Web Aided Confined Spaces Risk Assessment: Development Of A Web Portal Supporting The Risk Assessment Of Work In Confined Spaces

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Abstract: Past and recent statistics on industrial accidents show that work in confined spaces is a high-risk activity that frequently leads to multiple fatalities and serious injuries. The analysis of accidents dynamics reveals that the leading cause of such events is the lack of awareness about the risks that may be present within the confined space.

This paper introduces an innovative web-based tool supporting employers, safety professionals and practitioners during the risk assessment of confined spaces in industry. The proposed tool is based on the Web Aided Confined Spaces Risk Assessment algorithm, i.e. a decisional flow chart that drives the user during each phase of the risk assessment for work in confined spaces. The aim was to support the prevention of occupational accidents during work in confined spaces and to promote the awareness about the risks of such activity. The proposed tool investigates critical issues dealing with confined spaces, e.g. the definition and the classification of confined spaces and the identification of hazards and risks, the qualification of the companies, the emergency and rescue procedures and the personal protective equipment. Two additional sections introduce a collection of previous cases of accidents in confined spaces and an archive of documents, e.g. reports and international regulations on work in confined spaces. Finally, a tutorial allows the interactive consultation of regulations, documents and media.

A case study shows the application of the proposed tool to a grain silo and the investigation of the ordinary maintenance intervention performed inside the confined space. After completing the procedure with the flow chart, the user has proper information to make decisions about the confined space intervention. The dynamic structure of the web portal allows the user to interact with the contents by adding new case studies, work procedures and critical events, e.g. accidents, dangerous occurrences and near misses.

Keywords: Confined space; risk assessment; algorithm; web-aided tool; web portal.

1. Introduction

Past and recent statistics on industrial accidents show that work in confined areas is high-risk activity that frequently leads to multiple fatalities and serious injuries. Previous studies on the analysis of accidents dynamics revealed that the leading cause of such events is the lack of awareness about the risks that may be present within the confined area (BARPI, 2008; Botti et al., 2018; Botti, Mora, et al., 2017; Selman et al., 2018; Sundal et al., 2017). Several events reported multiple fatalities after an accidents in a confined space, where multiple rescuers succumbed, one by one, by attempting to rescue an injured colleague (Muncy, 2013; Wilson et al., 2012). Confined space rescuer deaths are typically the result of hasty and unplanned rescue attempts. This attitude to underestimate actual and potential risks of confined spaces reveals a lack of training at multiple levels of the organizations, from the top management, to the employees who perform the tasks. A proper and effective training plan should ensure the exhaustive flow of information between customers, contractors and other sub-contractors about risks and hazards in the confined space. Such flow should reach each worker involved in the confined space intervention.

Common activities performed in confined spaces include cleaning, inspecting and maintenance tasks (Botti, Ferrari, et al., 2017). Cleaning tasks typically require the use of chemicals and other substances that may alter the atmospheric conditions inside the confined space. Previous studies revealed that the activity performed by the entrant caused the presence of toxic gas or oxygen deficiency in several accidents due to hazardous atmospheric conditions (Botti et al., 2018). Accidents with engulfment are the result of the attempt to unclog an accumulated deposit of materials, e.g. maintenance tasks in storage tanks containing flour or granular material. Confined space fatalities are significant cause of workplace death in Italy and internationally. A recent investigation into the mechanisms of incidents of work-related confined space fatalities revealed a fatality rate between 0.05 and 0.08 deaths per 100,000 workers (Selman et al., 2018). Such fatalities include both entrants and rescuers. Physical hazards and toxic atmospheric hazards are the major causes of death among entrants (Botti et al., 2016; Selman et al., 2018). Specifically, engulfment is the most prevalent mechanism of incident in the agricultural industry, while oxygen deficiency and toxic airborne contaminants are the main cause of incident for rescuer fatalities. An international standard on health and safety in confined spaces is not yet available. The worldwide regulations on confined spaces are fragmented. Specifically, each country adopts its own regulations reporting the procedures and the best practices for safe confined space work (Botti et al., 2018). Such legislative fragmentation results in widespread haziness and sense of confusion about the requirements and safety procedures for work in confined spaces. Confined space fatality rates reveal that worldwide organizations have difficulties in complying with the requirements for risk assessment of interventions in confined spaces. Employers, particularly of small and medium-sized enterprises, claim that risk assessment support tools are needed to help them identify all the risks and potential issues related to work in confined spaces. The lack of an international definition of "confined space" is a further cause of uncertainty. The US Occupational Health and Safety Administration (OSHA) defines a Permit-Required Confined Space (PRCS) as a confined space that is large enough and configured that an employee can enter and perform work, has limited openings of entry or exit, and is not designed for continuous occupancy (OSHA, 1993, 2004; U S Departmentof Labor, 2014). The OSHA's PRCS Standard (OSHA, 1993) proposes a decision flow chart supporting practitioners and safety professionals to determine access requirements for confined spaces. Similar decisional tools were proposed by different institutions, e.g. the Australian Safe Work (Safe Work Australia, 2018) or the UK Government Agency Health and Safety Executive (HSE, 2014). The use of these tools is simple and intuitive. Despite the simplicity and user-friendliness, these flow charts do not provide sufficient directions for risk identification and estimation.

In 2015, Burlet-Vienney et al. proposed a five step risk assessment tool for confined spaces based on risk management standards. The tool consists of a structured questionnaire that investigates the configuration, the environment and the work situations in the confined space. The answers allow to estimate potential risks that may be present in the confined space, and to categorize the interventions. Despite the exhaustive list of potential risk situations in the questionnaire, the proposed tool does not investigate further aspects of safety in confined spaces, e.g. ER interventions, health surveillance or PPE. More recently, Selman et al. (2019) proposed a five step procedure for safe confined space entry rescue, including a focus on the hierarchy for protection (rescuers, bystanders, and casualties) and the hierarchy of the level of confined space rescue (self-rescue, non-entry rescue, and entry rescue). Given the importance of cooperation, coordination and information actions between the actors, the aim of this paper is to provide a conceptual, operative and interactive tool supporting employers and safety professionals during the risk assessment of work in confined spaces. The result is the Web-Aided Confined Spaces Risk Assessment (WACOS) web portal. The WACOS web portal includes an innovative risk assessment support tool. The tool is based on a structured algorithm that defines an effective training path for the planning and the management of safe confined space interventions. The aim was to support the prevention of occupational accidents during work in confined spaces and to promote the information and the awareness about the risks of such activity. The algorithm investigates the characteristics of the confined space and the requirements of the intervention, providing detailed information about the risks and the hazard that may be present. The results of the investigation allow the identification of the personal protective equipment (PPE), the risk control measures and the emergency and rescue (ER) operations that should be implemented during each phase of the confined space intervention. Several commercial tools are available for standardized risk assessment and quantification. However, the aim of our research was to provide a dynamic tool that supports and stimulates the user during the risk assessment. Two additional sections in the web portal introduce a collection of previous cases of accidents in confined spaces and an archive of documents, e.g. reports and international regulations on work in confined spaces. Finally, an interactive tutorial allows the dynamic consultation of regulations, documents and media.

2. Method

This section introduces the WACOS algorithm and the web portal supporting the risk assessment of confined spaces. Specifically, the WACOS algorithm is the core of the risk assessment support tool accessible from the web portal.

2.1 The WACOS web portal

A web portal was realized supporting industrial practitioners during the risk assessment and the design of confined space interventions. Registration is required to access the sections on the WACOS web portal. The web portal is organized in four sections dealing with different aspects and in-depths analyses related to work in confined spaces (Figure 1).

Section 1 includes the WACOS algorithm supporting the risk assessment of the confined space intervention. The access to Section 1 is limited to qualified users, e.g. employers and safety professionals (2nd level users). 1st level users, e.g. workers and other personnel, can explore Sections 2, 3 and 4. Section 2 collects various documents and regulations on work in confined spaces, e.g. reports, standards and validated work procedures. A database with more than 600 accidents occurred worldwide is in Section 3. Both the documents archive and the accidents database are organized into sub-sections that the user can explore with filters and keywords.

Figure 1: Structure of the Web-Aided Confined Spaces Risk Assessment (WACOS) web portal

Finally, Section 4 includes a tutorial where the user can examine in depth various topics included in Section 1, e.g. the definition of confined space, the risk assessment, the qualification of the companies involved in confined space interventions, and the ER procedures. Both Section 1 and Section 4 propose an interactive approach for the investigation of the problem of safety in confined spaces. A semi-structured path drives the user through the exploration of the contents included in the portal. The portal navigation path consists of multiple crossroads, i.e. open-ended and close-ended questions. Each question is provided with additional documents, e.g. regulations, guidelines and factsheets, supporting the user decision-making process.

2.2 The risk assessment support tool

The risk assessment support tool in Section 1 of the web portal is based on the step-wise investigation process in Figure 2. The investigation process consists of six steps dealing with critical aspects of safety in confined spaces.

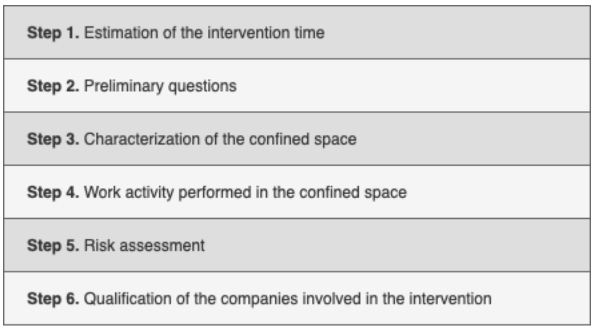

Figure 2: Structure of the Web-Aided Confined Spaces Risk Assessment (WACOS) support tool

Each step includes a decisional flow chart that drives the user, i.e. the employer or the safety professional, during the investigation of the confined space intervention. The investigation process starts with the estimation of the intervention time. In Step 1, the user is required to provide information on the time required for technical and health support (e.g. the time needed by firefighters and rescue teams, or the time needed by first-aid teams to reach the confined space) and the distance from ER services. The second step proposes a set of preliminary questions aiming to contextualize the investigated confined space. Such questions investigate the location of the confined space, e.g. indoor or outdoor, the presence of potential obstacles to reach the confined area and the presence of other confined spaces nearby. Step 3 explores the answers to the preliminary questions, providing a characterization of the confined space. A set of technical questions investigates the features of the confined space, e.g. the shape, the geometric dimensions, the internal configuration and the means of entry. The analysis of the activities performed in the confined space is the focus of Step 4. The user is required to provide additional information about the type of activity that is performed inside the confined space (e.g. cleaning, inspection, maintenance, etc.), how often the activity is performed and the number of workers involved. The information retrieved in the first three steps provide the basis for the decisional flow chart in Step 5, i.e. the WACOS algorithm (Figure 3). The algorithm drives the user during the in-depth analysis of the atmosphere, the preliminary activities and the risks related to the confined space intervention. The atmosphere assessment investigates the presence of toxic or dangerous substances, the type of ventilation and the monitoring techniques, providing technical and legislative documents. The analysis of preliminary activities collects information on the presence of systems that introduce materials inside the confined space, power sources and available locking devices ensuring the tagout during the intervention. The user is then invited to investigate the risks that may be present during the confined space intervention, e.g. asphyxiation, engulfment, vibrations, etc. For each risk, the user receives additional information that help him identifying the risk presence and the required PPE. After the risk investigation, the user provides information about the implemented PPE. The results of the WACOS algorithm allow the qualification of the companies involved in the confined space intervention (Step 6). In this Step, the user provides more details about the contract (e.g. procurement and subcontract), the training and the experience of the workers with work in confined spaces, the ER procedures, and any health surveillance undertaken.

3. Case study

The following case study describes the investigation of a grain silo and the risk assessment of the ordinary maintenance intervention. The intervention consists of unclogging the materials on the walls of the silo and inspecting the grain. The risk assessment was performed adopting the support tool on the WACOS web portal. This Section introduces the information collected with the proposed tool.

3.1 Estimation of the intervention time

The silo is situated in the milling plant of an Italian medium enterprise in the countryside of the Region Emilia Romagna. The distance from the closest emergency room is 12 km. The closest fire station is situated at 2 km from the milling plant.

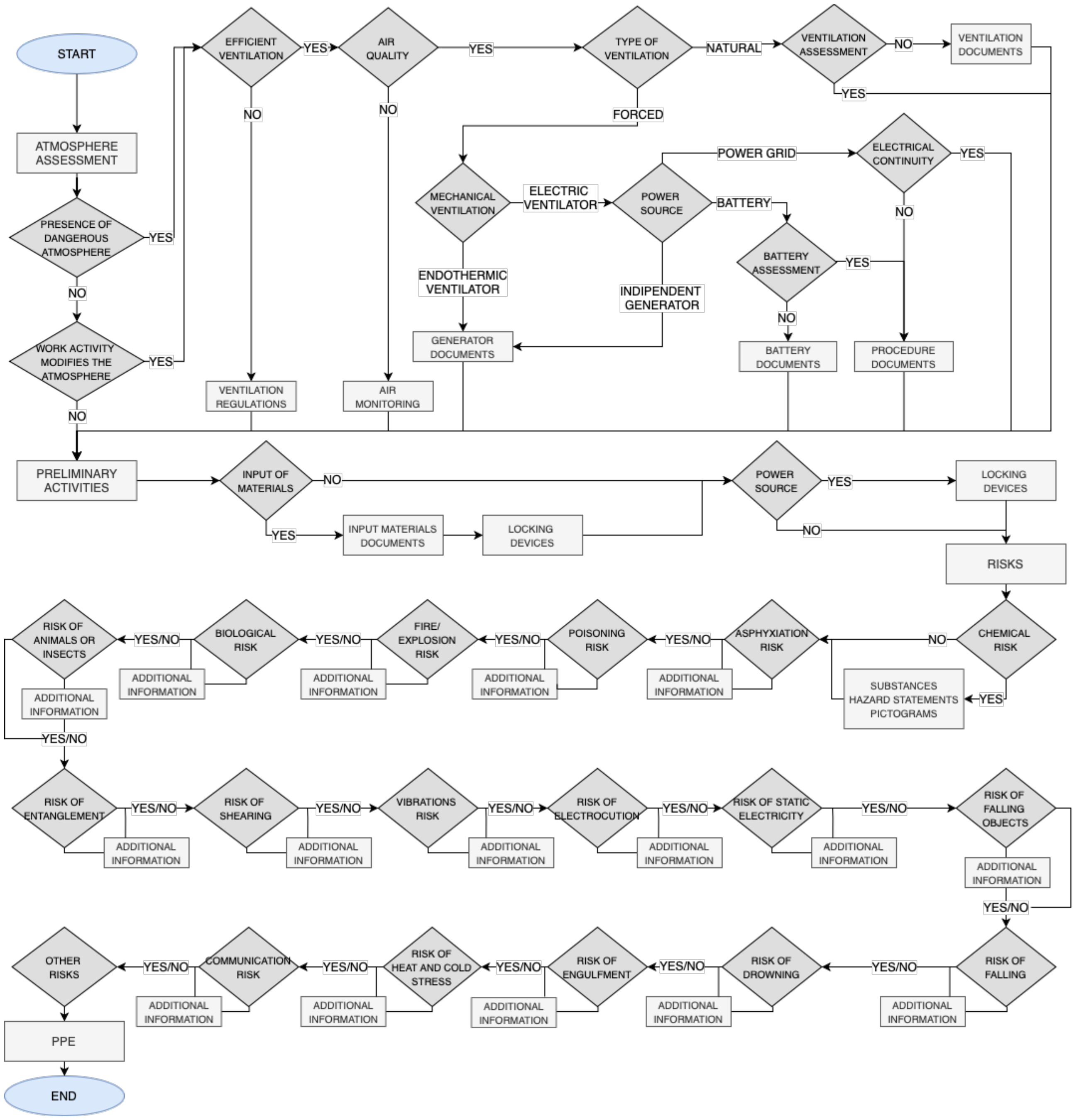

Figure 3: Decisional flow chart for the Web Aided Confined Space Risk Assessment: the WACOS algorithm (Step 4).

3.2 Preliminary questions

A grain silo is situated in an outdoor area in proximity of a flour milling plant. Four other silos are situated nearby the investigated structure. Trucks and other tractor-trailers reach the silos for loading and unloading operations, from the plant courtyard. Only authorized trucks have access to the loading area.

3.3 Characterization of the confined space

The silo contains granular material, i.e. wheat seeds. No containment reservoirs are present in proximity to the silo. The shape is cylindrical and it has a height of 40 m. The top is a plan surface, while the bottom has a conical shape. The external diameter of the confined space is 20 m. The whole structure is made of uninsulated reinforced concrete. No obstacles are present inside the silo. However, the conical-shaped bottom makes it difficult to walk through the confined space. Two manholes allow the access to the internal area. The first manhole is horizontal and situated on the top of the silo. The workers reach the roof of the silo by ordinary stairs or by elevator in case they need to enter the confined space through the top manhole. The stairs and the elevator are situated inside an adjacent building. The second manhole is on the lateral surface, at 3 m from the bottom of the silo. Specifically, the workers reach an intermediate floor by stairs or by elevator. The manhole is vertical and it is situated at 1.5 m from the floor. A portable ladder is necessary to access the lateral manhole. The top manhole is 50 x 60 cm, while the lateral manhole is 50 x 50 cm. No fall-arrest systems are available.

3.4 Work activity performed in the confined space

The worker accesses the silo to perform grain inspections and ordinary maintenance interventions. A typical maintenance intervention consists in unclogging the materials on the walls of the silo with a shovel. Grain inspections are performed with a torch. Ordinary inspections and maintenance interventions are performed up to four times a month, adopting professional equipment for use in explosive atmospheres.

3.5 Risk assessment

Atmosphere assessment

Dust can be generated from the cereals handling operations. The presence of dust inside the silo may determine inhalation hazard and risk of explosion. The characteristics of the internal configuration of the confined space do not ensure efficient ventilation in every accessible area. Hence, workers must be equipped with PPE.

Preliminary activities

Material input systems equipped with locking devices are present in the silo to allow the cereal transfer and the lockout in case of emergency. No power source is present inside.

Risks

Risks that may be present inside the confined space include: asphyxiation, explosion, biological risk, risk of animals or insects bites, risk of falling and engulfment.

PPE

Workers are required to wear the PPE during work activities inside the silo. Such equipment includes safety shoes, respiratory protective equipment and anti-fall systems.

3.6 Qualification of the companies

The operators at the milling plant perform the ordinary maintenance operations. No contractors or subcontractors are involved in the intervention. Risk assessment for the ordinary inspection and maintenance operations was performed two years before the intervention, by the company's safety manager, as required by the Italian legislation on occupational health and safety (Ministero del Lavoro e delle Politiche Sociali, 2008). All the personnel employed by the company has been recruited with a fixed-term employment contract. The workers performing the confined space intervention are subject to health surveillance on a regular basis. An ER plan was realized three years before the investigation in this study. Since then, the layout of the flour milling plant outside area was modified. Specifically, a movable barrier was positioned aiming to control the truck access in proximity to the silos. The barrier separates the loading area near the silos from the rest of the plant's courtyard. The operators involved in the confined space interventions were informed and trained for the correct use of PPE and systems for air monitoring, and for ER in confined spaces. An operating procedure for ordinary maintenance inside the silo describes the phases of the intervention, in chronological order, the required equipment and the machinery, and the personal and collective protective measures. No details about the personnel competences and skills are provided.

4. Results and discussion

The investigation of the silo with the WACOS tool allows the identification of critical areas that were not addressed in the previous risk assessment performed by the company's safety manager. The following Table 1 shows the results of the risk assessment for the introduced silo, with the WACOS support tool.

Table 1: Results of the investigation of the silo with the WACOS support tool.

Investigated issue	Solution	Status
Step 1. Estimation of the intervention time		
Time from technical and health support structures	Details on time from technical and health support structures	Not present
Step 2. Preliminary questions		
Presence of other confined spaces in proximity to the silo	Control access to the area of the silo	Present
Step 3. Characterization of the confined space		
Difficulty to walk inside the silo	Include this information in ER plans	Not present
Difficulty to access from the lateral manhole	Include this information in ER plans	Present
Step 4. Work activity performed in the confined space		
Interventions in explosive atmosphere	Adopt professional equipment for use in explosive atmospheres	Present
Step 5. Risk assessment		
Atmosphere assessment		
Inefficient ventilation	Efficient ventilation systems	Partially present
	Air monitoring systems	Not present
Preliminary activities		
Input of materials	Locking devices	Present
Risks		
Asphyxiation		Addressed
Explosion		Addressed
Biological risk		Addressed
Animal and insects		Addressed
Falling		Addressed
Engulfment		Addressed
PPE		
Provide proper PPE	Safety shoes	Present
	Respiratory equipment	Present
	Anti-fall systems	Present
Step 6. Qualification of the companies involved in the intervention		
Outdated ER plan	Update the ER plan, inform and train the personnel	Not addressed
Limited accessibility to ER teams	Define ER paths	Not addressed

No details about the personnel in the operating procedure	Details about required personnel competences and skills in the operating procedure	Not present

Each Step of the WACOS support tool is investigated, aiming to identify potential safety issues that may arise during the intervention in the reference silo. For each investigated issue, the tool suggests the solutions that should be implemented. The status of the intervention describes if proper solutions are present or not. The investigation of the grain silo with the WACOS support tool starts with the estimation of the intervention time for technical and health support. The first Step of the tool reveals that no information about the time for technical and health support intervention is present in the ER plan. The distance from the closest emergency room is 12 km, which corresponds to an estimated intervention time for first-aid support is about 20 minutes (26 minutes during rush hours). The closest fire station is situated at 2 km from the milling plant and the estimated time for rescue teams to reach the silo is about 3 minutes (4 minutes during rush hours). The employer shall include this information in the updated version of the ER plan. The investigation in Step 2 with the preliminary questions reveals that other silos are present in proximity to the investigated confined space. Access to such silos is monitored. The characterization of the silo in Step 3 shows that the conical-shaped bottom makes it difficult to walk through the confined space. This condition is familiar to operators who regularly access the silo for ordinary maintenance. However, the actual ER plan does not consider this issue. Furthermore, a portable ladder is necessary to access the lateral manhole. This information is included in the ER plan. Conversely, the ER plan does not consider the difficulty to reach the top level of the silo in case of rescue intervention from the top opening. The rescue procedure should include the operations required to bring the rescue equipment in proximity to the top opening and to transfer the rescued worker from the top level to the ground. Step 4 investigates the work activities performed during maintenance interventions and inspections, stressing the importance to adopt professional equipment for use in explosive atmosphere. In this case study, the employer is aware about the explosive atmosphere inside the silo and the importance of using proper equipment. The risk assessment in Step 5 reveals that a ventilation system is present. Nevertheless, the characteristics of the available system do not ensure proper ventilation in every accessible point. Also, no air monitoring systems are present. Hence, these issues require further investigations. Step 6 reveals that the actual ER plan is out-of-date. Specifically, the ER plan was realized before the installation of the movable barrier in proximity to the silos. In case of emergency, such barrier may determine an obstacle to the ER teams. This factor is not included in the ER plan. The WACOS tool allowed the identification of such safety issue, reminding the safety manager to update the ER plan. The tool suggests to include a specific path for ER teams that is integrated with the company's viability plan. The employer is required to inform the workers about the new ER plan and to provide proper training. The training session will address the modalities for the inspection and maintenance operations described in the operating procedure, aiming to prepare the personnel before intervention. Finally, Step 6 suggests to implement the procedure with the details about the competences and the skills required to the workers involved in the confined space intervention. Documentation should be provided stating the person in charge of the intervention and affirming that the personnel involved (at least the 30%) has at least three years of documented experience related to work in confined spaces (Ministero del Lavoro e delle Politiche Sociali, 2011). The WACOS tool reminds the user that the Italian legislation requires both internal and external personnel involved in the intervention to meet the requirements in the DPR177/2011 (Ministero del Lavoro e delle Politiche Sociali, 2011), i.e. minimum 30% of the personnel with at least three years of documented experience related to work in confined spaces, 100% of the personnel with a fixed-term employment contract and, in case of procurement, the contract must be certified.

5. Conclusion

The proposed Web-Aided Confined Spaces Risk Assessment (WACOS) web portal aims to provide an operational support for employers and safety professionals dealing with confined spaces and with regulations on work in confined space. The tool is not intended to replace the risk assessment and the confined space entry requirements for employers (Ministero del Lavoro e delle Politiche Sociali, 2008, 2011). The primary aim was to provide a reliable contribute to the dissemination of accurate information on the risks associated with working in a confined space. This is in line with the objectives and the needs of the modern industry, which promotes the diffusion of the Internet of Things (IOT) technologies. IOT technologies refer to a paradigm where objects and people are interconnected and share information between each other and with the environment (Botti et al., 2016). In this context, the WACOS web portal provides a methodological support for companies that operate in confined spaces, enhancing and promoting the sharing of data, information and documents within the organization. Small and medium-sized enterprises were the main target of this study. However, this tool supports all the companies dealing with work in confined spaces, i.e. each question proposed during the portal navigation path is provided with additional documents, e.g. regulations, guidelines and factsheets, supporting the dynamic user decision-making process in a Business Process Modeling (BPM) perspective. The answers provided by the user define customized navigation paths, which allow the identification of potential improvements and safety issues related to work activities in confined spaces, as well as the reduction of the time and the activities required for the emergency intervention, i.e. the intervention chain. The case study proposed in this paper showed the application of the tool to a grain silo and the investigation of the ordinary maintenance intervention performed inside the confined space. After completing the procedure with the flow chart, the user has proper information to make decisions about the confined space intervention.

Specifically, the WACOS tool allowed the identification of safety issues, reminding the safety manager to update the ER plan. Finally, the WACOS web portal collects statistics and information on the characteristics and the risks of confined spaces. Specifically, the WACOS algorithm allows the investigation of silos and tanks. Previous studies revealed that accidents and fatalities due to work confined spaces mostly occurred in such spaces, with high prevalence of fatalities in agriculture, wastewater and food industries (Botti et al., 2018). Future developments of this research will include the extension of the WACOS algorithm to the investigation of other typologies of confined spaces. The analysis of the events collected by the users through the WACOS web portal will allow the identification of recurring hazardous work conditions and the definition of apparent causes of accidents and fatalities (Botti et al., 2021). Following the requirements of the Machinery Directive 2006/42/EC (European Parliament; and European Council, 2006), this information will support the identification of reasonably foreseeable users' behaviors, and the design of standardized operating procedures for ER plans.

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