Applications of Engineering 4.0 to Improve the Safety of Metalworking Operators: The Ansaldo Energia Case

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Abstract. The paper describes how, on behalf of Ansaldo Energia Spa, a multidisciplinary team developed a methodology based on Industry 4.0 technologies, an approach that allows rescue teams to quickly intervene in the event of a 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. Under the supervision of the team, a highly specialized supplier created a suitable hardware and software device to achieve this outcome. Such a device can immediately warn rescue crews in real time as soon as an incident occurs, as well as geo-locate the man on the ground with exceptional precision.

Once developed, the approach was standardized in a set of sequential and generic procedures in order to make it adaptable to any sort of firm, construction site, or workshop where a man-down event may happen. The methodology is set up as a real toolkit to protect operators from severe damage that can result from long waits for rescue teams, whenever operators experience negative events for their safety being them exogenous (fainting illnesses, heart attacks, epileptic attacks, strokes, etc.) or endogenous (accidents in the workplace).

Keywords: Artificial Intelligence, Blockchain, Case-Study, Connectivity, Digital Twin, Industry 4.0, Man-Down, Safety, Sensors

1 Introduction

An important objective of the project (indicated as OR6) was dedicated by the company to the study and subsequent implementation of tools-and-methodologies suitable for increasing the safety of its operators 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 [1, 2].

It must be taken in consideration that a worker dies every 15 seconds on the planet, and 153 employees are injured in the workplace every day [3]. This is why Ansaldo has chosen to improve the safety of its operators by using Industry 4.0 technology and applications as part of the "smart safety" initiative.

Protecting the man-down condition, which occurs when an operator is lying on the ground and is unable to move in isolated areas of the plant, outside the field of vision of any other operators or safety officers, is an aspect of safety that the project team, the company, and the workers' organizations consider to be of particular importance.

He may stay in this area permanently, with serious implications for his safety (e.g., in the case of a stroke the person injured must receive medical specialized intervention within 45 minutes to prevent permanent damages).

In addition to the Ansaldo Energia application in Genoa factory, the outcome is a generic technique that may be repeated in many different operational circumstances, as discussed in detail below.

The technique is built on cutting-edge hardware and software solutions that were custom-designed by the team and developed by the provider, and were chosen for their proven dependability and experience.

The suggested approach is able to offer consistent results after a cautious period of testing, followed by a number of early implementations in the organization, thus it can be regarded a legitimate instrument for ensuring the safety of the unlucky operators who encounter this situation.

2 Literature Review

The following three steps were used to conduct the literature review: (i) identification of keywords and their combinations; (ii) database selection; (iii) analysis of findings. Due to the limited amount of information accessible in the literature, “man-down” was the sole keyword employed, and its search was applied to the Article Title, Abstract, and Keywords. Two separate abstract and citation databases of peer-reviewed literature have been chosen for the second search stage (ii): Scopus and Google Scholar. Twenty-six articles were collected at the end of this phase.

Only six publications published between 2010 and 2021 have been included in the search. A fresh systematic study of key specifics was undertaken during the third stage (iii). This literature study demonstrates that researchers have spent only a few energy in this area, which is critical for worker safety.

Guilbeault-Sauvé et al. understood the need of having a dependable, durable, and simple-to-use system with a low false alarm rate, quick reaction time, and acceptable ergonomics. The suggested approach is based on three observable states: worker falls, worker immobility, and worker on the ground. These are based on the characterization of bodily movement and orientational data from accelerometer and gyroscope sensors. The technique was tested on a public database and found to be 99 percent accurate [4].

Tayeh et al. developed a system based on Long-Range (LoRa) technology to detect man-down situations in persons conducting tasks in areas where there is no network connectivity.

This is accomplished by sending an alarm message via LoRa that includes the individual's status as determined by a system that includes a GPS-enabled IoT device, a wristwatch, and a smartphone [5].

Cerruti et al. have proposed a system called Smart Safety. The authors developed a system for real-time position estimate that consists of a network, a number of IoT sensors, and a central monitoring system. It is particularly beneficial in a variety of circumstances, including man down. The technology sends different notifications to the worker based on their position, which is presented in real-time in a three-dimensional plant map. The efficiency of this system has been demonstrated in a variety of

industries, including power plants, petrochemical plants, refineries and oil processing facilities [6].
Schlesser et al. developed a technique to improve worker safety, particularly in the blast furnace area, which is exposed to a variety of hazards. Because GPS cannot be considered as a good choice for inside position location, the authors created Smart Safety Guard, a tracking system that uses specific features like geofencing to enable live visualization of every worker's position in the form of a visual depiction [7].
For safety surveillance, Ugolini implemented a geo-localization and communication system. It can locate and identify all operators inside a production area that is covered by Wi-Fi, GSM-GPRS-UMTS, Bluetooth, and ZigBee networks and is monitored by a CCTV system. Each operator is outfitted with a unique helmet that includes a headset and microphone, as well as a Wi-Fi/GSM-COM device and a ZigBee belt tag for location tracking [8].
The oldest of the systems examined is Johnson et al.'s, which integrates Wi-Fi and location-based technology with gas detectors to allow companies to remotely monitor situations in areas where wireless networks were previously unavailable. The Accenture Life Safety Solution is intended for use in hazardous work areas such as refineries, chemical plants, and other sites where dense steel infrastructure makes wireless safety solutions difficult to implement [9].

3 Material and Methods

3.1 Detection and Surveillance of High-Risk Areas

Installation of man-down devices and accompanying acoustic/visual detection systems for the geo-location of the operator in the case of an emergency is part of this endeavor (e.g., illness). The installation of these devices will affect operators who work in remote locations where proper surveillance results objectively impossible.

The team's solution will enable the creation of a speedier and more effective warning system through the use of an intelligent tracking system based on logic and rules for the analysis of growing data correlations (Bayesian approach). The potential of a system certification carried out in complete conformity with the law's principles and directives in terms of privacy will be assessed. It should be noted that the technology does not monitor the operators' movements and is used exclusively to geo-locate man down events for this reason.

Furthermore, several prediction models based on machine learning techniques will be constructed and evaluated using the acquired data to offer evolutionary signals on the risk situations under consideration.

During the course of an operator's daily activities, one of the many accidental causes (such as a fortuitous fall, a bump on the head, an illness resulting in loss of consciousness, the sudden onset of a serious pathology such as heart attack, stroke, epileptic attack, etc.) may result in the operator collapsing to the ground and being unable to move.

When such an event occurs in areas of the plant where other operators are present, any worker can issue an alert to summon the rescue team; however, if the same event occurs in isolated or confined areas (where continuous surveillance is not possible), the accidents may lead to tragic consequences for the unfortunate individual (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).

As a result, the team deemed a collection of devices capable of reporting to the operation center when any operator monitored is laying on the ground following an accident or sickness as a critical component for ensuring the operators' safety.

Therefore, an outstanding supplier (Smart Track) has been identified as capable of producing a tool based on the team's specifications that, as a consequence of the man-down event, allows to geo-locate the exact position where the event occurred, in real-time, using appropriate acoustic-visual systems, ensuring the rescue team's prompt intervention. To get to the point where the device could be manufactured, the team took many stages under the supervision of the adviser.

First and foremost, once the supplier was chosen, the team worked with Ansaldo and the supplier to define the technical specifications for a system that included a wearable device, a reference beacon, and management software that could fully meet the team's technological expectations, which were deemed essential by the team and whose unalienable goal was to provide the fastest possible assistance to injured operators.

3.2 Device

Different types of sensors have been selected and chosen for the detecting side, keeping in mind the functions intended by the device:

- 1 accelerometer to detect a sudden fall by an operator and/or a protracted lack of movement by the operator and the angle of inclination of the operator's body in relation to the expected vertical axis
- 1 temperature/barometric pressure sensor for the operator's safety by sensing the operator's distance from the ground and/or the unwanted event of any fires
- 1 GPS sensor for the wounded operator's geo-location

Figure 1 depicts the device.

Fig. 1. Device used

On the communication front, it should be taken in consideration that the device doesn't communicate with the anchors (beacons), but rather listens to them for geo-localization (a principle that's almost identical to that of a lighthouse in navigation). By "sniffing" the Bluetooth signal emitted by the anchors, the device is able to determine its precise location and communicate it in the event of an alarm. To activate the alarms, the device also talks with the server.

The communication device is equipped with the following features:

- New integrated BT (Bluetooth) 5.1 control (communication with anchors)
- 2.4GH Wi-Fi (communication with the LAN)
- Machine-to-Machine roaming with GSM/GPRS Sim cards (communication with the central server)
- NB (narrowband) - IoT 4G (geolocation with +/- 5m precision)
- Extendable to UWB (ultra-wideband) with 50cm precision (additional applications include COVID19 detection for gatherings, forklift man collision, hands-free entry management in some business areas by detecting inclination angle in the pocket without swiping the badge...)

The device is powered by a LiPo (lithium polymer) battery that can be recharged in 60 minutes through USB. Depending on how it's used, it can last from 2 days to 12 months. It's worth noting that the device's primary function is to send the information gathered by the sensors to the nearest security officer, concierge (guard), and infirmary via redundant real-time notifications (call, messaging, email, SW Smart Studio interface).

When the instrument identifies any risky incident, the operator wearing the device is notified by a buzzer and an appropriate vibration before the alerts are transmitted to the security personnel, the infirmary, and the reception.

In addition to the above-mentioned functions, the device must also supply the rescue squad with the required elements for the geo-location of the man-down. The device works in conjunction with other equipment (beacons) known as anchors to accomplish this task.

The current number of operators covered each shift under the LHP OR6.2 project is 29.

Anchors

Each machine or inside the isolated or limited regions to be monitored has a variable number of reference anchors (beacons) installed, so that each device worn by the operators present can continually refer to one of the anchors installed.

Figure 2 depicts the anchor.

Fig. 2. Anchor

The anchors send out a Bluetooth signal that the device can pick up. As a result, the anchors are unable to interact with the system. The anchors' technical equipment includes:

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

There are already 86 anchors put as part of the LHP OR6.2 project.

The functional system is depicted in Figure 3.

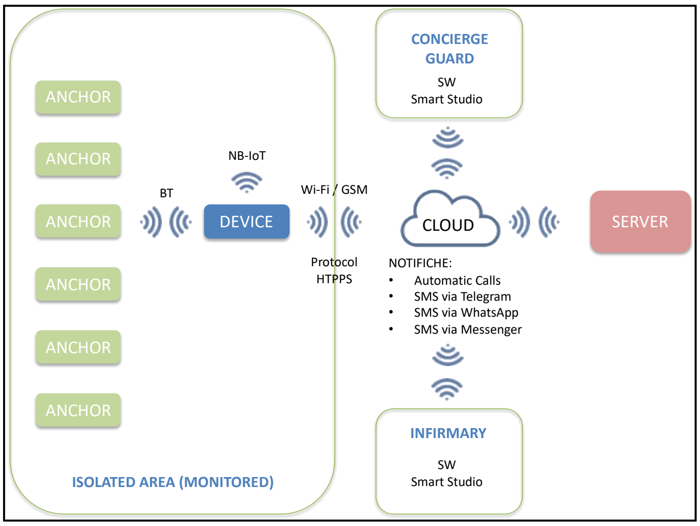

Fig. 3. Functional Scheme

3.3 Smart Studio

It is a graphical interface software installed at rescue team desks, such as the heads' cabin (supervisors), the concierge (guard), and the infirmary, that allows for precise geo-location of the man-down by indicating the site, the area, the department, the machine, the position of the reference anchor on it, and the device ID worn by the operator.

The program also offers specific information on the impacted operator, including his or her name, last name, and IP address, as well as the accident's geo-localized position, address and device type (release), as well as the Bluetooth signal threshold, status, and battery level. The program may also provide a history of all man-down occurrences that have happened across the production.

3.4 Respect for Privacy

As previously stated, the device has been designed to fully respect the operators' right to privacy, so it does not monitor or record any operators' path or any interruptions to regular activities (such as breaks, toilet visits, coffee shops...), and instead is limited to geo-locating and disclosing detected man-down events.

3.5 Other Functions

The device has also two essential functions:

- the operator's voluntary and preventive alert submission through an appropriate button installed on the device, which may be used to alert the rescue team even

though the scenario is unrelated to the man-down (e.g., injuries of various kinds, malaise, request for intervention for third parties)
- the processing of false alerts, with the option of canceling them

This is when the operator makes deliberate moves that the device may misinterpret, such as activities that he must undertake while lying down on the ground, sudden leaps to achieve a certain position, periods of stillness (e.g., the need to work on the computer or moments of rest), and so on.

3.6 Organization

On an organizational level, the team has assigned one device (complete with battery charger) per operator every shift to each department and has created a set of essential documentation for the proper administration of safety tasks, including:

- A list of training participants, which is required to determine whose operators are authorized to operate the device.
- 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 exten d the life cycle of the power supply components
- Informed consent to participants, to ensure that operators and their safety repre sentatives understand the importance of the system and approve its use in full respect of privacy
- A delivery and return register, in which the assignment of devices to operators is recorded.

4 Further System Developments

After the first cycle of implementations in Ansaldo, the authors carried on the phases of research and development necessary for the activation of some new functions previously identified, which consist of the following:

1. Extension and accuracy of connectivity
2. Integration and enhancement of the Software
3. Digital Twin
4. Artificial intelligence
5. Service 4.0
6. Blockchain

The interactions of all those technologies are shown in figure 4.

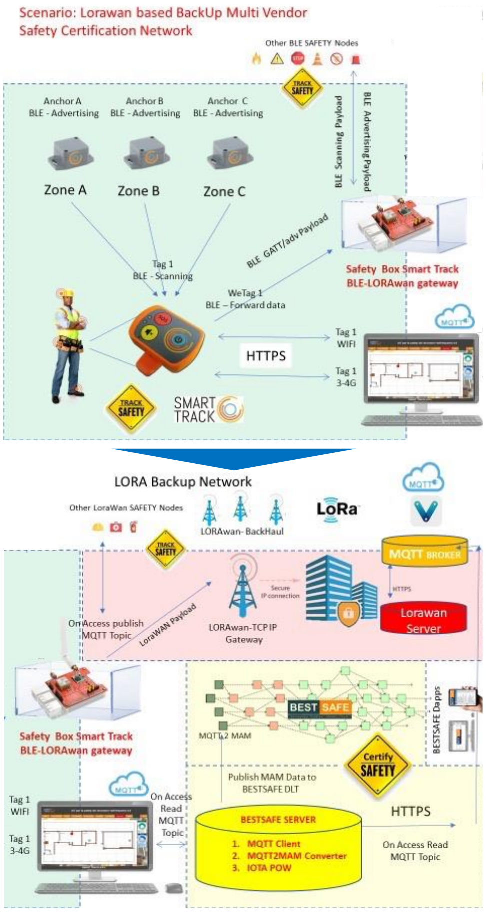

Fig. 4. Functional Scheme of the safety system

4.1 Extension and accuracy of connectivity

The scope of this job was to extend the applicability of the service to companies that work on multiple sites, dislocated throughout the territory and not belonging to the same LAN (Local Area Network). The extension is applied to all multinational companies, consortia, business associations that want to guarantee a safety standard. The software is designed to offer an overview, with the possibility of drilldown to reach the target level of detail, with a geo-localization accuracy of 50cm, through the extension from the previous NB-IoT 4G (Narrow Band Internet of Things), whose accuracy reaches +/- 5m, at the UWB (Ultra-Wideband) standard. In addition to the obvious benefits generated in the field of safety, the positive effects are not negligible in terms, for example, of scoring in the event of participation in tenders, an area in which site safety is of primary importance.

4.2 Integration and enhancement of the Software

In accordance with the 4.0 standards, which provide for the maximum integration of company systems (Departmental, WMS, ERP, …), the authors decided to deeply investigate an already performing software, with the specific aim of maximizing the benefits produced by the system, by sharing the data collected and processed with other company platforms. A point of particular interest was identified in the transformation of system analytics, initially conceived exclusively as a data logger, now becoming progressively more suitable for the generation of usable information from the data source. The new functions include, for example, the creation of statistics on the frequency and type of injury in order to allow to trace the root causes of accidents, for improving prevention, on the one hand, and the timeliness of rescue operations on the other. Again, the system integration produces second-order positive effects, although no less important. In fact, by integrating the system with the internal quality function, the company benefits from an effective tool in the event of an AUDIT by customers, or certifying bodies, or in the event of participation in tenders.

4.3 Digital Twin

The replication of the system in cyberspace opens the doors to completely new horizons, in fact this represents the transition from the basic characteristics of monitoring and control to a system connected online and real time, able to “live the life” of the physical system in parallel (through the connection that allows continuous data collection) and an autonomous “cyber-life”, being adaptive according to the collected data.

This means:

- both being able to take advantage of the real database, to project an accelerated replication of events into the future, thus being able to learn the critical issues and predict accidents
- being able to generate system perturbations, through the setting of new scenarios that can impact on the case history of accidents (such as the increase in work in confined areas, the extension of work to different shifts, the introduction of new machines, layout, ...)

By associating basic Machine Learning algorithms, the system will thus be able to learn simultaneously from the experience and from the simulated, in view of a continuous improvement of the overall safety performance (e.g., trends, seasonality, cyclicality that can lead to risk phases, which can be mitigated through the introduction of ad hoc procedures).

4.4 Artificial Intelligence

Cognitive algorithms applied to the Digital Twin allow it to improve performance in order to ensure Continuous Improvement. In this view, the role of these algorithms is to raise the System to an Expert System capable of using the large amount of data, partly collected, and partly simulated, to learn from experience with logic comparable to how the Human brain would do, with the difference of the processing capacity offered by the computers available today, on a scale that is not comparable to the performance achievable by man. The authors therefore consider the application of A.I. (as the normal evolution to complete the Digital Twin. The algorithms used will range from neural networks to decision trees, to Bayesian classifiers, to bagging boosting and stacking techniques, to deep learning.

4.5 Service 4.0

In consideration of the trend of companies focus on core business, aimed at obtaining better business performance and, at the same time, on non-core services, the idea was to make the monitoring and emergency intervention relating to the Man Down event. The concept is based on the centralization of the continuous monitoring service (performed in outsourcing) in a service center shared by multiple companies, thus requiring a smaller number of pure local rescue operators (located as insourcing). In this way, in accordance with the BCG 11/2018 definition of Service 4.0, the service offered could adapt to the growing expectations of a constantly evolving clientele, transforming:

- the service offering from reactive to proactive, from standardized to custom (focused on the safety of the individual operator), from experience-based to data-driven.
- the provision of the service from remote to present (multi-channel), from predefined paths to dynamic paths (formed in real time) and from separate to shared systems.

Once again, thanks to the level of innovation brought about by the adoption of 4.0 standards, the benefits produced in terms of Operator safety are widely evident.

4.6 Blockchain

Smart Track (innovative Startup and spin-off of the University of Genoa that develops IoT systems for the safety and security of workers in indoor and complex environments in which the GPS does not work) is configured as a project partner, who developed the system, covered with a specific patent, called BEST SAFE (nr. 102019000021537 released on date 08/03/2022), whose purpose is to certify the safety of workers on blockchains. A further feature is therefore defined, namely the possibility of directing the tracking of data from sensors, equipment and IIoT applications in industrial and professional scenarios of various types (for example, and not exclusively Industrial Plants, Construction Sites, Logistics Systems ...) in which operate multiple Suppliers, using heterogeneous tools, networks, and protocols, to make the reconstruction of events objectively reliable for:

- Insurance (e.g., objective reconstruction of the exact sequence and concatenation of events)
- Legal (e.g., assessment of any behavioral responsibilities)

- Maintenance (e.g., compensation for any coverage of the equipment and systems involved)
- Healthcare (e.g., reconstruction of social interactions between workers in case of need for "contact tracing" during pandemic crises)

In particular, the architecture at the base of BestSafe method provides for the presence of:

- A semantic protocol, called BestSafe 3S (Safety & Security Statements), for the preparation of worker Safety tracking messages (shareable, interoperable, and interpretable both by Human Operators and in M2M exchanges between third-Party applications and machinery).
- An external register called BestSafe Registry containing the different vocabularies and profiles, to be used for different sets of declarations that can be expressed according to the BestSafe 3S Language for different operational contexts (eg. Industrial Plants, Construction Sites, Construction Sites Shipping ...)
- A DLT (Distributed Ledger Technologies) type distributed archive, called “BestSafe Ledger”, on which various Providers can publish messages expressed in BestSafe 3S semantics, in order to guarantee both the necessary levels of interoperability and immutability and marking at the same time independent temporal of the same.

It is estimated by the Authors that BestSafe will facilitate the penetration and use of the blockchain to certify the use of innovative solutions for safety in the workplace with legal and insurance value, in particular with a distributed new generation blockchain infrastructure (IOTA TANGLE) designed directly to certify data transactions.
In particular, BestSafe 3S is a semantic representation of interoperability that allows Companies to describe data, metadata and observations coming from peripheral IIoT sensors for Personnel Safety and Plant Safety, making them uniformly interpretable and processable by heterogeneous Actors, both in Human communication scenarios and M2M.

5 Implementation Process and Process Phases

Given the necessity of monitoring man-down incidents through a system that can prompt rescue teams' action, thereby ensuring the unfortunates' survival, the test phase was given special attention.

A test step like this was required to ensure that the system met the expectations of the team who implemented it.

Both Ansaldo, the adviser, and the supplier who constructed the system demanded that the team examine the system's resilience in a very thorough and thorough manner.

This is because, once implemented, the system must be able to ensure its operation and efficacy in a wide range of conditions, depending on the type of location where the incident happened (distance from the receiving stations, size of the area, type and arrangement of the machinery...).

After conducting an in-depth analysis of the Genoa plant's production departments, Ansaldo and its team have chosen the following departments to conduct the pilot project: the Large Mechanical Department (MECG) in AREA CAMPI 1, the Medium Mechanical Department (MEME), and the Rotors Department (ROTO), all of which are located in the FEGINO AREA.

Once the test phases were completed, the same Departments (MECG, MEME, and ROTO) were chosen as areas and departments to expand the project, gradually increasing the number of machines under observation, then the Ultra Speed Test Cell for Rotors in AREA FEGINO, the Diagnostic Center in AREA CAMPI 2, and the Mechanical Tests Workshop in AREA BOSCHETTO.

Following the identification of the departments, it was necessary to proceed with the list of machines to cover and, as a result, to determine the number of beacons (in relation to the machine's dimensions) and their relative positioning on the field in order to ensure adequate coverage of the Department's isolated areas.

Before beginning with the installation of the new system, it was agreed, in complete agreement with the company, to have a series of preparatory informational sessions with the area managers, the RLS (workers' safety managers), the security officers, the infirmary, and the concierge (guard).
The objective of these sessions is to deliver timely information on the new system to all operators of the Functions who will be actively involved in its implementation, as well as to raise awareness of the need of a tool capable of quickly activating assistance to accident operators.

Ansaldo and the team have defined the areas and departments to which the project will be extended in the future based on the results of the first phase of the test.
The next step was to install the beacons on the machines in the previously identified positions, which was not an easy task because, on the one hand, it had to avoid the risk of damaging complex and delicate machines, and on the other hand, it had to ensure stable beacon anchoring in any operating conditions of the machines, taking into account vibrations, large movements, and various configurations.

As a result, a double-sided sticky tape, adequately approved for such purpose, was chosen as a remedy, to be used after meticulous cleaning/degreasing of the afflicted surface.

To prevent the anchors from being accidentally removed, an informative sign was erected next to each one (reporting that they are part of the LHP Ansaldo project financed by MISE in the safety field).

The registration of the anchors to achieve geo-localization and placement is the final step in this phase.

The security personnel' mobile phones were then updated with notifications, and the smart studio software was installed on the computer in the chiefs' cabin.

However, in order to proceed with the pilot project, adequate training for the department operators was required, as well as having them sign the document on informed consent to the project and the participation register, after which the device, along with its battery charger, was delivered and notified to the infirmary and concierge (guard).
The favorable conclusion of the pilot project allowed us to gain team agreement for the system's adoption, the testing departments, and the project's expansion to the previously indicated regions.

6 Conclusions

Given the critical necessity for timely man-down rescue, any organization wishing to mitigate the effects of bad occurrences should use the recommended methodology.

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

The system has been subjected to a cycle of continuous improvement, as per one of the fundamental principles of Engineering 4.0, such 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).

Because the suggested system was broad in nature, it was also standardized at this time. By following the set of consecutive stages outlined below, it was feasible to modify it for any sort of Production and Processing Department:

1. The organization appoints a project leader who is an expert on worker safety problems (granting him the powers and budget appropriate to the project ojectives)
2. The corporation appoints a technical and scientific advisor to oversee the technologies selected and their implementation.
3. The company's selection of an acceptable technology supplier
4. Identifying the regions and departments to which the project will be applied
5. Identifying the machines included therein and their dimensions
6. Determination of the number and location of beacons required to guarantee constrained area coverage
7. Meetings with area leaders, RLS, security officers, infirmary, and concierge to provide information
8. Beacons are installed in the departments as part of the trial project.
9. Installation of security personnel' mobile phones with alerts
10. Installing the smart studio software in any rescue team's workplace is number ten.
11. Departmental operator training
12. System functioning test
13. Commissioning of the system when all of the preceding tests have been passed.
14. Extending the tested projects to other areas of the company

Lastly, the authors want to emphasize the importance of all those measures that can reduce the occurrence of man-down events, including, far from being secondary, the protective clothing and PPE (Personal Protective Equipment) that operators must wear, which vary depending on the type of company, job, task, and specific activities.

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