Engineering 4.0 to Improve the Safety of Plant Operators in a Metalworking Company of International Importance: The Ansaldo Energia Case

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Abstract—**The paper describes how a multidisciplinary team has developed, on behalf of Ansaldo Energia Spa, a methodology based on the technologies made available by Industry 4.0; a methodology that allows rescue teams to quickly intervene in the event of man-down in isolated areas of the plant where the unfortunate person would risk being found with significant delay and consequent problems for his physical well-being.**

To achieve this result, an appropriate hardware and software device has been developed by a highly specialized supplier, under the direction of the team. Such a device makes it possible to alert automatically rescue teams in real-time, at the occurrence of the event, and geo-locate, with extreme precision, the man on the ground.

The methodology, once devised, has been standardized in a series of sequential and generalized steps, in order to make it applicable to any type of company or construction site, or workshop in which the event of the man-down may occur. The methodology is configured as a real toolkit for the protection of operators from damage, even extreme, that can derive from prolonged waits of the rescue teams, each time that operators incur negative events for their safety, whether they are exogenous (illnesses with fainting, heart attacks, epileptic attacks, strokes...) and endogenous (accidents in the workplace).

Index Terms— **Case-study, Industry 4.0, Man-Down, Safety, Sensors**

I. Introduction

IN In the context of the Ansaldo Energia LHP Project (co-financed by the Ministry of Economic Development) for the adoption by the company of Industry 4.0 standards an important objective (indicated as OR6), was dedicated by the company to the study and consequent implementation of tools-and-methodologies suitable for increasing the safety of its operators [1].

To understand the importance of operators' safety, just think that today worldwide a worker dies every 15 seconds, and 153 workers have an accident at the workplace (source International Labor Organization (ILO). This is the reason behind the Ansaldo choice to increase the safety of its operators by using technologies and applications proper of the Industry 4.0 plan within the "smart safety" project.

An aspect of safety considered to be of particular importance by the project team, the company, and the workers' organizations is about safeguarding the man-down, condition that occurs when the Operator is lying on the ground and unable to move in isolated areas of the plant,
outside the field of vision of other operators or safety officers.

In this place, he could remain indefinitely with the related consequences for his safety (e.g., in the case of an ictus the person injured must receive medical specialized intervention within 45 minutes to prevent permanent damages).

As explained in detail below, the result is a generalized methodology and, as such, can be replicated in many other operational situations in addition to that of the Ansaldo Energia plant located in Genoa.

The methodology created is based on innovative hardware and software tools, specifically conceptualized by the team and developed by the supplier, selected based on proven reliability and experience.

After a careful phase of experimentation, followed by a series of early implementations in the company, the proposed methodology is able to provide consistent results so that it can be considered a real tool for safeguarding the safety of the unfortunate operators who incur this problem.

II. Literature Review

A literature review has been performed according to the following three steps: (i) identification of the keywords and their combination; (ii) selection of a source database; (iii) results analysis. (i) Due to the poor quantity of material available in the literature, the only keyword used was man-down and its search has been applied to Article Title, Abstract, and Keywords. In the second search step (ii), two different abstract and citation databases of peer-reviewed literature have been selected: Scopus and Google Scholar.

Manuscript received June 04, 2021; revised August 31, 2021.

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At the end of this phase, twenty-six articles have been collected.

The search has been narrowed down to only six papers published from 2010 to 2021 included. During the third step (iii), a new systematic analysis of core specifics has been performed. This literature review shows a little effort by researchers into this area that is pivotal for the safety of workers.

Guilbeault-Sauvé et al. recognized the importance of having a reliable, robust, easy-to-use solution with a low false alarm rate, short response time, and good ergonomics. The solution proposed is based on three observable states: i) worker falls, ii) worker immobility and iii) worker down on the ground. These are based on the characterization of body movement and orientational data from sensors like accelerometer and gyroscope. The strategy has been tested on a public database and showed accuracy up to 99% [2].

Tayeh et al. introduced a system based on Long-Range (LoRa) technology to detect man-down situations in people who are performing activities in the area with no network coverage. This is possible by transmitting through LoRa an alert message contained the status of the individual obtained through a system composed of a GPS-enabled IoT device, smartwatch, and a smartphone [3].

A solution called Smart Safety has been introduced by Cerruti et al. In their work, the authors created a system composed of a network, a series of IoT devices, and a central monitoring system for real-time location estimation that is particularly useful in many scenarios, among them, man down. Different alerts are sent by the system to the worker based on their location which is displayed in real-time in a tridimensional plant map. Different applications in different fields such as power plants, petrochemical plants, refinery, and oil processing facilities showed the effectiveness of this system [4].

Schlesser et al. introduce a system in order to increase safety in workplaces, particularly in the blast furnace area which is subjected to dangerous of different nature. Since GPS is not a good option for inside position location, the authors developed a tracking system called Smart Safety Guard that provides live visualization of any worker's position in the form of a visual representation thanks to customized features such as geofencing [5].

Ugolini introduced a geo-localization and communication system for safety supervision. It is able to identify and determine the position of all operators inside a production area covered by Wi-Fi, GSM-GPRS-UMTS, Bluetooth, ZigBee networks and monitored by a CCTV system. Each operator is provided with a special helmet composed of a headset and microphone, with a Wi-Fi/GSM-COM device, and with a ZigBee belt tag for position determination [6].

Among the systems analyzed, the oldest one is introduced by Johnson et al. and it combines Wi-Fi and location-based technologies with gas detectors to allow companies to remotely monitor incidents in locations previously not suited for wireless networks. The Accenture Life Safety Solution is designed for hazardous working environments, e.g., refineries, chemical plants, and other locations where dense steel infrastructure can make wireless safety solutions difficult to introduce [7].

III. Material and Methods

A. Detection and Surveillance of High-Risk Areas

The activity involves the installation of man-down devices and related acoustic/visual detection systems for the geo-localization of the operator in the event of an emergency (e.g., illness). The installation of these devices will concern operators who work in isolated conditions, where there are objective difficulties in ensuring adequate surveillance.

The solution studied by the team will allow the implementation of a faster and more effective alert system through an intelligent tracking system based on logic and rules, for the analysis of the correlations-emerging data (Bayesian approach). It will be evaluated the possibility of a system certification carried out in full compliance with the principles and dictates of the law in terms of privacy. For this purpose, it should be specified that the system does not track any movement of the operators, but it is limited to geo localize the man down events.

In addition, some predictive models based on machine learning techniques, applied to the collected data, will be developed, and tested to provide evolutionary indications on the risk scenarios considered.

During the daily activities carried out by an operator in performing his duties, it may happen that, for one of the many accidental causes (such as a fortuitous fall, a bump of the head, an illness with loss of consciousness, the sudden onset of a serious pathology such as heart attack, stroke, epileptic attack, etc.), the operator collapses to the ground and is unable to move.

When such an event occurs in areas of the plant populated by other operators, any worker can launch the alert to make the rescue team intervene, on the other hand, if the same event occurs in isolated or confined areas (where it is not possible to guarantee continuous surveillance), then the accidents can lead to tragic consequences for the unfortunate person (as it is precisely the timeliness of the rescue that, in many cases, can make the difference between survival and death, or the possibility of avoiding permanent damage).

For this reason, an element of fundamental importance for safeguarding the safety of the operators was considered by the team as a set of devices capable of reporting to the operation center when any operator monitored is lying on the ground after an accident or illness.

Consequently, it has been identified a supplier (Smart Track) capable of producing a tool, based on the specifications issued by the team that, as a result of the man-down event, allows to geolocate the place where the event occurred through appropriate acoustic-visual systems in real-time, to guarantee the rescue team prompt intervention.

The team proceeded with several steps under the supervision of the advisor to reach the production of the device.

First of all, once the supplier has been selected, the team defined together with Ansaldo and the supplier itself, the technical specifications of a system consisting of a wearable device, a reference beacon, and management software, capable to fully satisfy the technological expectations, considered indispensable by the team, which inalienable objective is guaranteeing the fastest possible assistance to injured operators.

ISBN: 978-988-14049-1-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

B. Device

On the detection side, having in mind the functions expected by the device, different types of sensors have been selected, precisely:

- 1 accelerometer, to detect
  - the event of an operator subject to a sudden fall
  - a prolonged absence of movement by the operator
  - the angle of inclination of the operator's body compared to the expected vertical axis
- 1 temperature / barometric pressure sensor, for the safety of the operator, by detecting
  - the distance of the operator from the ground
  - any fires
- 1 GPS sensor for the geo-localization of the injured operator

The device is shown in figure 1.

Fig. 1. Device used

On the communication side, it should be noted that the device does not communicate with the anchors (beacons) but listens to them only for geo-localizing (principle virtually analogous to that of the lighthouse in navigation), so, in technical jargon, "sniffing" the Bluetooth signal emitted by the anchors, the device is able to define its precise position and to communicate it in the event of an alarm. The device also communicates with the server to launch the alarms.

The equipment of the communication device consists of:

- New integrated BT (Bluetooth) 5.1 control (communication with anchors)
- 2.4GH Wi-Fi (communication with the LAN)
- GSM / GPRS Sim card Machine to Machine in roaming (communication with the central server)
- NB (narrowband) - IoT 4G (geolocalization with accuracy +/- 5m)
- Extendable to UWB (ultra-wideband) with 50cm accuracy (other applications such as COVID19 detection for gatherings, forklift man collision, hands-free access control in certain areas of the company by detecting inclination angle in the pocket without swiping the badge…)

The device is powered through a LiPo battery (lithium polymer) rechargeable via USB in 60 minutes. The duration ranges from about 2 days to 12 months, depending on use.
It should be noted that the fundamental task of the device thus conceived is to transmit the information captured by the sensors to the nearest security officer, the concierge (guard), and the Infirmary through redundant real-time notifications (call, messaging, email, SW Smart Studio interface).
The operator wearing the device, when the instrument detects any dangerous event, is alerted by a buzzer and by an appropriate vibration before the aforementioned notifications are sent to the security officers, the infirmary, and the reception.
A further essential task of the device, in addition to those already indicated, is to provide the rescue team with the necessary elements for the geo-localization of the man-down. For this operation, the device acts in combination with other tools (beacons) called anchors.
The operators currently covered per shift under the LHP OR6.2 project are already 29.

C. Anchors

The reference anchors (beacons) are installed in a variable number (usually 2-4) on each machine or within the isolated or confined areas to be monitored so that each device worn by the operators present therein can continuously refer to one of the anchors installed. The anchor is shown in figure 2.

Fig. 2. Anchor

The anchors emit a BT signal that the device is able to listen to. The anchors, therefore, do not communicate with the system. The technological equipment of the anchors consists of:

- BT 5.0, a beacon for connection to devices (maximum communication distance: 80m)
- Ambient temperature sensor
- 1 Amp lithium button cell batteries (5 years)

The anchors currently installed as part of the LHP OR6.2 project are already 86. Figure 3 summarizes the functional scheme.

ISBN: 978-988-14049-1-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

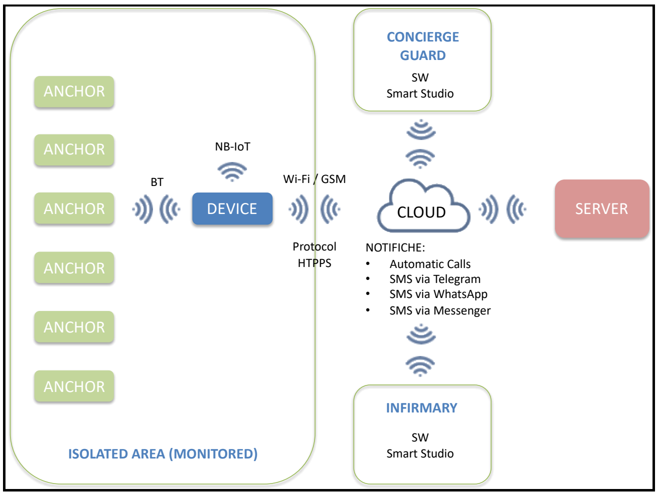

Fig. 3. Functional Scheme

D. *Smart Studio*

It is a graphic interface software installed towards the rescue team desks, e.g., the heads' cabin (supervisors), the concierge (guard), and the infirmary, which allows the precise geo-localization of the man-down by indicating the site, the area, the department, the machine, the position on it of the reference anchor and the device ID worn by the operator.
The software also provides detailed information on the affected operator such as the name and last name and its IP address, the geo-localized location of the accident, the address, and type of the device, as well as the Bluetooth signal threshold, the status, and the battery level. The software is also capable of producing a history of man-down events that occurred throughout the factory.

E. *Respect for Privacy*

It is important to highlight, as already indicated, that the device has been designed in such a way as to fully respect the operators' right to privacy, so it does not monitor or record any operators' path or any interruptions to usual activities (such as breaks, toilet visits, coffee shops...), but is limited to geo-localized and report the detected man-down events.

F. *Other Functions*

Two important functions have also been provided in the device:

- the voluntary and preventive alert submission by the operator through an appropriate button installed on the device, by which it can be required the intervention of the rescue team, even in situations not pertaining the man-down (e.g., injuries of various kinds, malaise, request for intervention for third parties)
- the management of false alarms with the possibility of cancellation

This is the case in which the operator makes intentional movements that could be erroneously interpreted by the device, such as activities that he must be performed while lying on the ground, sharp jumps to reach a certain position, periods of stasis (e.g., the necessity to work on the PC or moments of rest), etc.

G. *Organization*

At the organizational level, the team has assigned for each department 1 device (complete with battery charger) per operator per shift and has prepared a series of essential documents for the correct management of the safety activities, namely:

- Register of training participants, an essential document to establish which operators are enabled to use the device
- Informed consent to participants to ensure that operators and their safety representatives understand the importance of the system and approve its use in full respect of the privacy
- Instruction manual, to ensure compliance with the correct use and maintenance of the device supplied
- Battery management manual, to improve the efficiency of the device and extend the life cycle of the power supply components
- Register of delivery and return, in which to record the assignment of devices to operators

IV. Implementation Process and Process Phases

Given the importance, for the health of the operators, of monitoring the events of man-down through a system that is able to timely generate the intervention of the rescue teams, therefore being decisive for the survival of the unfortunates, the test phase particularly cared.
Such a test phase was needed to validate the compliance of the system with the expectations of the team that had implemented it.
It was required by both Ansaldo, the advisor and the supplier that created the system and performed by the team in a particularly deep and severe way, also to assess the robustness of a system. This because, once adopted by the company, the system must be able to guarantee its functionality and effectiveness in the most diverse situations by type of site where the event occurred (distance from the receiving stations, size of the area, type and arrangement of the machinery...).
Ansaldo and the team, after an in-depth analysis of the production departments of the Genoa plant, have-selected as the departments in which to conduct the pilot project: the Large Mechanical Department (MECG) located in AREA CAMPI 1, the Medium Mechanical Department (MEME) and the Rotors Department (ROTO) both located in the FEGINO AREA.
As areas and departments to which to extend the project, once the test phases have been passed, the same Departments (MECG, MEME, and ROTO) were chosen, gradually increasing the number of machines under observation, then, subsequently, the Ultra Speed Test Cell for Rotors located in AREA FEGINO, the Diagnostic Center in AREA CAMPI 2 and the Mechanical Tests Workshop in AREA BOSCHETTO.
Once the departments had been identified, it was necessary to proceed with the list of machines to cover and, consequently, to identify the number of beacons (in the function of the dimensions of the machine) and relative positioning on the field, to ensure adequate coverage of the isolated areas of the Department.
At this point, in full agreement with the company, before proceeding with the installation of the new system, it was

ISBN: 978-988-14049-1-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

decided to hold a series of preliminary meetings of an informative nature, respectively with the area managers, the RLS (workers' safety managers), the security officers, the infirmary and the concierge (guard).

The purpose of these meetings is to provide timely information on the new system to all operators of the Functions who will have an active part in the exercise of the same, to make them aware of the importance of a tool capable of promptly activating aid to accident operators.

From this first phase of the test, Ansaldo and the team have identified the areas and departments to which the project would be subsequently extended.

The next step was to proceed with the installation of the beacons on the machines in the previously identified positions, not an easy operation to be performed as, on the one hand, it must be avoided the risk of damaging complex and delicate machines, and, on the other hand, it shall ensure stable anchoring of the beacon in any operating conditions of the machines, also considering the vibrations, the large movements, and the different configurations.

As a solution, it was therefore chosen to use a double-sided adhesive tape, suitably certified for such use, applicable after careful cleaning/degreasing of the affected surface.

An information sign was placed next to each anchor to avoid the accidental risk of their removal (reporting that they are part of the LHP Ansaldo project financed by MISE in the safety field).

The last step of this phase is the registration of the anchors to obtain the geo-localization and positioning.

This was followed by the installation of notifications on the mobile phones of the security officers and the smart studio software on the computer located in the chiefs' cabin.

In order to proceed with the launch of the pilot project, however, it was necessary to provide adequate training for the department operators and to have them sign the document on informed consent regarding the project and the participation register, after which the device, with its battery charger, was delivered and notified to the infirmary and concierge (guard).

The positive outcome of the pilot project allowed us to obtain the approval of the team about the adoption of the system, the testing departments, and the extension of the project to the other areas already identified.

V. Conclusions

Given the absolute need for prompt rescue of the man-down, any company willing to reduce the consequences of negative events should adopt the proposed methodology.

Thanks to this system, the traditional management of the Man Down events, with all the well-known limits and the related risks for safety, can be transformed into the best breed of an Engineering 4.0 application, as shown by the methodology devised by the team, implemented by Ansaldo and required by the new company.

The authors hope that this methodology will soon have the widest diffusion.

It should be noted that, as per one of the fundamental principles of Engineering 4.0, the system has been subjected to a cycle of continuous improvement so that the first model has been improved in progress by generating second-generation devices and anchors (or Bluetooth 5.0 Communication, vibration enhanced, impact-resistant polycarbonate injected shell, previously prototyped in resin with 3D printing).

At this point, the proposed system, by its nature generalized, was also standardized. It was thus possible to adapt it for any type of Production and Processing Department, by following the series of sequential steps are summarized below:

1. Appointment by the company of a project leader expert on workers' safety issues (granting him the powers and budget appropriate to the project objectives)
2. Appointment by the company of a technical and scientific advisor for the supervision of the technologies adopted and their application
3. Selection by the company of an appropriate technology supplier
4. Identification of the areas and departments to which the project is to be implemented
5. Identification of the machines they contain and their dimensions
6. Identification of the number and position of beacons necessary to ensure coverage of confined areas
7. Information meetings with area heads, RLS, security officers, infirmary, and concierge
8. Launch of the pilot project with the installation of beacons in the departments
9. Installation of notifications on the mobile phones of the security officers
10. Installing the smart studio software in any rescue team office
11. Training of department operators
12. System functionality test
13. Commissioning of the system after the full passing of the tests described above
14. Extension of the tested project to other areas of the company

As a last complementary consideration to the work done, but of sure importance, the authors want to highlight the importance of all those measures that can reduce the occurrence of man-down event and among these, far from secondary, the protective clothing and PPE (Personal Protective Equipment) that operators must wear, and which vary about the type of company, job, task, and specific activities.

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ISBN: 978-988-14049-1-6
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