, over the 28% of the total EU population is expected to be over 65 years of age (European Union, 2019). At the same time, the proportion of the working-age population (15–64 years) to those aged 65 and over is decreasing every year. Between 2003 and 2018, the ratio of people aged 55 years or more to the total number of workers in the EU-28 increased from 12.1% to 19.7% (European Union, 2019). Consequently, the working-age population is continuously shrinking.

Workforce ageing involves significant implications for the society and for the socio-economic systems. Important social challenges go hand in hand with the ageing of the working population. An evident consequence of increasing longevity is the increasing retirement age. Pension systems are expected to face hard pressures in the next years, as a greater number of pensioners will require the support of contributions from fewer workers.

Public health services will face a rise in the costs for age-related services and long-term care. Ageing also has major impact on Occupational Safety and Health (OSH) systems. Older people, like people in other age groups, are exposed to various risks in the workplace, in traffic and at home, which may lead to accidents and injuries. As older workers are a significant share of the EU's workforce, some employers may need to redesign their OHS strategies aiming to address emerging OHS risks in their companies. Recent statistics show that although older workers are less involved in occupational accidents, they are more likely to be serious or fatal (European Union, 2019). The severity of an accident at work increases with the probability that the accident involves an aged worker. In addition, older workers are more likely to suffer from chronic health problems and they are exposed to workplace hazards for longer.

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https://doi.org/10.1016/j.ssci.2021.105475
Received 27 May 2021; Received in revised form 16 July 2021; Accepted 27 August 2021
Available online 21 September 2021
0925-7535/

In this context, OSH management has to evolve, developing return-to-work procedures and workplace changes to avoid long-term sickness absence and early retirement for health reasons.

Although workforce ageing raises new problems, such phenomenon is both a challenge and an opportunity. Older people are more likely to be satisfied at work. Job satisfaction has significant implications on active ageing, inducing people to postpone retirement. Beside the salary, job satisfaction is related to multiple other factors, as safety perception, job security, promotion opportunities, and autonomy (Raab, 2020). Furthermore, older workers allow many opportunities for cross-generational exchange and vocational training, thanks to their experience, skills and know-how.

Addressing the ageing challenge and turning it into an opportunity depends on the ability of companies and society to delay the exit from work of aged workers. Company management should consider age related factors in work organization and design workplaces and tasks, so that every worker, regardless of age, feels safe and committed to reach personal and corporate goals (Botti et al., 2020a; Botti et al., 2017a; Čiutienė and Railaitė, 2014). Such actions require the support of structured retirement policies, which include supplementary pensions and social protection for all the workers, especially those with health problems (European Union, 2019).

In this context, OSH management and company safety performances play a fundamental role. The safety performances of a work system depend on the capability of the management to control the work processes and to avoid accidental events that may cause injuries, damages and loss of resources. OSH regulations and safety procedures help employers and safety professionals to improve the control of the work processes. However, the presence of a complex regulatory system may lead to ineffective, unproductive and unsafe behaviors, and various situations in which the compliance to the regulations is difficult or impossible to achieve, especially in case of an unexpected event (Dekker, 2003; Rocha et al., 2015). The activities performed by the people involved in a work process are capable of modelling the propagation of a sequence of accidental actions, causing the deviation from the desired work flow and triggering an adverse flow of events. The presence of unexpected conditions may lead to adverse events, as accidents and injuries. Such conditions are related to difficulties of human operators in processing the information under unexpected work conditions (Kim and Seong, 2019).

In the last decades, research on work support systems focused on the design of models for individual actors and decision makers that could combine the objectives of different disciplines, from OSH and risk management, to work organization and supply chain management (Rasmussen, 1997). However, the rapid variation of the socio-technical systems required a different approach to address multiple issues deriving from the various aspects of the modern industry. The fast pace of technological change, the ageing of the work population, the increasing scale of the industrial plants and the aggressive and competitive environment that characterize our society made the previous models not useful for analyzing the performance of such complex systems. Furthermore, previous researches showed that the loss of control of physical processes causes accidents, injuries, environmental contamination, damage to the equipment and loss of resources (Rasmussen, 1997).

This paper proposes an integrated approach for the improvement of OSH and safety culture in industry, based on workers involvement and participation. The aim is to analyze the correlation between safety deficiencies and process inefficiencies in a holistic perspective, investigating the mechanisms of propagation of improper top management decisions that may lead to unsafe work conditions or improper behaviors. Specifically, the research questions driving this research were "How can top management decisions lead to unsafe work conditions or improper behaviors?" and "Is it possible to understand the mechanisms of propagation of top management decisions to company safety performances?". The remainder of this paper is structured as follows. The following Section 2 introduces a literature review on the state of the art of the research on safety indicators for the evaluation of safety performances in industry, with a focus on the importance of learning from past experiences and the methodologies for improving workers participation. Section 3 and Section 4 show the proposed approach for the improvement of OHS and the results of its application in the manufacturing industry. Finally, Section 5 and Section 6 discuss the results, providing suggestions and directions for future research.

2. Research background

The dynamic characteristics of the technical progress and the evolution of the socio-technical systems require the modern industry to adopt a system-oriented approach, based on the concept that a system is more complex than the sum of its elements (Rasmussen, 1997; Rocha et al., 2015). Several strategies were raised in the last decades aiming to increase the availability of work processes and the quality of the products, to improve OHS and to reduce human errors. The world-class manufacturing model and the management philosophy of lean manufacturing have been implemented in different industries since the early 90′s (Botti et al., 2017b,a). Lean manufacturing integrates multiple tools for the improvement of productivity and quality performances of industrial work processes (Negrão et al., 2017). However, the present society and the modern market conditions require the organizations to consider the performances of a work process from a multidimensional perspective, which also includes environmental and safety implications (Caroly et al., 2010; Henao et al., 2019; Maudgalya et al., 2008; Seuring and Müller, 2008). Then, the success of an organization and the efficiency of a work process depend on the ability to seek the excellence in three strictly related aspects, i.e. productivity, quality and environment, which find their best condition under the umbrella of OHS.

Organizational and environmental factors contribute to the creation of a safe work system. Specifically, organizational factors include: the position of individuals within an organizational hierarchy (Tear et al., 2018); the interactions between different groups of workers (Li et al., 2019); communication and coordination between the colleagues and with the emergency response team (Arigi et al., 2019; Li et al., 2019); presenteeism and absenteeism levels (Arjona-Fuentes et al., 2019); the factors that influence learning (Anderson and Kodate, 2015) and improve safety culture, climate and safe behaviors (da Silva and Amaral, 2019; Ismail et al., 2012; Kim et al., 2019); the situation awareness and the inclusion of human factors in decision-making (Arigi et al., 2019; Jirkof and Schmutz, 2019; Karanikas et al., 2018); the leadership and the management commitment (Fernández-Muñiz et al., 2017; Hadikusumo et al., 2017; Haslam et al., 2016; Jirkof and Schmutz, 2019); the workload perceptions and the presence of demanding working conditions (Nævestad et al., 2019). Environmental factors are related to the conditions of the work environment, in terms of effectiveness of safety audits and management systems (Ismail et al., 2012), workplace cleanliness and tidiness, lighting, noise, adequacy of tools and equipment, and working space features (Fernández-Muñiz et al., 2017).

A third category of factors that impacts on the effectiveness of a safety strategy is related to the technical performances of the work process. Such technical factors reflect the conditions of the work system, in terms of plant availability (Amin et al., 2018), maintenance strategy (Bağan and Gerede, 2019; Dobromirov et al., 2018), and adequacy of human-machine interfaces (Kim and Seong, 2019).

Industrial practice shows that OHS measures are rarely integrated in company management as information that could impact on the performances of the work process. Productivity measurements and analytical models include forecast and actual operating rates of machinery, and available production resources (Caroly et al., 2010). However, such calculations do not consider the correlation between the performances of the work processes and OHS measures.

In 1987, Paul O'Neill, shocked numerous Wall Street investors and stock analysts when, opening his first speech as the new CEO of the

Aluminum Company of America (Alcoa), stated “I intend to make Alcoa the safest company in America. I intend to go for zero injuries”. In 2000, the Alcoa’s annual net income was five times larger than before O’Neill arrived, and the company’s market capitalization raised by $27 billion (Duhigg, 2012). The Alcoa case study proved that the design and the implementation of an improvement plan must include the monitoring of safety indicators and the analysis of the interactions between safety and other dimensions of manufacturing performances (Spear, 2000). O’Neill’s experience changed the role of workplace safety in industry, from *ex post* required obligation, to *ex ante* optimization strategy.

2.1. Safety performance indicators

A large number of studies have focused on different approaches to improve OHS in industry. Past researches and case studies on workplace interventions addressed different types of work-related injuries or diseases (Aburumman et al., 2019; Laing et al., 2007; Oakman et al., 2016; Sámano-Ríos et al., 2019; Van Der Molen et al., 2016; Van Eerd et al., 2016). Other studies focused on the effectiveness of interventions to improve work ability and the recovery of industrial workers (Gupta et al., 2015, 2018).

The measures to evaluate the effectiveness of OHS interventions should be defined prior to their implementation. Such measures provide the management with a practical means to control the quality of the OHS program, and support the adoption of safe behaviors during work (Chang et al., 2019). Organizations always assess and re-define their strategic decisions, aiming to ensure the best performances of their processes. Safety performances should be evaluated, quantified and interpreted with the same attention that managers pay for strategic processes. However, the concept of “safety” conventionally defines something which is measured by its absence (Reason, 2000), e.g. the absence of injuries or accidents. Consequently, organizations are more likely to put efforts and to invest resources on assets that produce quantifiable results, in terms of increased productivity and product quality. Recent researches have proposed a new approach to OHS, intended as the process of positive actions and focused efforts to identify potential causes and consequences of future accidents (Schulman, 2020; Swuste et al., 2020). In this context, the continuous learning from root causes of accidents, near misses and misconducts is fundamental. In the last years, there has been a growing interest in developing safety indicators to understand how accident prevention impacts on safety outcomes (Manuele, 2009). Safety indicators can provide information on the performance of organizations, encouraging employers and employees to improve their safety practices and increasing the organizational potential for safety (Reiman and Pietikäinen, 2012). Furthermore, the use of safety indicators supports the identification of practices and processes that may lead changes in the safety performance of organizations. Different categories of safety indicators are present in the scientific literature. Leading and lagging indicators are the two conventional categories for safety indicators adopted in the industrial practice. Leading indicators provide information that support the response to dynamic conditions and the achievement of desired safety outcomes, e.g. avoid unwanted events or reduce a risk factor. Lagging indicators describe the tangible results of the safety strategy, e.g. the number of unwanted events as injuries and accidents.

Compared with lagging indicators, the use of leading indicators is conventionally encouraged (Ziebell et al., 2000). Industrial practice shows that the use of leading indicators predominates over the use of lagging indicators (Pęciłło, 2020). Lagging indicators, e.g. the total recordable incident rate, provide quantitative information on past safety performance, but no clues about the future outcomes (Choe et al., 2020). From an epidemiological perspective, leading indicators support the identification of latent failures and system deficiencies before they occur (Health and Safety Executive (HSE), 2006). Also, monitoring leading indicators supports the reduction of the time required for risk perception (Bugalia et al., 2020).

In 2012, Reiman and Pietikäinen developed a theoretical framework proposing three categories for safety indicators: outcome, monitor and drive indicators. Outcome indicators describe the consequences arising from situational and contextual factors, similarly to the function of lagging indicators. Drive indicators are leading indicators that address the sociotechnical activity in the organization by encouraging and promoting safety-related activities. Monitor indicators describe the organizational potential for safety, in terms of practices, abilities, skills and motivation of the personnel. The authors suggested that organizations should better acknowledge the significance of leading indicators as monitor and drive indicators in safety management.

In 2015, Sinelnikovet al. showed the results of a study involving an expert panel and a quantitative survey to explore the views and experiences of OHS practitioners in relation to leading indicators. A recent study from Versteeg et al. (2019) examined the safety indicators adopted in the construction industry, focusing on leading indicators, such as site inspections and toolbox talks, and lagging indicators, as injuries and first aid interventions. Both the studies concluded that more efforts are necessary to improve the safety indicators that are currently adopted for creating the basis of OHS promotion.

In conclusion, safety performance indicators provide a quantified approach to accident processes, which may result in the analytical translation of a complex succession of events into a number. Quantification produces enquiries and questions about the interpretation of such numbers. Both qualitative and quantitative approaches are therefore necessary to analyse the accident processes and to design effective OHS interventions (Swuste et al., 2020).

2.2. Learning from the past

Organizations should use safety indicators to identify and continuously monitor the antecedent conditions for accidents and act to prevent them (Schulman, 2020). Herbert William Heinrich, the famous industrial safety pioneer, stated that past experience offers the clues to the future, because “rarely is a problem unique” (Lateiner and Heinrich, 1969). The main role of safety science is to investigate and understand the accident dynamics, with the ultimate aim to design and develop effective interventions (Swuste et al., 2020). However, such reactive approach, based on a “learning from the past” model, should be integrated with proactive approaches to risk management, and supported by safety leading indicators. The use of leading indicators supports the reduction of the long-time lags between the increase in system risks and the risk’s manifestation in the form of accidents or injuries (Bugalia et al., 2020).

The main critics to reactive approaches based on learning from the past is the need for memory, which organizations and companies may not have, unless previous events and experiences are registered, well structured and organised (Swuste et al., 2020). Companies from different industries tend to underreport accidents, injuries and near-misses (Choe et al., 2020). A recent investigation among industrial safety practitioners and OHS experts showed that safety management systems focus their resources on building the ability to respond to safety issues (Pęciłło, 2020). Insufficient support is given to building the ability to learn. Companies should assign more resources to the study of major accident scenarios, including the most relevant events in terms of probability of occurance and seriousness of possible adverse effects (Swuste et al., 2020). Interviews with workers and managers, company documentation and previous studies from the literature should be the preferred sources for information. Data collection should be as accurate as possible. Underreporting has a negative impact on the identification of the root causes of accidents and injuries (U.S. House of Representatives Commitee on Education and Labor, 2008). The common assumption is that these safety system failures are the results of mis-perception, mis-specification, and misunderstanding errors, which lead to improper behaviors that did not ponder system-level causes and effects (Schulman, 2020). A healthy accident reporting system is one of the most effective safety management practices for the identification of accident root causes and for future accident prevention. A good and reliable indicator for the assessment of a safety management strategy is the analysis of the company accident reporting practices. Therefore, an holistic and multicriteria approach is necessary for designing safety management strategies (Choe et al., 2020; Janackovic et al., 2020).

(Janackovic et al., 2013) identified four main safety performance factors that describe the quality of a safety system: technical, human, organizational, and environmental factors. In a recent study, the authors revealed that OHS experts identify human factors as the most important, followed by technical, organizational, and environmental factors (Janackovic et al., 2020). Human error is the most important causal factor in occupational accidents (M. Liu et al., 2020). Hence, minimizing human error is the key to improving the performances of safety systems. An exceptional example of ultra-safe complex system is the Japanese High-Speed Railway, known as the *Shinkansen*. The *Shinkansen* was introduced in 1964 and no passenger fatalities have occurred since then. Multiple factors, i.e. technical, human, organizational, and institutional factors, contributed to such outstanding safety performance. For the *Shinkansen*, researchers and safety practitioners mainly focused on the role of technical and human factors for ensuring the achievement of high safety performance (Bugalia et al., 2020). Nowadays, in the Industry 4.0 era of control interfaces and human-machine interactions, ergonomics and human factors are even more important (Badri et al., 2018).

2.3. Participative approaches to OHS

Many studies focused on the identification of barriers and facilitators to the success of OHS interventions. A recent review identified eleven common barriers encountered during the implementation of interventions to improve OHS in industry, i.e. lack of time; lack of resources; lack of communication; lack of management support, commitment, and participation; lack of knowledge and training; resistance to change; changing work environment; scope of activities; lack of trust, fear of job loss, or loss of authority; process deficiencies; and difficulty of implementing controls (Yazdani and Wells, 2018). Furthermore, some correlation with the company size was found. Specifically, an increasing frequency of the barriers to the success of OHS interventions was found from micro to small enterprises. Such trend inverts from small to medium-large enterprises (Masi and Cagno, 2015), where larger companies appear to have better safety management strategies (Choe et al., 2020). Success factors for safety management strategies are the visible role of the management and the proactive participation of the workers. The management's engagement, the emphasis on the importance of safety and the leadership style characterize the most effective OHS interventions (Aburumman et al., 2019; Hale et al., 2010).

The proactive participation of the workers in the design of safety strategies and regulations supports safety-related behaviors related to safety compliance, which is associated with rule-following, and safety participation, which involves an active commitment with safety concerns (Grote, 2020; Neal et al., 2000; Schulman, 2020). Other facilitators for OHS interventions are knowledge and ergonomists' support (Yazdani and Wells, 2018). The commitment and the leadership exerted by the intervention coordinator, i.e. usually a safety professional within the organization, are strictly related to the success of the intervention (Aburumman et al., 2019; Hale et al., 2010). Productivity and comfort are the results of a process in which the management and safety professionals, e.g. ergonomists and safety leaders, play an active and visible role (Vink et al., 2006).

Both individualized and organizational interventions are necessary to achieve effective OHS intervention outcomes (Aburumman et al., 2019; Hale et al., 2010). Specifically, workplace interventions should be targeted for particular groups of workers or individuals rather than to apply a generalized practice to everyone in the organization (Chang et al., 2019). In their research, Aburumman et al. (2019) found that the participation of the workers is a fundamental factor for the success of an OHS intervention. Furthermore, higher returns on investments were found in companies that placed the workers at the core of their safety programs (Vink et al., 2006).

Participatory OHS interventions are popular approaches to reduce occupational hazards, work-related musculoskeletal disorders and to improve OHS. The success of a participatory OHS intervention is strictly related to the engagement and the support of the management, the union representatives and the workers (Dwayne van Eerd et al., 2010). Several studies have described multiple success factors for participatory OHS interventions, as the presence of a steering group with responsibilities, the step-by-step approach, the continuous check of the effects and the extended focus on multiple aspects, and not limited to health and safety issues (Vink et al., 2006).

Participative approaches, e.g. participative ergonomics, developed from the Japanese quality circles (Noro, 1991, 1999), and from the social participation in Europe and Scandinavia (Jensen, 1997, 2001). Participative techniques usually involve a work team with a supervisor and a limited number of workers, who have a deep knowledge about specific issues that need to be addressed (Straker et al., 2004). Participative ergonomics is the participative approach that seeks the active involvement of workers in developing and implementing critical workplace changes, with the aim to improve productivity and OHS (Burgess-Limerick, 2018; Straker et al., 2004). Two common participative techniques used in safety management are interviews and focus groups (Wilson, 2010). Interviews with the workers, for example, may help investigators and OHS experts understand technical failures that lead to accidents or serious injuries. Focus groups are interviews conducted with 5–8 participants (Bisantz and Roth, 2009; Krueger and Casey, 2015). The aim is to give all participants the opportunity to contribute and to promote the spontaneous and sincere involvement. Focus groups with mixed participants, e.g. employees and managers, physicians and technicians, should be avoided (Krueger and Casey, 2015). Compared with the interview, the focus group encourages the synergy among the participants, promoting the spontaneous discussion and supporting the deeper comprehension of mental processes that cause individual behavior (Huang et al., 2018; McQuarrie and Krueger, 2006; Schonfeld and Farrell, 2010).

Dwayne Van Eerd et al. (2018) proposed a qualitative participatory approach employing structured interviews, consultant logs and a focus group to monitor the implementation of OHS interventions. The study showed that the participatory approach resulted in positive outcomes, such as increased awareness and self-efficacy. Then, the staff participation is a central element for the success of a participatory intervention and people's engagement requires multiple channels of communication (Dwayne Van Eerd et al., 2018). Other studies proved the positive impact of participatory interventions on OHS for reducing musculoskeletal symptoms, injuries and workers' compensation claims. A consequent reduction in lost days from work or sickness absence was found in the companies that adopted a participatory approach to OHS interventions (Rivilis et al., 2008). However, the literature reveals a gap in methodological studies proving strong and quantitative evidence for the effectiveness of OHS interventions (Rivilis et al., 2008).

Few studies investigated the impact of OHS interventions on process factors that are important to achieve better comfort and productivity (Vink et al., 2006). However, unsafe behaviors and work conditions may be the consequences of deficiencies in the work process. In 2019, Mosconi et al. proposed a structured participatory approach, known as FGW-FTA methodology, for the design and the implementation of OHS interventions in industry (Mosconi et al., 2019). Such methodology includes the participative technique of the Focus Group with the Workers (FGW), based on the Fault Tree Analysis (FTA) method. The aim was to promote the active participation of the workers in the analysis of consequences and causes of unsafe behaviors that may result in OHS issues. The authors showed that the participative approach and the structured methodology allowed the identification of the causes of unsafe behaviors within the work process.

Four strategic focus areas, on which the methodologies for the design and the assessment of industrial safety practices should focus, emerged in this literature review:

- The European demographic profile is changing. The increasing presence of older workers in industrial processes is raising the challenge to adjust the workplaces accordingly to the needs and capacities of an aged workforce. Therefore, the daily management is required to include age-related factors in work organization, so that every worker, regardless of age, feels safe, empowered and motivated to accomplish personal and corporate goals;
- Safety indicators, as leading and lagging indicators, are useful tools for quantifying company safety performance. However, a holistic and proactive approach to safety management is necessary;
- Safety management systems should build the ability to learn from the past, giving support to investigating the root causes of major accidents. Furthermore, a combination of quantitative and qualitative approaches to accident processes is necessary for investigating technical, environmental, organizational and human factors;
- Safety culture is the cause of individual behavior. Participation in rule making and safety management are important drivers to foster individuals' motivation to fulfill safety requirements. The personal engagement, associated with safety culture, and participation from top management to employees and personnel, are critical for reducing process uncertainty and, therefore, for accident prevention and safety improvement.

To address the above-mentioned gaps of traditional OHS practices, this study proposes a holistic approach to the investigation of safety leading indicators, based on the root-cause analysis of major accidents and on the active participation of the working population.

3. Research methodology

The research methodology adopted in this study is based on three investigation levels (Fig. 1). The first level aims to identify the root causes of major accidents, e.g. accidents that caused serious injuries, experienced by the company or that occurred in the same industry. The second-level investigation involves the active participation of the workers, using the FGW-FTA methodology proposed in (Mosconi et al., 2019). Finally, the third-level investigation explores the company processes aiming to identify potential connections between the safety gaps emerged from previous investigations and process inefficiencies.

3.1. 1st level investigation

The first step of the research methodology proposed in this study aims to investigate the root causes of major accidents experienced by the company or in the same industry. Accident reports provide useful information for understanding the causal relations between the factors that determined the accident. However, such information suggests the

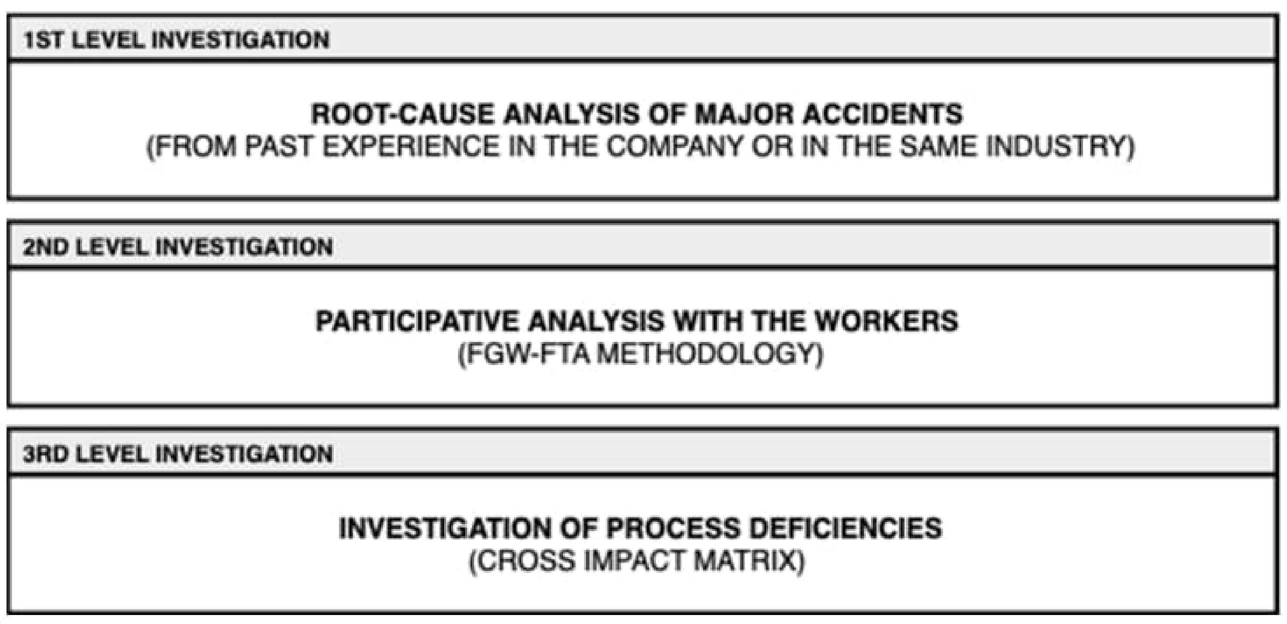

Fig. 1. Research methodology adopted in this study.

accident apparent cause, as described by the occupational physician who compiled the report. A deeper investigation of apparent causes and a structured analysis of the accident dynamics are necessary to identify the actual root causes of the accident, i.e. the system variables that impact on the safety of the work system. The research methodology adopted in this study for the identification of accident root causes is the investigation approach proposed in (Botti et al., 2020b) and based on the Five Whys technique (Leino and Helfenstein, 2012). The approach allows to define a visual, structured and deductive temporal sequence of the events that lead to the accident and their interactions in a formal logical hierarchy (Fig. 2).

Fig. 2 shows the investigation approach proposed by Botti et al. (2020b) for the analysis of the causes hierarchies. Specifically, the first level cause defines the main determinant of the accidents, i.e. typically the worker malposition of the hands in proximity to an operating machine. The adoption of an improper procedure justifies such misbehavior. Common causes for the adoption of an improper procedure are the lack of safety guards or the complete absence of a machinery protection system. In the first case, the personnel may have intentionally removed or disabled the safety guards. It is also possible that protection broke and no maintenance intervention was performed to replace them. In the second, the machine could have been designed with no protections.

This investigation approach improves the knowledge about the sequence of the events, extending the temporal dimension of each accident to the analysis of its actual root causes (Botti et al., 2020b). The complexity of the investigation process depends on the dynamics of the investigated accidents. The better the accuracy of the description in the event reports, the higher the reliability and the consistency of the results. Though, information on the reports may not be accurate and the language adopted to describe the events reflects the heterogeneity of the technicians and physicians who fulfilled the reports.

For these reasons, the first-level investigation should be realized with the support of certified safety professionals with multiple years of experience in OSH in industry.

3.2. 2nd level investigation

The reliability and the consistency of the results of the first-level investigation process strongly depend on the accuracy of the event description in the accident reports and on the ability of the investigators to interpret the information properly. The accuracy level of the information in the accident reports is variable, depending on the event complexity and on the competences of the expert who reported the

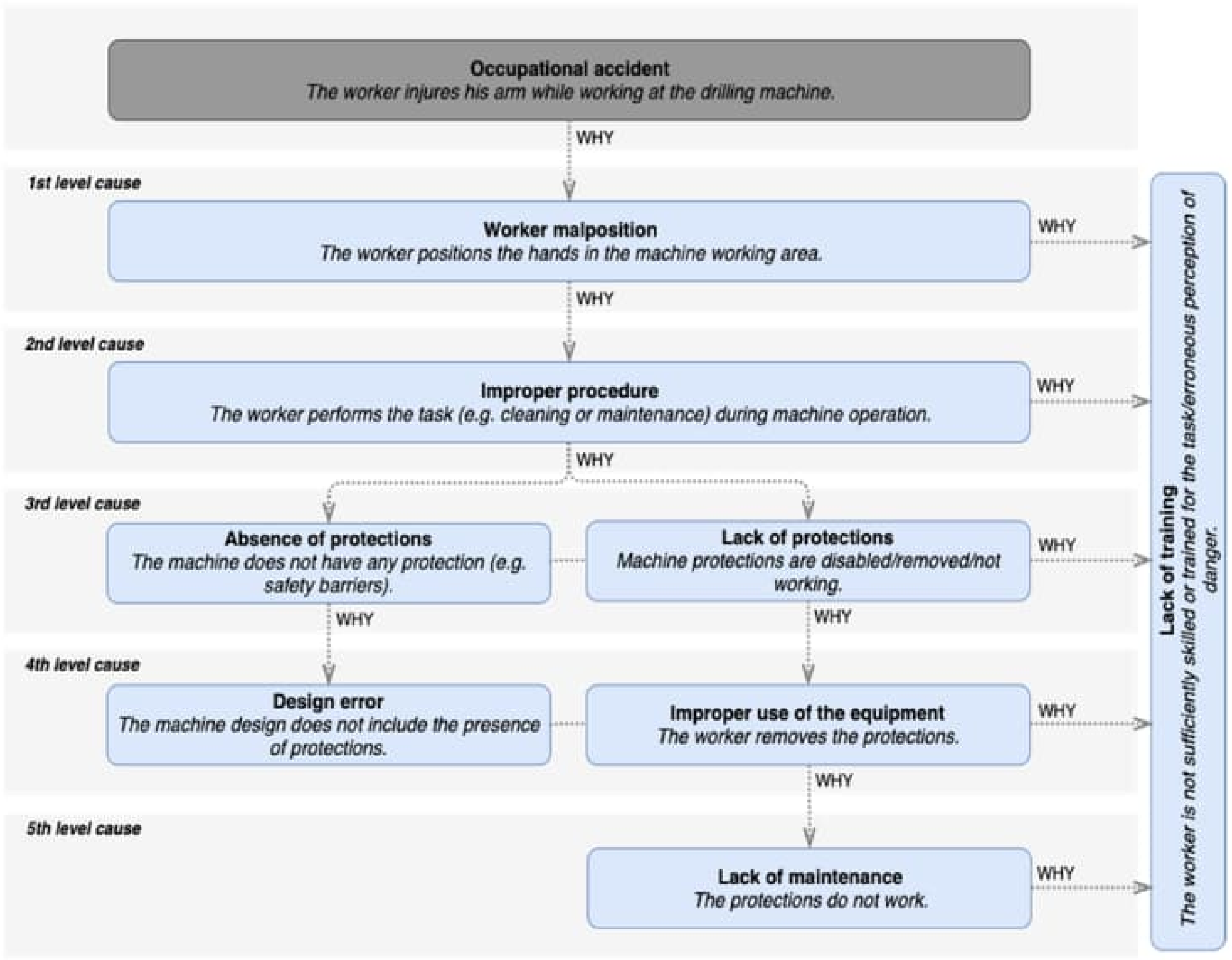

Fig. 2. Causes hierarchy for the investigation of apparent and root causes of occupational accidents (Botti et al., 2020b).

accident. For example, occupational physicians are more likely to describe the causal factors that determined an injury, e.g. the worker malposition of the hands in proximity to an operating machine, rather than explaining the reasons of such improper behavior. This approach confines the investigation to the purpose of finding those responsible for the accident. Additional information are then necessary to deeply investigate the causes of workers' behavior.

The second-level investigation includes a participative approach for the analysis of the consequences and the causes of unsafe behaviors that may result in OSH issues. The methodology proposed to achieve this is the Focus Group with the Workers (FGW), based on the Fault Tree Analysis (FTA) method, as proposed in Mosconi et al. (2019). Specifically, the FTA method is a popular approach used in different industries, e.g. power plants and manufacturing, to understand the cause-effect relationships in critical assets and to investigate the risks related to the plant safety (Rogith et al., 2017; Ruijters and Stoelinga, 2015). The FGW-FTA methodology includes a structured investigation procedure, operated by and with the workers, for the identification of the consequences and the causes of unsafe behaviors (Fig. 3). A safety professional, the workers' safety representative and the workers are involved during the FGW. The safety professional moderates the discussion between the workers during the FGW, following the procedure in Fig. 3. The aim is to improve the workers' ability to identify the risk factors in their workplace and the measures to improve health and safety at work. Specifically, during the focus group, the workers are invited to identify the risk factors for OHS in their workplace. The moderator of the FGW, i.e. the safety professional, addresses the discussion inviting the workers to reason on the consequences and the causes of each identified risk factor and of unsafe behaviors. The proposed approach allows the workers to express their concerns and perceptions about the OSH issues that may be present in the workplace and to become aware of the consequences and the causes of unsafe behaviors.

Finally, the moderator encourages the participants to list the preventive measures present in the workplace and to suggest a set of improvement measures for addressing the identified OSH issues (Fig. 3). The aim is to increase the workers' risk perception and to stimulate their ability to find the solutions for improving OSH in their workplace (Mosconi et al., 2019).

3.3. 3rd level investigation

The research methodology concludes with the third-level investigation for the identification of potential connections between the emerged OSH issues and the process variables of the industrial system. The cross-impact matrix is the techniques adopted in this step (Gordon and Hayward, 1968). This method allows researchers, employers and safety professionals to understand how the process variables may influence the safety performances of the industrial system. Fig. 4 shows an example of cross-impact matrix. The matrix horizontal axis describes the process variables, e.g. any deficiency identified in the production process.

The safety issues emerged during the first two investigation levels are in the vertical axis. Starting with the process variable at the top of the left-hand column, the investigation proceeds with the comparison with each safety issue across the matrix from top-to-bottom and then from left-to-right (Fig. 4). For each pair of process variable and safety issue, the aim is to identify in which measure a change in the process variable affects the safety issue. A simple plus/minus grading system may be used to represent the impact of each process variable on the safety issue, in each matrix box. For example, double plus (++) refers to a "strong positive" impact, plus (+) is for "positive", blank for "neutral", minus (−) for "negative", and double minus (−−) for "strong negative" impact. The company management is involved during this phase.

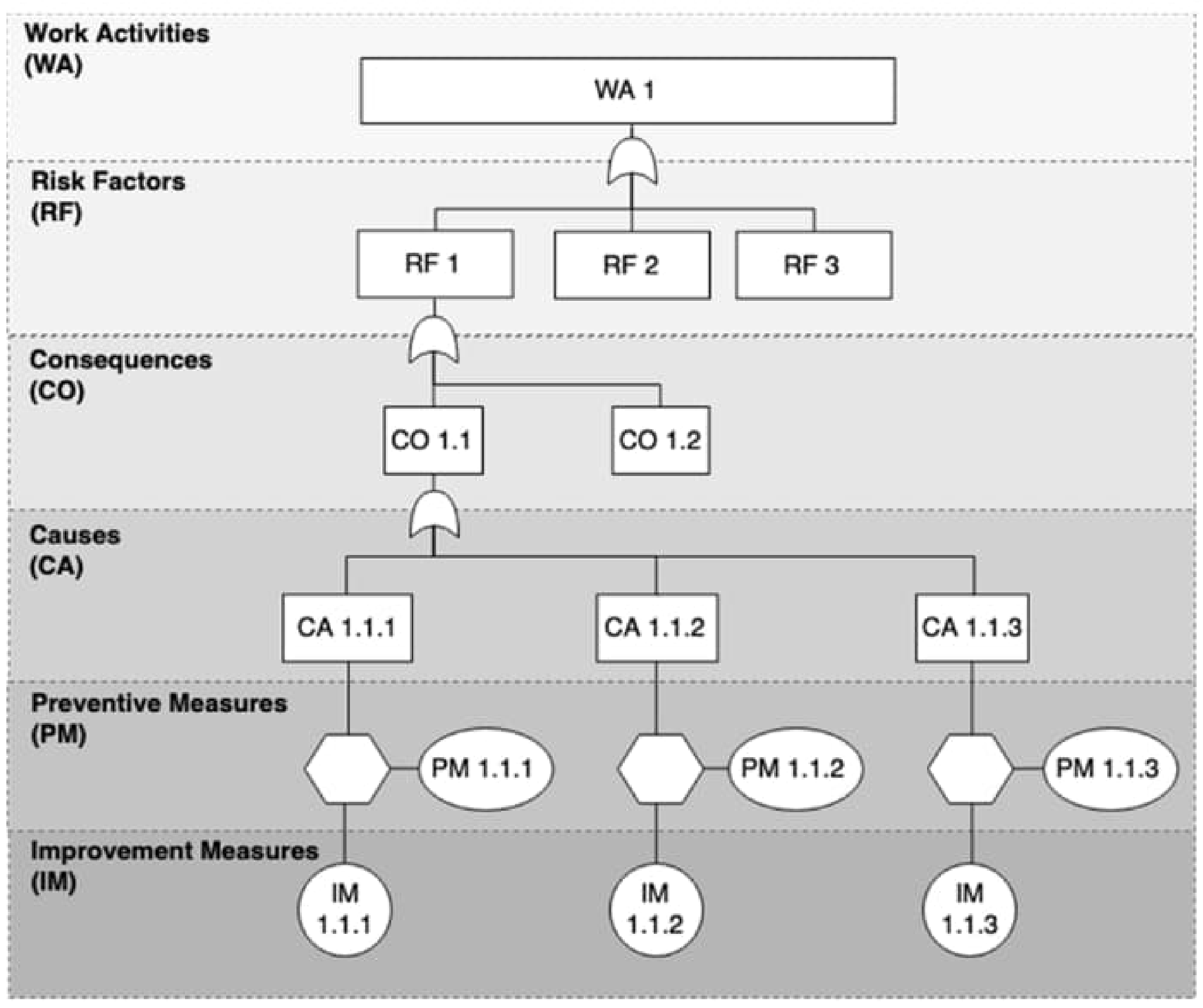

Fig. 3. The structured investigation procedure in the FGW-FTA methodology (Mosconi et al., 2019).

4. Results

This section shows the results of three investigations following the research methodology introduced in previous Section 3. The proposed approach was applied aiming to identify the mechanisms of propagation of top management decisions that may lead to unsafe work conditions or improper behaviors in industry.

The 1st-level investigation in this study refers to a sample of more than one hundred occupational accidents occurred in the Italian manufacturing industry between 2002 and 2015, as introduced in Botti et al. (2020a,b). All the investigated accidents caused a serious injury to the worker involved. The 2nd-level investigation involved the active participation of the workers from an Italian manufacturing company to examine the causes and the consequences of improper behaviors. Finally, the 3rd-level investigation with the cross-impact matrix allowed the cross-analysis of safety issues and process deficiencies emerged during the 1st-level and the 2nd-level investigations.

4.1. Root and apparent causes of major accidents in manufacturing

The occupational accidents included in the first-level investigation are from the accident database of the Italian National Institute for Insurance against Accidents at Work (INAIL) (INAIL, 2019). Data used in this study include the results from Botti et al. (2020a,b) and other previously unanalyzed official accident reports available only in Italian in the INAIL database. Major accidents that occurred in the Italian manufacturing industry from 2002 to 2015 were selected. Specifically, the analysis includes 118 occupational accidents in which the contact of the worker with the moving parts of an industrial plant or machinery resulted in a serious injury. Specifically, 81% of such events involved the contact of the injured worker with fixed machinery. Minor percentages, between 2% and 4%, were found for other risk factors, e.g. the contact

	Process 1		
	Variable 1	**Variable 2**	**Variable 3**
Safety issue 1			
Safety issue 2			
Safety issue 3			

Fig. 4. Cross-impact matrix for measuring the impact of process variables on safety issues.

with electric tools or material handling systems.

Table 1 shows the distribution of the occupational accidents due to the contact of the worker with fixed machinery, based on the type of machine tool and operation.

The contact with fixed machinery reproducing compression forces during operation, e.g. pressing machines and punch presses, accounted for 45% of the investigated accidents (Table 1). Other relevant percentages were found for accidents that occurred during hole-machining operation (12%), operations with cutting machinery (11%), milling machinery and grinders (8%) and lathes (8%). Minor percentages were found for accidents due to the contact with other machines as, for example, shears, calenders and mixers. A deep investigation of each accident was performed, aiming to identify apparent and root causes of the events. The identification of the apparent causes was based on the event description in the INAIL database. The structured investigation process in Fig. 2 was adopted to define the causes hierarchies and the root causes for the investigated events (Botti et al., 2020b). Table 2 shows the results of such investigation.

The voluntary adoption of an improper procedure, e.g. the bypass of a risk control measure, was the apparent cause of 60% of the accidents due to the contact of the worker with fixed machinery that use compression forces during operation. The lack of training was the leading root cause. Lack of training and improper equipment, use of improper equipment, and haste were further frequent root causes of these accidents. A recurring example is the case of a worker who is operating a drilling machine with double-hand control and no safety barriers are present to prevent the positioning of the hands close to the machine operating tool. The accident occurs when the worker, who is holding the processing product with the left hand, activates the drilling machine with the right hand and the body movement, crushing his left hand. In this case, the worker voluntarily bypasses the risk control measure, i.e. the double-hand control. This information is reported on the records. No additional information is provided to understand why the worker does not use both the hands to activate the machinery. In fact, the accident report suggests the adoption of an additional barrier to prevent placing the hands in proximity to the machine operating tool.

The failure or the improper use of equipment, and the lack of coordination are additional apparent causes of accidents due to the contact of the worker with fixed machinery that use compression forces during operation (Table 2). In the first case, frequent root causes are lack of training, lack of maintenance, interference and haste. Finally, the absence or lack of protections, and the absence of protections and lack of training, are the root causes of the accidents apparently caused by lack of coordination. No additional information is provided on the records to further investigate such root causes.

4.2. Participative approach and cross-analysis of safety issues and process deficiencies

The second-level investigation in this study involved the active participation of the assembly workers of an Italian manufacturing company, leader in the production of mural boilers. The boiler assembly line consisted of 16 assembly workstations and 9 workstations for test and quality controls. The production capacity of the assembly line was 175 mural boilers per work-shift (8 h). A material handling system with fixed powered conveyors supported the horizontal movement of the boilers between the workstations. Further material handling equipment, e.g. cranes and hoists, supported the workers during the assembly of heavy and bulky components. The company engineering department designed the assembly line and the material handling system aiming to support the adoption of ergonomic work postures and to prevent the overextension of arms, neck and back. The pace of the assembly line was determined by the machinery and the cycle time for the assembly operations was 150 s. The company Methods-Time Measurement (MTM) team analyzed the assembly operations for each workstation and determined the cycle time ensuring that workers had sufficient time for performing value added and non-value added activities. 12 FGW were conducted during the study. Each focus group involved 10 assembly workers. Each worker was included in the company workplace safety training program, as required by the regulations on OHS. The moderator of the FGW verified and confirmed the knowledge and the competences of the workers about safety practices, procedures and risk control measures available in their workplace. However, the workers revealed their willingness to adopt improper procedures in specific circumstances, which may determine the adoption of awkward postures and excessive exertions. Specifically, the first workstation required the workers to pick up the boiler frame from a large container (each container held 50 frames). A manipulator with considerable weight and dimensions supported the workers during the pick and placement of the boilers. The workers reported the necessity to handle the manipulator with caution, aiming to contrast the inertia of the object, especially during the start and stop phases. The MTM team considered this issue during the analysis of times and motions required to perform the manual activities in the first workstation. Nevertheless, the workers reported that this operation required great efforts, causing a general sense of fatigue at the end of the work-shift. The investigation of the cause-effect relationship with the FGW-FTA methodology revealed the absence of technical-procedural deficiencies in this phase of the assembly process. The workers associated the excessive exertions with the lack of time available for the accomplishment of the manual operations at this workstation. A deeper investigation revealed that the cycle time defined by the MTM team was too limited in case of blockages at other workstations of the assembly line, i.e. the blockage of one workstation determined the block of the whole assembly line. Consequently, the workers had to accelerate the manual operations after the system restore, to make up for lost time and productivity. This situation remarks a strong correlation between the improper behavior and the inefficiency of the assembly line.

Similar conditions were found in other workstations in which the saturation level was higher than the cycle time. For example, after the system restore, the workers did not position the boiler close to the body during assembly operations. They stated that turning the frame was considered a time-consuming operation. Furthermore, the workers

Table 1
Distribution of the occupational accidents due to the contact of the worker with fixed machinery, based on the type of machine tool and operation.

Type of machine tools	Operation/exerted force	Percentage
Presses and bending machines	Compression	45%
Drilling and boring machines	Hole-machining operation	12%
Cutting and sawing machines	Cutting	11%
Milling and grinding machines	Shaping and planing	8%
Lathes	Turning	8%
Other machines	Various operations	16%

Table 2
Apparent and root causes of occupational accidents due to the contact of the worker with fixed machinery that use compression forces during operation.

Apparent causes	Root causes	Percentage
Improper procedure		60%
	Lack of training	42%
	Lack of training and improper equipment	35%
	Improper equipment	19%
	Haste	4%
Failure or improper use of the equipment		28%
	Lack of training	42%
	Lack of maintenance	42%
	Interference	8%
	Haste	8%
Lack of coordination		12%
	Absence or lack of protections	60%
	Absence of protections and lack of training	40%

revealed a *memory effect* such that they chose to adopt the same improper behavior, i.e. the incorrect positioning of the boiler frame during the assembly tasks, regardless the time availability.

The cross-impact matrix in Fig. 5 summarizes these results, showing the correlations between the process variables and the safety issues emerged during the FGW.

The results in Fig. 5 suggest to further investigate the blocking conditions affecting the productivity and the safety performances of the assembly line. The analysis of the assembly process revealed that 3 workstations for test and quality controls were responsible for the blockages of the assembly line. Frequent false alarms occurred at the visual quality control workstation. The causes of such alarms most often were not related to product deficiencies or quality issues. Consequently, the workers used to ignore the alarms and to eventually disregard defective products. Further blockages occurred at the gas circuit test workstation. These blockages were mainly caused by the lack or the improper assembly of components, gas leakages due to imperfect sealings, and defective measurement equipment. Finally, frequent blockages due to the lack of components and to production quality deficiencies occurred during the final test of the boiler. The test often revealed the imperfect alignment of the holes of the boiler frame with the control dashboard. The workers revealed that great effort and extra time were necessary to force the alignment of the components.

5. Discussion

The 1st-level investigation in Section 4.1 revealed common apparent causal factors for accidents that resulted in a severe injury in the manufacturing industry. The leading apparent cause of such accidents was the voluntary adoption of improper procedures, followed by failure or improper use of equipment, and the lack of communication (Botti et al., 2020b). The deep investigation allows researchers, employers and safety professionals to understand the root causes of the accidents (Table 1). The lack of proper training was the leading root cause of the accidents that were apparently determined by the adoption of an improper procedure and by the failure or the improper use of equipment. A common situation described in multiple reports in the INAIL database is the case of a worker who injured the upper limbs while operating in proximity of a machinery with no safety barriers. The contact with the operating tool occurred after the worker activated the machinery with the pedal, bypassing the machinery safety measure, e.g. the two-hand control. The solution suggested on the reports is to add an extra safety barrier between the worker and the operating tool, i.e. the source of the hazard. However, this solution may create additional difficulties to accomplish the task, encouraging new improper behaviors for bypassing the extra barrier. A different approach is therefore necessary in order to raise awareness of the consequences of unsafe behaviors and to contrast the root causes of the occupational accidents. In this case, additional resources should be assigned for workers' training, rather than for implementing a further barrier. Training classes should provide workers with knowledge on safe and unsafe behaviors, adequate risk and hazard perception, and competences on safe work practices (Botti et al., 2020b; Bugalia et al., 2020).

The main contribution of the introduced 1st-level investigation was to provide an overview of critical areas of intervention, suggesting how safety managers can allocate their capital and human resources for ensuring the success of their prevention strategies. The major limitation of this step was due to the quality of the information reported in the accident reports. Many events in the INAIL database miss a detailed description about the accident dynamics. The occupational physicians who fulfill the accident reports and forms use different languages and levels of details of information. The resulting accuracy level of the information in the reports is inconsistent. For this reason, the 1st-level investigation of the events included in this study concluded after the analysis of few causal factors. The lack of information in the events descriptions determined the early stop of the investigation process. The second limitation refers to the interpretation of the causal factors. In this study, two researchers and a full-time professor with multiple years of experience with OSH in industry selected and analyzed the events in the INAIL database. Team work and consultations among the research group are required to avoid interpretation errors and to ensure the quality of the investigation process. However, subjective judgements and personal interpretations are necessary for the analysis of the reports with poor information. For these reasons, an analytical validation process for the proposed methodology was not possible. Hence, a simple and structured methodology is necessary to collect the details of the accident dynamics and, ultimately, to understand the mechanisms that cause fatal and serious injuries. This information could provide sufficient data for defining a new set of leading indicators for occupational accidents in the manufacturing industry.

The results in Section 4.2 reveal strong correlations between OHS issues and process inefficiencies. The holistic and participative approach adopted in this study supported the analysis of such correlations and the design of an effective intervention plan. Specifically, the blockages of the assembly line in the reference case study appeared to be related to the improper behaviors of the workers. Such behaviors caused multiple safety issues, as excessive exertions and awkward postures. The findings of the 2nd and the 3rd level investigations showed that the improper behaviors were the results of the workers attempts to fix the process deficiencies. Such deficiencies caused the blockages of the assembly line and the consequent reduction of the time available for assembly operations. The results also revealed the necessity of targeted interventions for the improvement of the quality control and test workstations.

The participative approach with the FGW-FTA methodology allowed the management to understand the motivations, the attitudes, the opinions and the mental processes that cause workers' behaviors. This is the core of the methodology introduced in this paper. The structured analysis, operated by and with the workers, focuses on their ability to learn from their direct experiences. This approach ensures the active involvement of the workers in the choices related to their OHS, the recognition of near misses and potential high-risk conditions that may result in accidents, and the improvement of workers' attention and caution during work activities (Mosconi et al., 2019). Furthermore, the last step of the FGW-FTA methodology focuses on the definition of a set of preventive and protective measures, and corrective actions for the improvement of OHS. The proposed participative approach allows multiple benefits, including: increased risk perception; improved support from the workers for the identification of high-risk tasks; increased commitment for the implementation of risk control measures; increased team work and cooperation; and improved safety culture within the organization (Mosconi et al., 2019). Such improvements are critical, especially when a relevant part of the workforce includes aged workers with multiple years of experience with the investigated tasks and, consequently, prolonged time of exposure to the same risk factors.

Process: Boiler assembly		
	Process variable 1: Pick up the boiler frame from the container with the manipulator	Process variable 2: Restore the system after a blocking condition
Safety issue 1: Excessive exertions	++ Necessity to handle the manipulator with caution (fatigue during start and stop phases)	++ Acceleration of manual operations (improper procedure)
Safety issue 2: Adoption of awkward postures		++ Incorrect positioning of the boiler frame during assembly tasks (improper behavior)

Fig. 5. Cross-impact matrix of safety issues and process deficiencies for the assembly line in the reference case study.

Recent studies suggest that greater workers' engagement in safety strategies and health-promoting behaviors result in better OSH, which in turn can lead to increased perceived risk control and job satisfaction (Bayram, 2019; S.X. Liu et al., 2020; Robinson and Lachman, 2017). Instead, employees who do not participate in active safety training, discussions and inspections are more likely to use equipment and machinery improperly (S.X. Liu et al., 2020). Unfortunately, older workers are generally less willing to participate in career development and training activities (Ng and Feldman, 2012). Other negative stereotypes as that aged workers are less motivated, or more resistant and less willing to change, do not find empirical support. However, the adoption of a participative approach increases the workers commitment with the company goals and objectives, preventing the early retirement of aged workers.

6. Conclusions

This paper introduced an innovative methodology for addressing Occupational Health and Safety (OHS) problems in industry. The proposed methodology involves a participative approach, which is based on the active involvement of the workers for the identification of critical risk factors in the workplace. Previous studies showed that the active participation of the workers in safety management allows multiple benefits, including an increased commitment for achieving the company safety goals and an improved organizational information flow between employees, employers and the safety professionals inside and outside the organization. Workers' commitment in safety goals is necessary for ensuring the success of OSH interventions, especially when a relevant part of the workforce includes aged workers. The aim of this research was to investigate the consequences and the causes of unsafe behaviors that can lead to serious injuries and accidents. The proposed methodology supports the definition of preventive and protective measures, and corrective actions for the improvement of health and safety in the workplace. Three steps were identified. The 1st-level investigation aims to understand the apparent and the root causes of accidents that lead to serious injuries, in specific industries. This investigation is based on the analysis of the information in the accident reports available from public databases. The results of the 1st-level investigation provide the answer to the first research question (How can top management decisions lead to unsafe work conditions or improper behaviors?), suggesting a potential correlation between top management decisions and unsafe work conditions or improper behaviors. The 2nd and the 3rd level investigations support the answer to the second research question (Is it possible to understand the mechanisms of propagation of top management decisions to company safety performances?).

Specifically, the 2nd-level investigation allows employers and safety professionals to verify the actual presence of such correlation, i.e. this investigation involves the active participation of the workers for the in-depth examination of the root causes of accidents and the consequences of unsafe behaviors. In this step, the workers actively participate in the definition of a set of preventive and protective measures, and corrective actions for the improvement of health and safety in their workplace. Finally, the 3rd-level investigation allows the identification of potentials correlations between the emerged OHS problems with the process deficiencies due to poor operation management. Such correlations provide the management with critical information supporting the selection of targeted leading indicators and addressing the proactive response to unsafe work conditions. Future developments of this study will investigate the dynamics of fatal accidents in the Italian manufacturing industry and the potential correlations between unsafe behaviors and process safety deficiencies, aiming to identify new leading indicators for accident prevention and for preventing early retirement.

Older workers are both a challenge and an opportunity. Tackling the workforce ageing and making it an opportunity depends on the ability of the organizations to postpone the retirement of older workers. Most employers believe that the main assets of older worker are experience, know-how, conscientiousness, timekeeping, dynamism and anger management (Nicholson et al., 2016). However, there are some negative perceptions, as that they are seen more expensive than younger workers and employers have concerns about their health status and flexibility (European Foundation for the Improvement of Living and Working Condition, 2011). The truth is that there is no consistent evidence that older workers are less productive than younger workers. Most studies conclude that job performance is mostly the same across age groups. When the skills and competences match the job requirements and when work experience is considered, there is little variance between the performance of older and younger workers. Ability, experience, know-how, skills and commitment can compensate for functional declines and diminished cognitive capacity due to ageing. Furthermore, declining health or functional capacities due to ageing have no impact on work performance in most jobs (European Foundation for the Improvement of Living and Working Condition, 2011). There is little evidence that age per se affects people workability. Older female workers between 50 and 58 may experience symptoms of menopause, which can impact on working life and cause poor concentration, tiredness, poor memory and lowered confidence (European Foundation for the Improvement of Living and Working Condition, 2011; Griffiths et al., 2013). Workability is reduced for overweight people and for those physically sedentary in their spare time. Conversely, researches show that work is generally good for health and wellbeing, for all age groups (Yeomans, 2011). Other studies report that when older workers are involved in accidents, they are more likely to implicate serious or fatal injuries (Farrow and Reynolds, 2012). There is also evidence that older workers need longer recovery periods after accidents and injuries (Turner et al., 2000). However, the most critical factor contributing to the risk of injuries and accidents at work is not age, but occupation. Safety managers, employers and safety professionals should invest more resources on the study and the prevention of adverse working conditions and workers' unsafe behaviors, regardless the age groups. Nevertheless, workforce ageing is a fact. Most workers with long-term health conditions or a decline in physical capacity continue to work for multiple years before they can reach the retirement age. Employers are required to take preventive actions which can mitigate the effects of the exposition to OSH risks over prolonged working lives.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was developed in the context of the project "A Modena la sicurezza sul lavoro, in pratica", with the support of the Italian National Institute for Insurance against Accidents at Work (INAIL), Agency of the Region of Emilia Romagna (RER). The authors are grateful for this valuable help. The authors would also like to thank Dr. Anna Maria Iotti, from the INAIL-CONTARP RER, and Dr. Maria Rosa Avino, from INAIL Modena, for their precious support.

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