Personal Protective Equipment Management and Maintenance. An Innovative Project Conducted in a Major Italian Manufacturing Company

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Abstract: - A major player in metal mechanic manufacture in Italy that has opted to implement Industry 4.0 standards. One of the key projects undertaken was the creation of a new vision for safety. The aim was met by a team created expressly for the company. The Team placed a high value on PPE (Personal Protective Equipment), which is equipment meant to increase the safety of the Operators while doing their responsibilities. The problem that the Team has clearly warned about, given the frequency of occurrences, is the periodic maintenance of PPE, which is required by law for each device and must be carried out according to strict guidelines to maintain their efficiency and safety certification. As a result, the Team investigated a novel methodology, the topic of this article, based on hardware and software technologies designed to monitor the legal revisions and crucial dates of each piece of PPE in use.

Key-Words: - PPE maintenance, PPE management, PPE 4.0, IIOT, Industry 4.0, Smart Safety.

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1 Introduction

This paper is the extension of previous research conducted by the Authors on the worldwide Operator safety problem, [1]. As evidence of this issue, data from the International Labor Organization show that every 15 seconds, an operator dies and 153 are injured worldwide, with an annual projection of 1.2 million deaths and 320 million accidents recorded, resulting in a total economic loss of approximately 225 billion USD. The immensity of this data, both humanly and economically, encouraged the team to make attempts to make a constructive contribution.

Investigating the problem, the Authors highlighted how a critical point in the Company was the PPEs, meaning those devices that have the task, activity by activity, of exercising adequate protection of the wearing Operator, from injuries that can be generated by that specific activity. PPE has: 1. Specific functions 2. The need for periodic maintenance 3. An end of life after which they lose their protective capacity. In the Company studied, as in many others highlighted by research carried out on the subject by the Team, the necessary attention was lacking towards this Equipment, both in terms of their management and terms of periodic maintenance and even more so at the end of their life. Such situations provoke the complete loss of PPE defensive power, leaving the wearing Operator convinced about his protection while, in reality, he is completely helpless. Starting from these considerations, the Team realized the need for the Company to create a specific PPE management and surveillance Body, which was entrusted with the task of following the Equipment process from the moment of assignment to the Operator to the date of redelivery, related to the activity requested for each PPE, thus avoiding that PPEs used improperly, incorrectly maintained or even expired (as described in the rest of the paper) would circulate the plant or construction site. This request was promptly accepted by the Company which assigned the management of the PPEs to a specific Body, which implemented the PPEs management control system proposed by the Authors. As a result, this project became the beginning point for developing and implementing viable solutions. The purpose of this article is to discuss the proper maintenance of PPEs (Personal Protective Equipment), which are critical if correctly revised and maintained on time (indicated by the manufacturer and made mandatory by law). In this context, the Company and UNIGE (DIME) agreed to take a technology partner with specialized expertise and to form a multidisciplinary project team to handle the challenge and construct a new 4.0 system.

A classification of the protection devices used in the company was, in this first phase, made by the Team according to their use, dividing the PPE into 3 categories, with different priorities, according to the scale below (1 means high priority):

1. “Life Savers”: PPE with direct impact on life (reels, belts, electrically ventilated helmets, harnesses, lanyards);
2. “Health Protectors”: PPE with impact on health (masks, helmets, glasses, safety shoes, headsets);
3. “Critical Equipment”: NON-PPE, with impact on safety (steel ropes, eye bolts, stretchers, shackles, lifting slings).

2 Literature Review

A thorough literature study was carried out, with a focus on Scopus, WOS, and Google Scholar. Over 32,800 publications were discovered when studying PPE, initially filtering by "PPE maintenance" and "smart PPE." The bulk of the papers were from Scholar, however, the majority of them were out of scope. In reality, the authors quickly discovered that "smart PPE" was a deceptive phrase, alluding to unique uses that were unrelated to the current study. As a result, a first choice was made by confining to "PPE maintenance," lowering the number of papers evaluated to 17.391. The term "PPE maintenance" was subsequently discovered to be utilized for a wide range of applications; therefore, the topic was narrowed to Industry, with a further limit of 299 publications. The articles received were more relevant, but still too general. Another filter was then applied to focus the research on the study's goals, by introducing new keywords such as "risk assessment, PPE 4.0, health monitoring, IOT, wearable devices, electronic devices," shortening the list to 86 papers that were thoroughly analyzed, further narrowing the selection to 25 papers that were completely consistent with the goals of this work. This finding made the authors realize that there isn't much in the literature regarding industrial automated monitoring of PPE to enhance maintenance and management. The PPE literature categorizes the devices according to their application (for example, usage, sector, materials, and how to wear them, [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16] [17]), but only a portion of the same, including that part of literature published by the bodies responsible for the operators' safety, emphasizes the critical importance of PPE management that ensures: a) efficiency over time, through compliance with the necessary maintenance; b) decommissioning on the expiry dates indicated by the manufacturers. Ineffective PPEs make protection decay and hence become harmful for people who feel safe by wearing them, posing dangers to the operators' safety. In this context, the INAIL (National Institute for Accident Insurance) in Italy released a document, [14], in 2019, which stated that for every piece of equipment (including PPEs), the preservation of performance and safety characteristics is ensured over time through maintenance. Article 78 of the Italian legislative order 81/2008 requires workers who use any PPE to maintain it in full efficiency. The ISO 14119 standard specifies the potential combination of PPE and RFID (Radio Frequency IDentification) and imposes some maintenance constraints, [18], [19]. The benefits of combining PPE with RFID are also discussed in this last piece, which is covered again in the article, [12]. Some publications, [13], [20], underline the need to maintain the PPEs that protect the operators' respiratory tracts. This is because, in the case that the protective equipment fails, they are compelled to tamper with it, risking their safety. The Internet of Things (IoT) is a popular technology for this purpose. The selection reported in the bibliography, mentioned at the beginning of this chapter, cites the extensive literature consulted by the authors on the subject, highlighting what is of particular interest for this paper, in relation to the importance of correct PPE supervision of dates established for maintenance and legal revisions, and the definitive expiry dates of the same, which concludes their life cycle, [11], [15], [18], [21], [22], [23]. Other Authors discuss about the importance of introducing the so called “Smart PPEs” to improve safety, like enabling IOT monitoring capability and Artificial Intelligence, [24], or being able to monitor the conditions to prevent heat stress, [25]. The literature review enabled the authors, who were already convinced by the company's investigation of the need to develop a methodology to monitor scheduled interventions to keep PPEs in good working order, to focus on: a) developing an appropriate management model for such equipment; and b) conducting an accurate benchmark among the available technologies to identify the most appropriate one.

As a consequence of the literature review conducted it is important to note that the Researchers, so far, although identified PPEs as a critical factor for Safety, they concentrated on different aspects from those proposed by the Authors. In fact, as a comparison between the state of the art and the current paper, the Authors would like to highlight the innovative aspects brought by the methodology proposed, in terms of an integrated System (hardware and software) to support correct management and maintenance of such Equipment.

2 Case Study

A Case Study was conducted on Ansaldo Energia, a Major Player in Italy in the production of components for Energy (turbines), in collaboration with the Italian Ministry of Economic Development and Genoa University. In particular, the Ministry co-financed the LHP project (Light House Plant) for the adoption of Industry 4.0 standards. One of the objectives of LHP was Smart Safety which included PPE management.

2.1 Team Building

Smart Track S.r.l. was chosen as the most suited technological partner after rigorous consideration due to its extensive knowledge of 4.0 tracking technology. The expanded team was then defined:

- The Company (EHS: Coordinator and Project Leader – ICT: Head of Department and System Engineer – DATT: PPE Responsible);
- Genoa University - DIME (Prof. Eng. Roberto Revetria, PhD: Scientific Coordinator, Prof. Eng. Marco Mosca, PhD: Technological e Scientific Advisor);
- Smart Track S.r.l. (Technological Partner: Eng. Saverio Pagano, AD, Eng. Simone Peirani, Coordinator, Eng. Alessandro Cortese, PM);
- Futuro S.r.l. (PPE Supplier, Ds. Margherita Pitto, Owner, Mr. Paolo Priano, Interfaccia A.E.).

2.2 Current Scenario

Currently, an internal function administers the PPEs manually, using paper registers to record personal data, deliveries, and withdrawals of new, stored, or assigned devices. Despite its efficiency, it is simple to see the objective difficulties inherent in this sort of operation, which is reliant on "many to many" interactions (such as producers, PPE, operators, usage locations, etc.).

2.3 Future Scenario (New Methodology)

The activity entails installing suitable sensors on a variety of PPEs linked to auditory and visual detection systems to monitor the scheduled dates for both periodic upgrades and expiry dates. The installation of these sensors will avoid any delays in control duties, ensuring that PPEs are maintained, revised, or replaced on time. It will also assist in making operators aware of the need for proper management and maintenance of protective devices for safety. At this stage, the team presented the created technique to the PPE manager. Once the objectives of this project were decided upon, the reference technology was chosen in collaboration with the technological partner (Smart Track). All of the PPEs used in the company were thoroughly evaluated, and the best ones for launching a pilot project were chosen. As a result, the team initiated a particular study project; during the first phase of the investigation, certain important factors surfaced, such as the fact that PPEs are subject to law modifications and have a fixed life cycle rather than an endless existence. It also became evident that monitoring and maintaining PPEs involves labor, making it difficult and time-consuming. Another consideration is that assigning PPEs to operators traveling to construction sites necessitates an accurate estimation of the trip duration and the proactive calculation of modifications/expiration dates. The absence of this practice would expose the firm and its operators to safety risks.

2.4 Benchmarking of Technologies

The next phase in the project was to emphasize the benefits and limitations of each specified technology (such as bar code, RFID, and NFC-Near Field Communication) in relation to the specific usage. The bar code was a standardized and low-cost technique. On the other hand, they are not suited for application on many types of surfaces, such as lanyards or any PPEs exposed to water; also, an unpleasant reading of the same if put internally, as well as the ease with which coded labels deteriorate. As a result, RFID was explored, with various advantages including system resilience, the increased quantity of information that can be stored on 96-bit tags, and the ability to make repeated scans modern. Furthermore, RFID tags are more suitable for the geometry of the chosen PPEs than bar codes. Another advantage is that RFID tags, when purchased in bulk, are quite inexpensive (in the order of Euro cents). The weakness of this solution for this specific application is that the gates to be monitored are numerous; in fact, the operators can enter and exit the workplace from various directions (different warehouse doors) and can insist on multiple work islands both in the factory and on construction sites. This configuration would indicate a redundant expense for antennas (ranging in price from € 600 to € 1000 each). The most recent technology explored was NFC, which has several advantageous characteristics such as the ease of installation, since this sort of tag may be integrated into the head of an electrical cable tie (Figure 1). Another advantage is the ease of reading and the fact that, unlike RFID antennas, NFC does not need expensive reading apparatus.

Fig. 1: Selected Technology (NFC TAGS on cable ties).

An App for NFC devices already allows for services such as tag reading and database access. The disadvantages of this technique over RFID include the necessity to scan every single piece of PPE and the cost of €1,00 per tag. After this benchmark examination, the team chose NFC as the technology with the greatest price-performance ratio while still ensuring effective and efficient performance for this sort of application.

2.5 Feasibility and Sustainability Study

In this phase of the project, the team was required to examine what had emerged from the previous phase in collaboration with ICT (Information & Communication Technology). It is the internal function managing both the contracts with technical suppliers and the systems installed in the factory). Two more reviews were performed, one with the DATT (internal function controlling and allocating PPEs to operators) and one with the external partner supplying PPEs (Futuro S.r.l.), to present the PPE selection for the pilot project. The Team, as previously foreseen, selected the following as priority (Figure 2, Figure 3): a) harnesses; b) lanyards; c) electrically ventilated helmets; d) dielectric gloves; e) reels; and f) belts. The provider re-evaluated this selection to ensure its acceptability. The provider also contacted each PPE manufacturer to obtain written assurance that the application of the tags was not tampering. In this regard, the producers contact the various certification agencies in turn to ensure that the application does not cause the certifications to lapse.

Fig. 2: PPE was previously defined as "life savers PPEs".

The investigation revealed that all of the choices selected were compatible with the integration of the NFC tags, except the dielectric gloves (Figure 3), which, if perforated to pass the cable tie containing the TAG, would lose their capacity to isolate. The team then expelled such PPE from the selection and continued with a re-evaluation of the remaining candidates in the field.

Fig. 3: Discarded and retrieved PPEs.

This type of application, therefore, required a second phase of analysis which led to the search for non-invasive systems for applying the tag to the dielectric gloves (not requiring to hole the surface of the glove or not to affect, in any way, its integrity). The Authors then came to the identification of NFC adhesive tags (on stickers), purchased in coils and simple to apply. Also, for this phase, the scrutiny of the Manufacturer and the Certifying Bodies was required. A meeting with DATT and Futuro to evaluate the application of the tags to each authorized PPE from an operational standpoint. The authors then proceeded to determine the appropriate use for each PPE, which meant that it should not interfere with the operators' task and comfort, cause aggravation, or be subjected to shocks or slides. The next stages were: a) designing the operating method; and b) designing the smartphone application.

2.6 Framework of the Project Steps

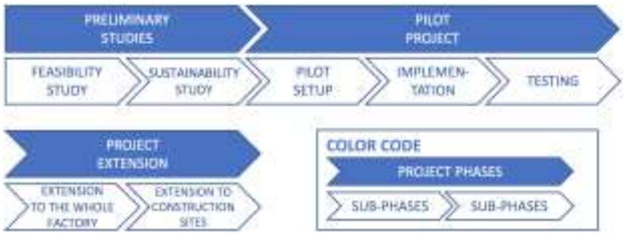

Fig. 4: Process of implementation.
Source: Image previously published by Springer, [1].

The structure seen in Figure 4 is applicable under the following conditions: a) full management sponsorship, providing the necessary resources (people and budget) to the project; b) creation of an internal function dedicated to the management of PPEs; c) census of PPEs available in the facility (type, supplier, brand, batch number, serial number, expiry date, ...); d) selection of the PPEs to be monitored; e) creation of a register for delivery and return of PPEs assigned to operators; f) system adoption (server, software, tags, NFC smartphone); g) tag integration on PPEs; h) training for concerned people.

2.7 Design of the Operational Process

The authors then prepared clear images for each tag affixed, demonstrating the integration with PPEs, to obtain manufacturer clearance. A new feature, fundamental to proper PPE management, was the development of a reporting process to follow the equipment during the assignment. This method is separated into four parts, which are appropriately documented in specialized books: a) a written request for PPE by the operator; b) approval by the relevant office; c) delivery to the operator; and d) return of the PPE to the office. The same method is used while replacing PPE.

2.8 IIOT (Industrial IoT)

The proposed system complies with Industry 4.0 standards, adopting IIOT (Industrial-IOT) principles such as the ability to generate a network of physical objects (not necessarily native for Internet connection, but appropriately the selected PPEs) by embedding them with electronics and software, enabling Cloud connection and data exchange. As a result, the System allows monitoring and control of functions via a wide range of heterogeneous peripherals such as PCs (fixed and mobile), tablets, and smartphones. This is accomplished through the developed application or by direct access through the website (only for authorized devices, in accordance with cyber security). The IIOT's influence on industry provides several advantages. Starting with safety in this example, but with the potential for a wide range of applications (like proactive maintenance, predictive maintenance, energy saving, monitoring-control-automation of the infrastructure in real-time, integration of heterogeneous devices and different manufacturers, environmental monitoring, ...). The ability to centralize data obtained at the peripheral level also allows for the creation of a high analytical capacity, resulting in considerable improvements in process knowledge. Given the huge number of deadly incidents that occur every day in industrial plants all over the world, this technology provides a substantial asset against both dangers to Operator safety and economic harm to enterprises.

2.9 Application for Smartphones

Fig. 5: System architecture.
Source: Image previously published by Springer, [1].

Figure 5 depicts the system's architecture, including the smartphone application, which was designed to exploit most of the available technologies, in a market that is increasingly adopting Industry 4.0. Indeed, many recent smartphones feature NFC technology, which permits information to be acquired by the right tags via the direct scanning technique mentioned above. The smartphone application connects with a cloud located on a business server (located in the company and redounded with a Remote Terminal Unit located in a separate business unit), which stores the data in a relational database (programmed on the Oracle platform and queried by SQL) on distinct channels (separate registries for PPEs, Operators, Functions, Destination, …, linked together by a unique key, which is the ID number of each PPE). The analytics software converts such data into meaningful information in the form of tables and graphs to integrate the data and make it understandable to the User. A "drill down" logic is applied the initial screen shows aggregated data that may be progressively exploded by the User in different directions: 1. per Function (which Operators are assigned with what PPEs), per Operator (which PPEs are assigned to the Operator pointed), 3. Per PPEs (which Operators it was assigned to and from what Operator it has been booked), 4. per review (storyboard of maintenance operations and certifications, next deadlines for maintenance or re-certification, and expiry date for replacement). Down to details, the main table is the PPEs register (displaying information relating to the manufacturer, the supplier, the date of purchase, the price, the lead time, the status, the duration of the batteries, the life cycle, the revisions required by law, the dates for replacement of consumables, and the deadlines). A second table records Operator assignments (registering name, surname, cost center, and serial number, as well as specific usage information such as collection date, possible replacement, delivery, status at the time of collection VS. status upon delivery, any use in an emergency that might have compromised integrity and would necessitate repair/replacement). During each scan, the program collects and centralizes peripheral data from the PPE scanned and compares it to information from the database. As a next step, it sends a simple and direct message to the Operator (traffic light logic), with green indicating total usability, yellow indicating partial usability (need for revision / imminent expiry / need to replace consumables / low battery level /..) and red indicating non-usability (revisions or deadlines not met / damage not repaired /..). Clear system notifications, linked to the light code, inform the Operator of any issues. The Manager can also contribute information to the database or use it just for reading purposes. The database is updated automatically upon each event.

2.10 Pilot Project

The pilot project was divided into stages. Initially, the project was set up by identifying appropriate PPEs, personnel to be involved, and those responsible for PPE supply. The whole crew that was chosen was trained. The information processes and procedures were specified, as well as the specifications of the chosen PPE and safety standards. The project's calendar was planned. The implementation phase then began with the attachment of NFC tags to the PPEs; at this point, a beta application on the server (to be extended, once tested, to the Cloud) was enabled, and the project was launched. Numerous measurements of operation times and mistakes were taken on the installed system to evaluate efficiency by comparing them to earlier measurements. Throughout the trial experiment, operators were assisted. The pilot project provided an opportunity to gather experience. A new phase of continuous improvement including hardware, software, processes, and procedures was initiated.

3 Results and Benefits

To understand the importance of the new methodology, it is sufficient to point out the enthusiastic welcome given to it by: 1. Operators who, because of this system, now wear complete protection equipment despite devices becoming ineffective or expiring due to lack of maintenance which, in case of need, would have compromised, often irreversibly, their state of health (lacking their ability to protect). As an example, helmets commonly used in factories, over time, become fragile and lose their protective prerogative, leaving the head exposed to the consequent impact; or the dielectric gloves, no longer protective, with imaginable consequences for the operator who gets accidentally in contact with an electrically active conductor 2. Workers Council and safety Managers who see the Operators' PPEs finally maintained in efficiency which, otherwise, would turn too easily into a trap for the Wearer (in the belief of being protected) 3. Company Management at all levels, in the event of serious accidents caused by PPE deficiencies, was held liable by the Judiciary for all the criminal consequences of the case. To conclude this excursus on the importance of the new PPE management system and methodology, the Authors, given that it will be marketed by a specialized company in the sector, are confident in its rapid diffusion to decrease the appalling number of fatal accidents certified by the International Labor Organization (as reported in the Introduction) which occur daily in Company departments and construction sites. This monitoring procedure provides significant benefits to the company, including: a) increased operator safety; b) time savings compared to the standard monitoring approach; c) the absence of maintenance errors, which is required to maintain efficiency; d) a longer duration of PPEs (e.g. the damage caused by the spillage of the acid of the batteries, compromising the efficiency of the device); and e) the timely replacement of consumable materials (as in the case of headphone pavilions), preventing operators who are irritated by malfunctioning from reducing their usage (proper consumable management also allows for greater hygiene for workers, as in the case of mask filters); f) the reporting procedures introduced allow for greater transparency in maintenance procedures; g) the provided register records the assignments, reducing the number of losses; h) the list of PPEs available is constantly updated, providing the manager with a real-time image of the equipment to take the most appropriate measures (such as urging operators to return PPEs that are no longer needed; or to provide for the replacement of PPEs or spare parts); i) increased competitiveness in tenders for the firm as a result of the advantage it has over competitors in terms of workplace safety.

4 Project Extensions

As already indicated in Paragraph 1, following a successful implementation conducted on PPE life-savers, the project was extended to second and third-priority categories (Figure 6, Figure 7).

Fig. 6: PPE was previously defined as “health protectors PPEs”.

Fig. 7: PPE was previously defined as “Critical equipment for safety (non-PPE)”.

This last category (Figure 7) relates to the handling and suspension of loads which, since not referring to wearing by the Operators, cannot be considered as PPE. However, the applicability of the introduced system (architecture, technology, and methodology) was also found to these devices, since, in turn, they are subject to maintenance, revisions, and deadlines, neglect of which generates phases of risk for the Operators.

5 New Versions for Upgrade

Faithful to the fundamental dictation of Industry 4.0 on Continuous Improvement, the Authors continued to study the problem of managing PPE. In this way, after the creation and implementation of the first series of devices of the type described in the previous pages, the Authors first conceptualized and then developed two further versions enriched with specific functions. In summary, while the PPE_STD version, described so far in this article, provides only the possibility of checking the status of the PPE (maintenance, revisions, deadlines, ...), the PPE_WEAR version has been equipped with a WeTag device for each Operator to be able to check that the PPE were worn by them, rather than abandoned elsewhere. Finally, the PPE_WMD version (Wear + Man Down), in addition to having all the functions of the PPE_STD and PPE_WEAR versions, has been integrated with a specific PPE (Man-Down) previously designed and implemented by the Authors, [16], [17], for the protection of an Operator on the ground through geo-location of the same in confined areas. It is reported in the following a brief description of the relevant technical features.

5.1 PPE_WEAR

It consists of the upgrade of the system by a small wearable "WeTag" device (Figure 8), which can be applied with velcro to the jacket or with a clip to the Operator's belt. This device has the purpose of monitoring the proximity of the PPE associated with it, therefore most likely worn by the Operator. The technology selected by the Team, as necessary for the communication of the WeTag with the associated PPEs, is Bluetooth 5.0 which, for the specific application, stands beside the NFC technology previously introduced by the Authors, [1]. For the correct functioning of this upgrade, it is required, in addition to the Hardware so far described, an adaptation of the installed Software and a specific Firmware on the WeTag controller.

Fig. 8: WeTag wearable device by Smart Track.

5.2 PPE_WMD

It consists of the integration, inside the WeTag_MD device (Figure 9, left), of the two technologies PPE_WEAR and Man Down previously introduced by the Authors, [16], [17], which involves the use of inclination sensors, accelerometers, temperature and barometric pressure meters and of GPS for the identification and immediate assistance of the man on the ground in confined areas. For the correct functioning of this upgrade, it is therefore necessary, in addition to the Hardware described here and the usual Software adaptation, again include the specific Firmware on the WeTag controller. Then, it is required the installation in the spaces considered critical, of anchors (Figure 9, right) designed for the transmission of the reference signals to the WeTags.

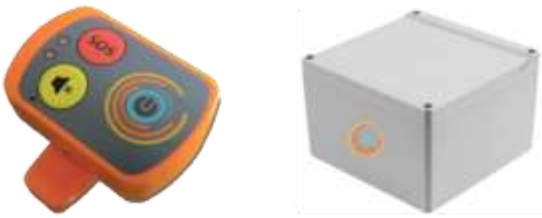

Fig. 9: WeTag_MD wearable device + anchor, [16], [17].

The aim of the Authors for this new research is to make the Hardware and Software system, previously conceived and implemented by the same, [1], even more complete, to allow a progressively more effective action on Operators being, at the same time, easier for the control of Safety Supervisors. The direct consequence is guaranteeing a superior level of protection for the Operators wearing PPEs managed by these systems.

6 Cost structure Analysis

Being an objective of this research the maximum diffusion in the world of work of a procedure considered essential to ensure the correct management of PPE, and therefore the safety of the Operators who wear them, authors in collaboration with the Smart Track Technicians have developed an accurate analysis of the investment of the three versions. The whole system was designed to obtain the lowest possible cost of each version to facilitate its maximum spread. Table 1 shows in detail the cost structure of the hosting system (Hardware, Software, Commissioning, Testing, Training, and Reading Device).

Table 1. System Cost.

PPE SYSTEM (Installed platform and basic Hardware)	COST PER UNIT	QUANT	TOTAL COST
SOFTWARE PLATFORM	3.000,00 €	1	3.000,00 €
COMMISSIONING E TESTING	3.500,00 €	1	3.500,00 €
TRAINING	1.000,00 €	1	1.000,00 €
NFC READER ON A SMARTPHONE	350,00 €	1	350,00 €
SYSTEM COST (NO TAGS)			7.850,00 €

The implementation of the PPE_STD version requires the purchase of cable tie Tags, available in lots of 1,000 units each (Table 2).

Table 2 PPE_STD (system completion cost).

PPE_STD VERSION (monitoring and control of the PPE status and maintenance)	COST PER UNIT	QUANT	TOTAL COST
1.000 TAGS	1,00 €	1.000	1.000,00 €
PACKAGE COST (1000 TAGS)			1.000,00 €

A possible extension to the PPE_WEAR version requires, for 200 Operators, the adoption of a package containing 200 WeTags PPE_WEAR and 1.000 Bluetooth Tags (Table 3).

Table 3 Upgrade cost to PPE_WEAR.

EXTENSION TO PPE_WEAR			(ADDITIONAL COST TO PPE_STD)
PPE_WEAR VERSION (monitoring and control of the PPE and its use by Operators)	COST PER UNIT	QUANT	TOTAL COST
SOFTWARE AND FIRMWARE UPGRADE	1.000,00 €	1	1.000,00 €
1.000 BLUETOOTH 5.0 TAGS	13,00 €	1.000	13.000,00 €
200 WeTag PPE_WEAR (associable to different tags)	195,00 €	200	39.000,00 €
PACKAGE COST (1.000 TAGS + 200 OPERATORS)			53.000,00 €

Finally, it is possible to upgrade the PPE_WEAR system to the PPE_WMD system by means of a further platform upgrade and electronic integration of the WeTag device (Table 4).

Table 4 Upgrade cost to PPE_WMD.

EXTENSION TO PPE_WMD			(ADDITIONAL COST TO PPE_WEAR)
PPE_WMD VERSION (monitoring + ctrl of the PPE, use and Man Down function)	COST PER UNIT	QUANT	TOTAL COST
SOFTWARE AND FIRMWARE UPGRADE	1.000,00 €	1	1.000,00 €
200 WeTag PPE_MD (associable to different tags)	100,00 €	200	20.000,00 €
60 Anchors (6 per machine on 10 different machines)	80,00 €	60	4.800,00 €
PACKAGE COST (1.000 TAGS, 200 OPERATORS, 10 MACHINES)			25.800,00 €

7 Scientific Contribution

With this manuscript, the Authors feel to have contributed to the Body of Knowledge because, starting from the analysis of the current methods to manage and maintain the PPEs in Companies, they developed and released a new methodology comprehensive of Processes (and procedures) and Technologies (hardware integration, smartphone application, database management, and analysis). The system proposed brings innovation and increases the level of safety for the adopting Companies. The original project, as described in the original paper, [1], was performed by a Team of a Major Player in Italy in the Manufacturing and DIME Department from the University of Genoa, and co-financed by the Italian Ministry for Economic Development as an objective, called Smart Safety 4.0, of the Lighthouse Plant project. The system proposed allows Operators to trust the PPEs that they wear, instead of feeling protected while they are not, due to the inefficiency of these Equipment due to wrong management, lack of maintenance, or expiry date.

8 Conclusion

PPE from life-saving equipment can even cause danger stages if it becomes outdated or is not properly maintained. This study addressed the topic of 4.0 management of PPE to maintain them efficiently throughout their life cycle and to detach them when they expire. The intervention is separated into two phases: a) the creation of tracking tools for delivery/usage/return that are consistent with requirements; b) the conception and development of a device for on-the-job management of crucial revision and expiry dates by security personnel; c) the extension with new features for maximizing the benefits produced by the installed system (Yield Management principle). This device does not interfere with the operator’s activity and may be utilized both inside and outside of the firm. The authors anticipate that other companies will swiftly follow this example in adopting an innovative technique to continually control the efficiency of PPEs to protect operators' safety. The Technological Partner (Smart Track) is actively proposing the system to a growing number of Italian SMEs and Large Companies operating in Manufacturing, moreover, the system is now under evaluation by an Italian Certification Body with the scope to make the achieved contribution objective. The Team's design architecture has demonstrated, after extensive testing, to react to the demands for which it was developed; for this reason, the authors say that it represents a true benefit for Safety 4.0, where PPEs are used. The team put special attention to standardizing and generalizing the new technique to create a system that can be utilized in any operating situation. Given the small size of the tags adopted as well as of the WeTag device and the ease of integration with most PPEs on the market, the suggested system may be standardized for expansion to other industries like as construction, quarrying, plumbing, and heating. This is also made possible by the low cost of the proposed solutions, in fact the unit cost starts from a minimum of 8,85€ per Operator, system costs included, calculated on a batch of 1.000 Tags, which progressively decreases as the number of Tags increases (e.g. 3,61€ on a lot of 3.000 tags).

Acknowledgement:
The Authors believe to have contributed to raising awareness about the importance for safety of the proper management and maintenance of PPE and hope to have stimulated the interest of Researchers to further extend this branch of study.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

All authors contributed to the study's conception and design. Conceptualization, material and image preparation, data collection, and analysis were performed by Roberto Mosca and Marco Mosca. The first draft of the manuscript was written by Roberto Mosca and Marco Mosca and all Authors commented on previous versions of the manuscript. Engineering solutions were designed by Saverio Pagano. Accurate review and consulting were provided by Roberto Revetria. The literature review was conducted by Federico Briatore as well as final editing. All Authors read and approved the final manuscript.

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Conflict of Interest

The Authors have no conflicts of interest to declare.