Coordinating inspection activities at hazardous equipment through an IOT platform


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Abstract: In Italy, hazardous equipment designed to lift things and people – like cranes, self-propelled variable reach trucks, elevating work platforms, etc. – needs to be controlled based on mandatory periodic checks aiming to control safety levels based on the actual level of utilization. During the use phase, interventions as well as faults could occurred thus modifying operative conditions of the system. By analyzing incident occurred in last years, it could be outlined that such equipment present multiple causes of failure including organizational ones. Among the causes of accidents occurring on such equipment, a significant role is certainly covered by the lack of information provided on the management of said equipment. A more coordinated approach for risk prevention could be adopted if correct information will be available. Thus, the aim of the proposed work is to define and design an IOT (Internet of Things) platform for effectively managing data about the whole life cycle of a hazardous equipment aiming to coordinate inspection as well as maintenance activities. The entire management process of the equipment is allowed through the use of smart tag attached to the lifting equipment, capable of interacting both with the user and the inspector during control activities. The platform will adopt IOT technologies for accurately identifying the equipment; a web-based software will be designed to manage all data about its “fault and maintenance history”. Different type of maintenance activities could be carried out on the equipment through a coordinated approach to optimize costs.

Keywords: Hazardous equipment, IOT platform, coordinated maintenance

Introduction

Complex machineries are still one of the main sources of risk at workplace (Aneziris, 2004). In this field, lifting equipment due to both their intrinsic hazardous features and the way that are used at workplace is currently one major source of injuries (Shepherd, 2000). Lifting equipment includes any equipment used at work for lifting or lowering loads, including attachments used for anchoring, fixing or supporting it, and lifting or lowering persons. Additional hazards can occur when equipment becomes unreliable and develops faults (Jannadi, 2002; Haslam et al., 2005; Raviv, 2017). Maintenance allows these faults to be diagnosed early and corrected to manage any risks. In Italy, for these machineries, specific legislation has been defined: starting from a general mandatory framework defined by the Decree 81/2008, a specific legislation (the Decree 11-04-2011) defines mandatory inspection programme to be developed by the employer. Italian legislation provides for periodic inspection for a wide range of equipment: self-propelled variable reach trucks, elevators and hoists for construction sites, hoists, mobile elevating work platforms. These inspections are scheduled according to different periodicity based on the equipment. To these tests must be added the checks that the employer manages on his own, according to the manufacturer's instructions. Although specific duties – mainly regarding equipment to be inspected and inspection frequency- are defined by competent authorities, other maintenance activities – e.g. defined by the equipment producer- needs to be still correctly planned and carried out.

These periodic checks also include the lifting accessories, which the equipment uses to take the load.

In Italy it has still found little diffusion, despite the legal obligation, the recording of maintenance and control interventions carried out on the equipment. The competent authority has defined a document – called Control Registry – to be complied by the employer.

A standard has not yet been adopted, thus, data about inspection activities are often not completely available to the inspector.

The study aims to propose an organizational guideline to coordinate maintenance and mandatory inspection activities for lifting equipment, which could support companies and inspectors in sharing useful information in a quick a common way. A prototype software tool and an IOT (Internet of Things) device – defined as smart label – will be also designed to support the application of this guideline to trace activities developed before, during and after a mandatory inspection. The paper is organized as follows: in section 1, an analysis about the hazardousness of the lifting equipment is proposed; next, the logical structure of the proposed software tool is detailed proposing guideline for managing information during the whole machinery lifecycle.

1. Safety analysis about the lifting equipment sector in Italy

At first, a quantitative analysis causes and factors that have led to an injury involving a lifting equipment has been carried out: the purpose is to outline most hazardous
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The 6 analyzed clusters (defined as GA, GB, GC, GD, GE, GF) represent almost all types of lifting equipment currently used in the Italian market: data outline two groups as the most dangerous ones; this is mainly due to their high utilization in different industrial sectors (e.g. from construction to manufacturing).

Figure 1. The proposed two-level classification of injury events

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Figure 2. Risk sources evaluated for non-compliance

Furthermore, other information has been deducted from a bi-annual report (Anastasi S. et al., 2017), which describes results of technical assessment activities carried out by INAIL for machinery market surveillance. Data about non-compliances outlined during activities have been analyzed in terms of risk sources: results are in Figure 2. The analysis shows that accuracy of certification together with not complete instruction (especially in the maintenance process) are the most frequent risk source of non-compliance outlined during inspection.

2. Main criticalities in the current inspection process

The current mandatory inspection process starts one, two or three years after the declaration of the first use sent by the owner of the machinery (put in to service declaration); periodic inspections are due depending on the equipment type. The inspection activity shall be carried out by Competent Authority (i.e. INAIL) or by a private authorized entity. A basic scheme is in Figure 3. Nowadays, the system works with a paper-based system.

Figure 3. The timeline of the mandatory inspection process

By analyzing the process as a whole, technical, organizational and procedural criticalities could be pointed out.

From a technical point of view, the main problem is that the maintenance activities managed directly by the employer must be coordinated with those of mandatory inspection (Walker, 2004). As the frequency of first category depends the policy adopted by the company to organize their internal machinery availability level, the latter has to be planned and organized in advance with a fixed calendar defined by the current legislation. A lack of coordination could determine an increased cost for company, an uncertainty in safety level of the machinery as non-compliance during inspection activities could increase. From organizational point of view, the main outlined criticality is due to the increasing diffusion of rental services: as defined by legislation, the rental company is the “owner” of the machinery but, in this case, the user is the rental service customer, which usually carried out the maintenance activity. Thus, maintenance activities over the lifting equipment are usually developed by different users (e.g. customers) – which could also apply different maintenance strategies- and, often, the owner – the rental company - is not completely informed about this process. Based on these conditions, information required during the inspection process could be not completely available thus making more complex evaluation of equipment safety levels. Moreover, problems for identifying each single equipment could also occur. This is a very hazardous condition, as the reliability of information provided is not guaranteed, and consequently, the safety level of the equipment.

This lack of information could be also due to the possibility of developing the inspection by different subjects, i.e. Public authorities and Authorized Private Bodies: as information from previous inspections are in paper-based system, the probability of losing such data increases if inspectors does not share them. To this must be added the difficulty of keeping the documentation
(instruction, EC declaration of conformity and reports of periodic checks) due to the movement of the work equipment or the characteristics of the work environment. From a procedural point of view, it could be outlined a lack of a common standardized guideline for developing the inspection and reporting data in a mandatory document called Control Registry. The lack of a standard procedure and registration process determines an unavailability of relevant information that shall be critical also for the safety of the machinery (Koehn, 1995; Dekker, 2014). All these occurred criticalities outline how the hazardous lifting equipment could contribute to reduce the safety level of workers.

3. A guideline proposal for developing “smart” inspection process

The idea is to define organizational guidelines and technical tools to increase the efficiency and the effectiveness of the mandatory inspection process. The use of smart devices will be evaluated for uniquely identifying lifting equipment and its components; in addition, procedures and a web software tool will also be designed to support companies as well as inspector for planning, developing and tracing inspection activities on lifting equipment.

3.1. The proposal for the system structure

At first, main roles about entities involved in the process have been analyzed. The system is based on interactions between four main category of “actors”: two are directly involved in the inspection process – i.e. the “inspector” and the “employer” – and other two – i.e. the “manufacturer” and the “competent authority”- are like “consultants” as they provide essential information to increase efficiency of the analyzed. Defining categories of actors in the process will support the design of the web-software tool as the degree of relationships between all determines information to be shared, permissions, etc. Relationships are depicted in Figure 4.

![Figure 4. Relationships between actors involved in the mandatory inspection process](image)

The first category is the “employer”: make sure employees have and use safe tools and equipment by carrying out maintenance activities as well as providing information about the equipment during the inspection process.

As detailed in the previous section, two main options could be found: the owner of the equipment, which buys and uses the equipment, but also a rental company, which buys the equipment but it could not be always responsible for its use phase. Rental companies stipulate contract with public or private entity for a limited period of time: depending on the type of contract, it could be or not be responsible for developing maintenance and supporting inspection activities. In several cases, the employer is the rental company customer, especially when the renting period is high. Both of these actors have to interact – by using a specific part of the proposed web based software tool – to share critical information to guarantee the safety of an equipment.

Next, under the “Inspector” category falls two entities: technicians from a public institution (e.g. INAIL, ARPA, Asl) or from a private authorized competent body, which is a private company. Their task is to check the equipment is maintained in an efficient state, in efficient order and in good repair. For this evaluation, the availability of documentation attesting to the control and maintenance measures carried out over time is essential. Should the inspector detect any shortcomings in the equipment, he should issue a negative report stating the shortcomings detected.

The efficacy of its activity mainly depends on the level of information about maintenance activities provided by the employer.

Two other categories are the Manufacturer, which provides information on the design and use phase of an equipment through the declaration of conformity and above all the instructions and the Competent Authority, which usually support inspectors in developing their activities from technical and organizational point of view in order to guarantee the safety of machinery and, consequently, to prevent the risk of injury / accidents.

After defining roles in the analyzed system, a proposal of the basic logic of the tool is developed and it is depicted in Figure 5.

![Figure 5. The proposed scheme of interactions](image)

The main innovation is the implementation of automatic communication between the lifting equipment and a web based software tool. A smart label based on IOT technologies will be attached to the lifting equipment when it was first used. Two technologies have been evaluated for the smart label: one based on proximity communication – the Near Field Communication – and one based on along range communication – the Bluetooth Low energy, BLE. Smart labels communicate with users –
i.e. equipment owner or inspector - trough mobile devices. In addition, a web based software will acquire data about each inspection date and provide information to users. In the web-software tool, each category of actors - previously introduced - have to manage information in different “cloud space” aiming to provide security of data: one regards information about company strategies adopted to maintain in a safe way equipment to be inspected periodically trough an external mandatory audit. A part of these – defined as the inspection audit module- will be shared virtually with inspectors before and during the inspection audit. The same occurs for the inspector side: some information and documents (e.g. the control registry, the audit report) will be virtually shared with employers in the cloud space; other data will be accessed only by technicians of the public or private body. Next, details about each module are described.

In Figure 6, the communication flows between users, IOT device and software tool is briefly described.

Figure 6. The communication workflow diagram

3.2. The design of the web-based software

Three main modules have been defined: Company, Inspector and Inspection Management. Accesses to the first two are allowed only by these, type for users aiming to save confidentiality data: shared accesses are on the inspection management module. These is accessible from specific users, who has storage and manages proprietary information. Following, each module is detailed.

The Company tool aims to support the employer for coordinating information about maintenance of each critical component, which is characterized by a mandatory inspection period. It is composed by four modules:

- **Equipment and Document Management Module**: this is an informative module as it includes all technical data identifying equipment and its working conditions related to safety such as construction year, number and type components to be inspected, safety devices and operating minimum and maximum working parameters. This data allow to identify uniquely the equipment and its components. Furthermore, documents regarding declaration of conformity are still saved in this section. These will be shared with inspectors before the inspection day. This module could be accessed only by the equipment owner and the rental company.

- **Maintenance Policy Module**: this is the core module of the software tool as it includes all information about maintenance/repair activities that have been developed over the equipment and its components during all its life cycle. These modules could be filled by owners of the equipment, directly by the rental company or its customer to apply on equipment’s components. Data about four maintenance policies are managed:
  - **Corrective maintenance**: it traces data about unplanned performed activities of repair or substitution; it is due by an unexpected fault;
  - **Preventive maintenance**: type and frequency of interventions are suggested by the manufacturer as requested by the CE procedure;
  - **Risk-based**: type and frequency of interventions are suggested by Competent Body through technical guideline (e.g. INAIL guidelines) aiming to support intervention on more hazardous equipment;
  - **Condition-based**: type and frequency of interventions are suggested by company policies aiming to increase safety and productivity performance of the company.

- **Coordinate Calendar Module**: all previous information is elaborated and coordinated. Finally, a graphical calendar – defined as Visual Control Registry (VCR) - will be developed for each component on the basis of check deadlines and maintenance type. It reports information that will be shared to develop the Control registry in the Inspection Management Module -Information regarding inspections carried out during time will be shared in the cloud space with inspectors thus contributing to create the mandatory Control Registry.

Figure 7. The company tool composition
An example of the VCR proposed in the Calendar Module is depicted in Figure 8.

The VCR outlines for each single equipment and its components (to be inspected) each planned dates for substitution/repair/check defined by each preemptive maintenance strategy. Information has been deducted automatically from the Maintenance Policy Module. In addition, corrective interventions will be also traced.

![Figure 8. Example of the Visual Control Registry.](image)

Each component, according to month, can present a different colored cells representing activities defined in different maintenance policies adopted. Different component categories could be outlined: the first one – i.e. i and j components - are deeply subjected to wear and tear, thus several repeatable maintenance operations are defined. Typically, these check intervals are imposed by the manufacturer. As it mentioned, during this time some orange cells can be appeared, that means corrective maintenance have been also carried out. After carried out corrective interventions, the system, if it's necessary, updates each deadline. The second category – i.e. k and l components- are not completely subjected to wear and tear, as a consequence maintenance activities are less frequent and no specific operations are needed. Thus, as an example, the k component is inspected annually, while the j component by eighteen-monthly. The monitoring period is provided by manufacturer, typically based on statistical analysis. The third category – i.e. m and n components - are special components (such as electrical/electronical or safety devices) essential for equipment safety, that have to be checked only during inspections (see green cells in Figure 8). Monitoring operation shall be carry out by user or qualified staff in order to avoid non-compliance during the inspection audit.

The second main module is Inspector one. This module is totally managed by (private or public) inspectors and it provides them all historical information to carry out equipment checks. Two main modules are included: one Document Management Module, where documents about equipment and how to be inspected are available-and the Inspection Process Management Module, where information about past and present inspections are saved. Thus, during the inspection audit, each document operations can be simply checked through a fast visual inspection. In this way the inspection is focused on real equipment checks, suggesting to inspector which checks must be carried out. At the end of the inspection, this module supports the inspector in preparing the final report. The third module is the Inspection Management this is the only touch point of information shared by company employer and inspector. The employer will share several information about maintenance activity, health status and actual working parameters useful for evaluating its safety during the inspection audit. On the other side, in Inspector Module, inspectors are able to receive in advance information in order to plan efficiently the audit. A part of these information can be shared with the Compensation Authority in order to improving the national guidelines.

Conclusions

The current study proposes a tool to coordinate, maintenance, control and inspection of dangerous equipment such as lifting equipment.

The aim is to overcome two current criticalities outlined for the mandatory inspection process in hazardous equipment: lack of information during inspection activities and lack of unique registry of control model. The first problem is being solved by creating an information system and an organizational structure able to support all lifecycle equipment information. Thus, a smart label to identify and to communicate between equipment and web-based software, and for this last one three specific modules for each specific actors of this activity are being proposed; access levels and interactions have been defined based on mandatory or voluntary activities to be developed. For all, basic logic and main functionalities have been defined.

Furthermore, the second criticality problems is being solved proposing an informational unique model of control registry (in a visual and documental form) able to adapt itself according the specific equipment and the company maintenance strategy. The proposed tool provides support both to employer and inspector for each specific activities. In addition, a coordination of different maintenance policies is also realized by the tool aiming to manage the risks, and possible present non-compliances, thus providing high level of safety for each equipment. One of the positive impacts of the proposed tool should be obtain is the better information management making the maintenance history lean and easy to access. Further developments will be oriented on evaluating physical devices based on IOT technology to uniquely identifying the lifting. More sectoral studies must be developed to choose the best hardware to apply in this system, so it will bring to an interesting tool to use to both big and small company.

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Reference


