Using smart PPE in waste management: advantages and disadvantages

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Abstract

Once hazards for workers are highlighted, engineering and administrative controls should be adopted in workplaces and, finally, Personal Protective Equipment (PPE). In Italy, INAIL is involved in studying the application of the national plan "Industry 4.0" to safety in workplaces and in improving the protective systems' performances through the use of "Industry 4.0" devices. Smart PPE are "Industry 4.0" products representing the most interesting way to increase protection standards in risk management. Smart PPE are advanced PPE, integrating materials, sensors and ICT solutions enhancing product multi-functionality. Many functions can be integrated in Smart PPE: health and environmental monitoring; wireless communication; personal localization (GPS) and geographic information system (GIS); cooling and heating; additional functions as an emergency stop or hazard reduction; smart textiles; wireless tracking and identification; physical security information management; augmented reality. There are advantages and disadvantages in using these items, to be taken into account for workers' safety. The aim of this study is to provide an overview of smart PPE's pros and cons referring to every phase of solid waste management, one of the most hazardous employment sectors in Europe, where PPE are essential to reduce risks. Moreover, some interesting features of existing smart PPE will be pointed out, such as the communication based on Bluetooth or RFID TAGs and sensors, the face recognition, or the integration of augmented reality. Finally, the first results of INAIL's project about a smart PPE will be illustrated. At the end of the project activities this item will be available free of charge.

Keywords: waste management, workers' safety, Personal Protective Equipment, Smart PPE, Industry 4.0, Internet of Things.

Introduction

In Italy the compulsory insurance against accidents in workplaces was introduced in 1898, however the National Institute for Insurance against Accidents at Work (INAIL[1]) was established much later in 1933 with the aim to make the occupational insurance system public and efficient. At the beginning, the Institute was involved in promoting the compulsory insurances, the automatic entitlement to healthcare benefits, and a modern concept of healthcare for workers with disabilities. Nowadays, INAIL is the only Italian authority able to operate for health and safety protection in workplaces, also undertaking several scientific research and prevention projects. The Institute promotes studies and experimental activities to develop and validate best practices, methods, risk management procedures and devices for workers' safety, according to the Industry 4.0 national plan. Therefore, INAIL's activities aim to realize these objectives: reducing injuries, protecting workers, also in hazardous jobs and making the return of people injured at workplace fast and easy.

Over time, the Institute has evolved its research fields due to emerging risks and challenges in occupational safety. In fact, the protection of physical and psychological integrity, commuting accidents, ergonomic needs, anthropometric and gender characteristics have become common issues for professionals dealing with risk management in Europe and industrialized countries. It could be said that these risks have been found out more in well-being countries, where new technologies have radically changed the working life. At the same time, the new means offered by "Industry 4.0" have broadened the horizons in work and safety management.

For these reasons, INAIL is studying the applications of "Industry 4.0" to safety in workplaces, such as cyber-physical systems, the Internet of Things (IoT), smart factory, cloud and cognitive computing. They offer several advantages, such as to allow workers being found in case of emergency by GPS systems, to control the access to dangerous areas through smart sensors, to give instructions during work activities thanks to Augmented Reality (AR) devices and to monitor environmental conditions of workplaces.

[1] INAIL stands for Italian "Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro".

With reference to waste management, the Department of technological innovations and safety of plants, products and anthropic settlements (DIT[2]) of Inail is carrying out research on “Industry 4.0” systems, which allow preventing risks for workers. At the same time, the Advisory department for risks assessment and prevention (CONTARP[3]) of Inail is detecting useful elements for risk assessment in every phase of waste management, thanks to its advisory activity for the Institute. There is no doubt that the collaboration between these two departments has been very important to come up with innovative solutions to safety issues in the waste sector. In fact, the assessment carried out by CONTARP on real cases is useful for DIT to find out feedbacks of research results about smart protective systems using “Industry 4.0” technologies.

Currently, INAIL is evaluating the use of smart Personal Protective Equipment (PPE) in waste management, in compliance with European regulations and Italian laws. Smart PPE recently developed are designed by integrating Industry 4.0 devices in standard PPE. In this way, they prevent workers from injuries through sensors that interact each other, with other systems and/or with workers.

In this paper, the authors firstly aim to give an assessment of the main risks for workers’ health and safety during every phase of solid waste management. This analysis will take into account the different jobs involved in the collection, transport, recovery and disposal of waste and the environmental conditions of workplaces. Then, it will be showed an overview of the advantages and disadvantages of smart PPE, which workers could wear/use to reduce risks in waste management. Finally, some examples of innovative applications of smart technologies to PPE will be given, including an innovative project carried out by INAIL.

Risks for workers involved in Solid Urban Waste Management

According to the consolidated version of the European Waste Framework Directive 2008/98/EC [1] waste management means the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker. Therefore, the expression waste management is related to the entire cycle of waste, from its production to its end. According to the last data on European waste management [2], the production of waste is different for every economic sector and country. The graphs point out that the total highest amount of waste is linked to construction, mining and quarrying sectors; however, it is also relevant the contribution of household and manufacturing waste as well as of wastewater (about 10%). With reference to the last report on solid urban waste released by the Italian national Institute for environmental protection and research (ISPRA[4]) [3], it could be argued that solid waste management represents an important sector in Italy. Just having a look at the report, you can find out that in Italy 29.6 million of tonnes of urban waste were produced in 2017 and 123 landfills worked out in 2017 for both dangerous and urban waste. The report shows that 23% of the total waste was sent to landfilling. Moreover, some statistics point out that activities linked to waste management are featured by high accident and illness rate [4, 5] due to workers’ exposure to chemicals, biological agents, etc [6] and to other synergic factors such as climatic factors, traffic, high noises exposure, construction site vehicles’ circulation etc. Looking at European data on fatal and non-fatal accidents at work, there is evidence that waste management is the eighth of 22 employment sectors for fatal accidents [7]. In Italy, INAIL registered about 5400 accidents from 2006 to 2011 in urban waste management sector [8]: however, the number of workers injured has gone down since 2010, thanks to a growing knowledge about risk prevention and protection (Figure 1).

[2] DIT stands for Italian “Dipartimento Innovazioni Tecnologiche e Sicurezza degli Impianti, Prodotti e Insediamenti Antropici”.
[3] CONTARP stands for Italian “Consulenza Tecnica Accertamento Rischi e Prevenzione centrale”
[4] ISPRA stands for Italian “Istituto Superiore per la Protezione e la Ricerca Ambientale”

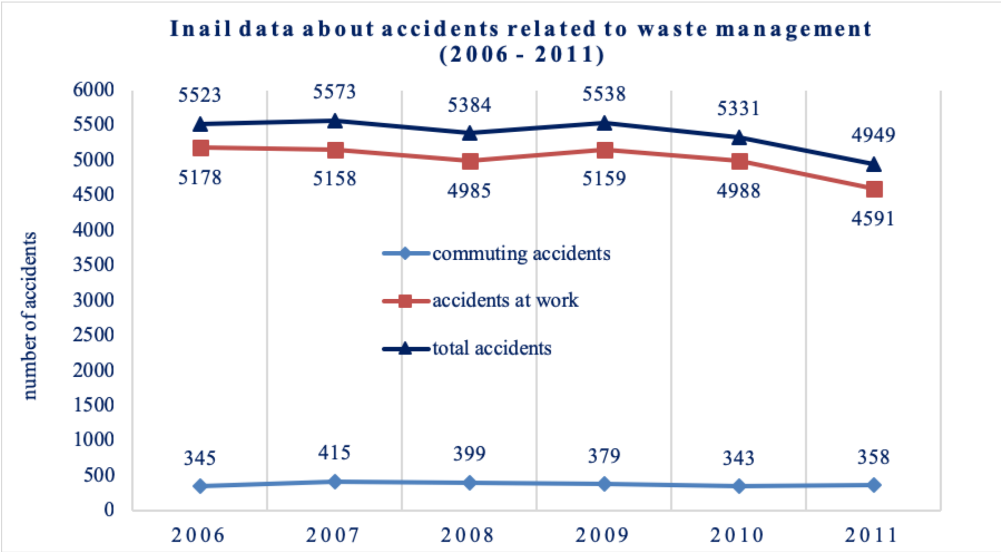

Figure 1: number of workers' accidents in Italy related to waste management in 2006-2011 [8]

According to the consolidated version of the European Waste Framework Directive 2008/98/EC and to the Safety and health of workers at work - Framework Directive 89/391/EEC, INAIL is working to connect safety needs to environmental aspects relating to waste management in Italy. Italian Legislative decrees 152/2006 and 81/2008 (environmental and health and safety framework decrees) are the main references to manage issues related to the collection, transport, disposal and monitoring of solid waste. Even though it is widely known that preventing workers from injuries and occupational diseases during their activities is fundamental, environmental protection measures are generally considered a priority in waste management.

Firstly, it is important to look for the main risks for workers during waste management phases. Through a deep analysis of accidents occurred in solid urban waste collection and disposal, these results were highlighted (tables 1 and 2) [9] in:

- solid waste collection, risks for workers are mainly related to environmental conditions, the interaction worker/machinery and the presence of solid waste;
- solid waste treatment and disposal, risks for workers are mainly linked to the vehicles' circulation, the contact with materials, interaction worker/machinery, features of workplace, fires and explosions and contemporary actions.

Table 1. Risks for workers related to the collection of solid urban waste

Risks	**Solid urban waste collection**	
	Waste collection with machinery	Hand waste collection and street cleaning
Accidents due to environmental conditions	• Road accidents, wrong vehicles' circulation • States of illness due to extreme climatic conditions • Slipping, tripping and falling due to bad road illumination and/or wet, dirty and irregular pavement	
Accidents due to the interaction worker/machinery	• Workers run over by vehicles • Slipping during the ascent and descent from vehicles • Crashes with parts of machinery • Crashes due to wrong load management related to waste	• Road accidents • Wrong use of machinery • Crashes with parts of machinery during street cleaning
Accidents due to solid waste	• Cuts and abrasions through contaminated objects • Crashes with large items • Risk of falling materials from a height	

Table 2 Risks for workers related to the disposal of solid urban waste

Risks	**Solid Urban Waste Disposal**		
	Treatment plants	Landfills	Incinerators

Accidents due to vehicles' circulation	• Workers run over by vehicles • Crashes with machinery • Falls from cabin	• Workers run over by vehicles • Crashes with machinery • falls from cabin • waste landslides	• Workers run over by vehicles • Crashes with machinery • Falls from cabin
Accidents due to the contact with materials	• Risk of falling material from a height • Cuts and punctures • Chemical burns due to the contact with dangerous substances		
Accidents due to the interaction worker/machinery	• Crashes • Risk of entrapment in moving parts of machines		
Accidents due to workplaces' conditions	• Risks related to confined spaces • Falls from a height • Risk of slipping and tripping	• Risk of slipping and tripping	• Risks related to confined spaces • Falls from a height • Risk of slipping and tripping
Accidents due to fires/explosions	• Fires due to the presence of organic and flammable solid waste • Explosions due to the presence of biogas		
Etc.	• Accidents among vehicles and workers • Accidents due to tiredness in the night or to work alone	• Accidents among vehicles and workers	• Accidents among vehicles and workers • Accidents due to tiredness in the night or to work alone

The analysis of the main risks for health and safety in Solid Waste Management (SWM) allows choosing correct safety measures and devices in different SWM operations, such as standard PPE. What's more, this overview is important to adopt innovative "smart PPE" in each SWM phase, taking into account their main advantages and disadvantages.

Standard PPE in solid waste management

The basic steps for safety in waste management are the identification of the hazards in the workplaces, the safety risk assessment (considering severity and likelihood of outcomes), the choice of the best control of the hazard, the implementation of the chosen control and the evaluation of the effectiveness of the control adopted.

Once hazards for workers are highlighted, they should be removed (that is the best way to control risks) or reduced (e.g. a product that is in dry powder can be replaced with something in the pellet form to reduce airborne dust and the inhalation hazard). Then, according to the hierarchy of safety measures, engineering controls should be adopted: design or modification to plants, equipment, systems and processes that reduce the source of exposure. Examples of the reduction of the source exposure are automation of hazardous processes, use of mechanical lifting devices or transportation instead of manual methods, prevention of workers from hazards through isolation, implementation of a local exhausting ventilation system. Moreover, administrative controls can be used in risk management. The administrative controls reduce the risks through a different work organization such as schedule maintenance when few people are working, job rotation and work rest schedules (to limit the workers' exposure to dangerous substances or processes), safe practices, *i.e.* standard operating procedures, emergency response training and good housekeeping and personal hygiene practices.

Finally, PPE should be adopted, considering the hierarchy of controls. PPE are worn to reduce exposures, such as chemical/biological contact or noise, and should be the last level of protection, when all other methods cannot be used or are inefficient. In many cases, a combination of control measures might be suggested to control risks.

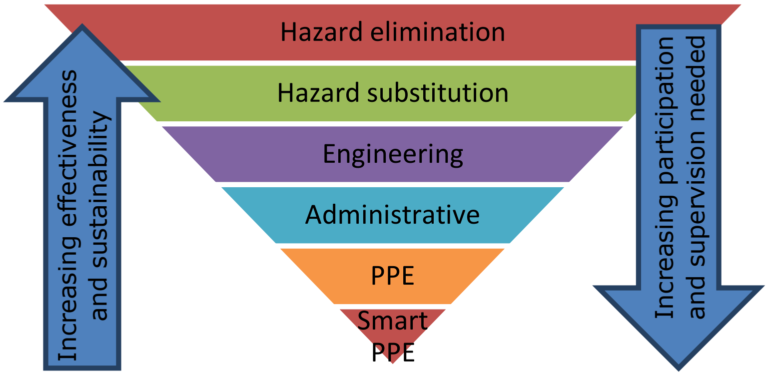

Figure 1 Hierarchy of risk controls

According to Regulation 2016/425/EU, the expression "Personal Protective Equipment" means *"... (a) equipment designed and manufactured to be worn or held by a person for protection against one or more risks to that person's health or safety; (b) interchangeable components for equipment referred to in point (a) which are essential for its protective function; (c) connection systems for equipment referred to in point (a) that are not held or worn by a person, that are designed to connect that equipment to an external device or to a reliable anchorage point, that are not designed to be permanently fixed and that do not require fastening works before use*".

Therefore, the purpose of personal protective equipment is to reduce the employee's exposure to occupational hazards when engineering and administrative controls do not allow reducing these risks to acceptable levels. PPE have got the serious limit that they do not eliminate the hazard at the source; so, they could expose employees to the hazard in case of fail. PPE go under the conformity assessment procedure carried out by a notified body and are classified in three risk categories:

- Category I, protecting exclusively from the minimal risks;
- Category II, protecting workers from other risks than those listed in Categories I and III;
- Category III, protecting exclusively from the risks that may cause very serious consequences, such as death or irreversible damages to health.

Workers in solid waste management are required to use PPE [10] including Respiratory Protective Equipment (RPE), protective clothing with high visibility features and/or rain, heat or cold protection, gloves, safety helmet, footwear, ear and eye protection. The use of different kind of PPE depends on the type of exposure, job, and duration of exposure.

Therefore, the choice of RPE should consider whether the atmosphere in workplace can be dangerous for eyes or dermal absorption (e.g. in waste disposal or recovery): in this case, a full-face mask should be used; otherwise a half face mask could be accepted (e.g. in adverse climatic conditions during waste collection). In addition, the type of contaminant must be taken into account, because many types of filters are produced respectively against particulates, gases or vapours. Reusable RPE must be maintained under a monitoring program. Self-Contained Breathing Apparatus (SCBA) should be used if the level of oxygen decreases under the value of 18%.

The kind of protective clothing also depends on different factors: the type and the duration of exposure, temperature and humidity conditions and ergonomic factors. In solid urban waste management, during the phases of recovery and disposal, apron or coveralls could be used, while in collection and transport coveralls with high visibility features, protecting also against rain and heat/cold, are the best solution. Protective clothing must be evaluated, from time to time, according to the workplace's conditions, with reference to monitoring phase, which is transversal to all the other work phases.

In any SWM operations workers should wear safety gloves (except sometimes in transport and monitoring) resistant to cuts and abrasions and allowing a good grip. During waste recovery and disposal, anyone working with hot equipment must use heat-resistant gloves. Gloves should be replaced immediately whether a puncture or tear occurs. Safety helmets must be used in case of risk of falls from a height, collisions or load fall. Choosing the type of protection given by safety shoes, in waste management, should consider risks (wet feet; slipping; impacts in the ankles; ankle sprains; cuts on the sides because of sharp objects; contamination by chemicals; impacts or crushes on the toe and ankle area) and working phase. During waste collection and transport, the main risks are slipping or suffering impacts or crushes on the toe area: therefore, the footwear should be waterproof, with a good slip-resistant outsole, and comfort (e.g. with a very flexible outsole). By contrast, in waste recovery and disposal great attention to the safety of feet and to the following hazards must be paid: crushes, cuts on the sides or ankles, impacts on the toe area, slipping resistant, etc. If a potentially explosive atmosphere can be present, as in landfills, safety shoes shall be non-sparking, ATEX certified as like as all other tools and devices used by the worker.

When there is a risk of struck in eyes or impacts to eyes, safety glasses will be used (better if equipped with side shields). In case of splashes, contact or use of chemicals, entering the eye area or the whole face, goggles or face shield should be used.

Suitable PPE should be selected basing on the: 1) specific work task, 2) work sub-phase, 3) workplace's features, 4) risks. Considering risks in each working phase of waste management, we can list PPE used by workers involved in solid waste management. During waste collection, workers are required to use protective clothing with high visibility features, thermal protection against cold or heat and ergonomic properties, gloves preventing from cuts and punctures and safety footwear protecting against slips, rain, impact or crushes. In this phase, respiratory protective equipment may be necessary, such as half mask and eye protection with safety glasses, after the evaluation of the type and concentration of contaminated dust particles.

Workers involved in waste transport must be prevented from risks through safety clothing with high visibility and ergonomic properties (with thermal protection against cold or heat) and safety footwear suitable for driving vehicles. Depending on the conditions, RPE, gloves, ear protection and eye protection may be adopted.

During the phases of recovery or sorting, workers must use RPE, protective clothing, gloves and footwear and they are sometimes strongly suggested to use protection against cold or heat, noise and struck in the eyes or impacts.

Finally, workers involved in waste disposal must wear RPE, protective clothing, gloves and footwear, while they can choose to use protective clothing against rain/heat/cold, safety helmets, ear and eye protection.

Municipal SWM operation	RPE	Protective clothing with high visibility features				Gloves	Safety helmets	Footwear	Ear protection	Eye protection
		cuts and punctures	rain	heat	cold					
Collection	o	X	X		o	X		X		o
Transport	o	o	X		o	o		X	o	o
Recovery (sorting)	X	X		o	o	X		X	o	o
Disposal	X	X	o	o	o	X	o	X	o	o
Monitoring	o	o	o	o	o	X	o	X	o	o

Table 3. Comparison between municipal SWM operation and PPE required (X) or suggested/depending on conditions (o) for workers.

The introduction of smart PPE and their role in solid urban waste management

Some EU programmes underline that Industry 4.0 devices can be used to improve health and safety protection for workers and population [11] The main objective of Industry 4.0 applied to waste management can be summarized as the introduction of intelligent systems during the execution of operations carried out to manage properly waste. Other objectives are the collection of operational data, the development of highly adaptable and modular systems, the integration of sustainable and advanced management technologies as well as the promotion of automation technology and human-machine interaction. The interest in innovations in waste management is highlighted for example by the Horizon 2020 "GrowSmarter" project in which there is a section entitled "Smart Waste Management" developed by ENVAC in Stockholm [12].

The use of smart PPE is one of the most interesting way to increase PPE's performances, and, secondarily, to improve workers productivity and reduce costs. Sensors and connectivity are more often adopted to yield greater value, not only through data, but also by providing better safety and long-term cost savings through active prevention of accidents. These products measure and react, but ultimately, prevent the individual from health issues and tragic situations. Nowadays, factories are designing smart PPE to improve worker health and safety without increasing significantly their production costs.

Smart PPE can be defined as "*Intelligent personal protective equipment, which integrate materials (e.g. technical textiles and smart materials), components and ICT solutions enhancing product multi-functionality*". In other words, smart PPE are designed using industry 4.0 technologies such as: sensors for body functions and environmental monitoring (temperature, humidity); wireless communication devices and systems; devices for personal localization (GPS) and geographic information system (GIS); cooling and heating elements; active PPE acting as an emergency stop or reducing the hazard; smart textiles; wireless tracking and identification of devices; physical security information management; augmented reality.

In this section, the functions of Smart PPE are related to the hierarchy of controls. The following functions in smart protection are linked to the engineering controls: sensing hazards, monitoring health state, activating engineering controls. Administrative controls in smart protection devices are related to real time safety warnings and instructions. PPE must guarantee essential protective functions and could be improved with advanced functions.

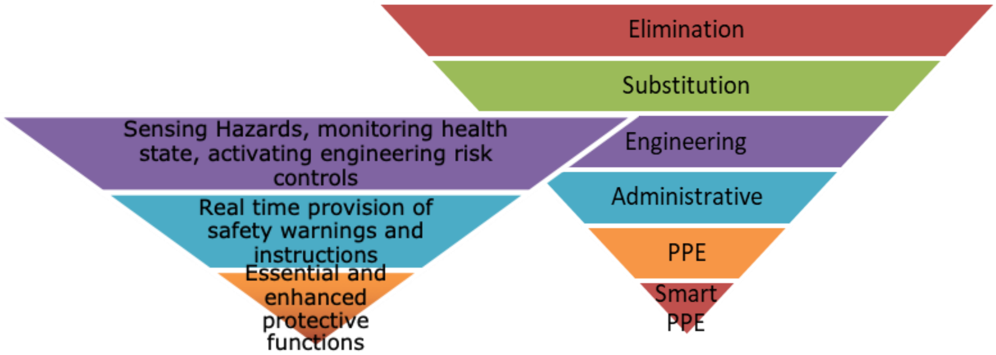

Figure 2: Functions of smart PPE related to the hierarchy of risk controls

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The IoT gives limitless opportunities to increase workers' protection: they are different for every industrial process and each risk. Here there are some of the most common applications of IoT sensors in PPE:

- Locating system to find workers in case of emergency everywhere (in smart factories it is becoming popular);
- Smart communication systems in helmets, ear muffs and face masks to provide fast and effective communication in loud or low-visual environments;
- Smart lockout/tag-out, backing cameras and warning devices, smart automation on machines and other automated safety measures to keep workers safer;
- Smart protective clothing with gas, chemical, heat, sound, UV, ionizing radiation, impact and pulse sensors to monitor both the external environment and the user, to alert workers and/or their supervisors in time if they are in hazardous situations (Environmental protection from invisible risks);
- Smart, connected safety containers where hazardous materials are monitored via sensors, sending regular notifications on status and alerting the control room directly (to improve efficiency through remote management);
- Smart sensors and wearables connected to apps which send crucial alerts to notify when PPE are out of date, alert workers when they misuse a piece of PPE or use the wrong equipment, give warnings about weather and emergency situations at a facility (phone-based app alerts);
- Augmented reality protective equipment: for example, safety glasses with augmented reality give more information than standard ones about work procedures, invisible risks and allow direct communication with an expert (as well as safety helmets with augmented reality);
- Virtual reality: VR helmets or glasses allow a zero-risks training or simulating risky situations.

The present work highlights the advantages and disadvantages in the use of smart PPE in the SWM to allow the correct choice of PPE for each operation [13].
The advantages linked to the introduction of smart PPE are:

- health monitoring. Through the application of sensors on the worker, some vital parameters are controlled in real time. This opportunity is particularly useful in contexts where workers are alone, isolated or in confined spaces;
- real time environmental monitoring. Through sensors, applied on the worker or in the workplace, some of the main environmental parameters are evaluated in real time: percentage of oxygen in the air, presence of toxic or dangerous volatile contaminants, presence of explosive atmospheres etc. If a dangerous situation related to external environment is detected, the worker will be asked to leave the place or activate protective measures;
- wireless communication Device to Device (D2D). Bluetooth, Wi-Fi or RFid based communication technologies allow smart PPE to "talk" to each other to exchange information detected by on-board sensors. Thanks to this technology, workers can also get in touch with each other;
- wireless communication Device to Other (D2X). Smart DPI can prevent workers from accidents by sending remote commands to systems and machinery for emergency stop if they detect the worker's tiredness or inattention. For example, a forklift could turn off if the worker nearby could be run over by it.
- checking correct use of PPE. Sensors installed on PPE allow verifying whether the piece of PPE is worn and it is worn correctly. For example, there are gloves with motion sensors that let you know whether they are worn during each work phase. Furthermore, by connecting the PPE sensors with the environmental sensors, you can check if PPE are adequate for risks highlighted in that workplace;

- real time positioning in case of emergency. Especially when the workers are alone or in emergency situations this function is very useful;
- authorized access based on GPS/wireless technology. Positioning, via GPS or wireless communication, of the worker can authorize the access or not to specific areas or control which and how many workers are present in a specific area for safety reasons. For example, a gate may remain closed if the worker is not authorized to enter in a specific workplace area;
- reacting to adverse climate conditions. Basing on data from climatic sensors, smart PPE (usually safety clothing) can change thermal conditions to ensure greater comfort to worker. For example, smart PPE can be heated to ensure better temperature and humidity conditions;
- active reaction to hazards. Some PPE can actively react to risks detected by sensors to protect the worker. For example, there are smart PPE that give a warning signal in case of proximity to a hazard;
- additional features linked to smart textiles. Some protective safety clothing exploit the innovative features of smart textile to provide additional features or higher levels of protection. For example, innovative textiles can react to environmental conditions by changing their colour to provide a visual warning of hazard;
- hazards forecast and warning to prevent accidents at work;
- additional information on working activities/workplace. The technologies associated with augmented reality can provide additional information on the risks, work activities and workplaces. For example, they give information about risks related to sources that the worker cannot perceive through senses, such as electromagnetic fields or ionizing radiations.

There are also disadvantages in using smart technologies such as:
- complex training and use of smart technologies. When workers get older, training and use of smart PPE could be problematic or longer because of their complex functions. In some cases, training could be difficult even for workers who have technical skills due to the presence of nano-technologies;
- respect of privacy rules. The respect of workers' privacy is considered a crucial point in smart PPE assessment. In fact, data provided by these objects may relate to the worker’s health, his/her physical and mental state and his/her position during the working time (when he/she uses them), which should be private information according to European Privacy Regulation;
- failures of complex technological devices. Smart PPE can be affected by failures because of their electronic components which allow complex systems with many functions;
- failures due to extreme environmental conditions. We must consider that PPE are generally used in workplaces with extreme conditions that can lead to malfunctions. These events are likely to occur more often if PPE are designed with electronic devices;
- uncertainty of environmental and health measures. All measurement systems are affected by precision errors. Even the sensors in smart PPE suffer from a certain measurement error, which is due to their small dimension;
- wireless communication depending on 3G/4G network. PPE with communication functions via GSM network depend on signal reception: therefore, smart PPE often work according to the quality of the 3G / 4G signal;
- production of electromagnetic fields. Any equipment that use radio signals produce electromagnetic fields that could interfere with the worker. That is true considering that PPE is generally in strict contact with the human body;
- reliability on wireless communication. The variability of wireless communications may be strongly affected by interference and distance. Therefore, the system is often required to foresee mechanisms to verify the correctness of the received signal to avoid false alarms;
- low resolution of positioning GPS based. The position of workers, based on the GPS signal, could have an error of even some meters. In fact, the accuracy of current satellite systems depends on the number of satellites received, whether the workplace is outdoor or indoor and on the orography of the land. Beyond that, it must be considered that the error could be voluntarily induced by the manager of the GPS system, (we must remember that GPS system was born for military aims). The new European "Galileo" system will allow much greater precision;
- high costs. The presence of electronic circuits, complex systems and additional features increase the costs of PPE. Over time, these costs are likely to reduce with the ever-increasing diffusion of microelectronic components and development of smart PPE, which are still at the level of prototypes.

Table 4. Comparison between advantages and disadvantages to use smart PPE in SWM

Advantages	Disadvantages

✓ Health monitoring;	⊗ Complex training and use;
✓ Real time environmental monitoring;	⊗ Respect of privacy rules;
✓ Wireless communication Device to Device (D2D);	⊗ Failures of complex technological devices;
✓ Wireless communication Device to Other (D2X);	⊗ Failures due to extreme environmental conditions (temperature, humidity, contaminants, etc.);
✓ Checking correct use of PPE;	⊗ Uncertainty of environmental and health measures;
✓ Real time positioning in case of emergency;	⊗ Wireless communication depending on 3G/4G network;
✓ Authorized access based on GPS/wireless technology;	⊗ Production of electromagnetic fields;
✓ Reacting to adverse climate conditions;	⊗ Reliability on wireless communication;
✓ Active reaction to hazards;	⊗ Low resolution of positioning GPS based;
✓ Additional features linked to smart textile;	⊗ High costs.
✓ Hazards forecast and warning;	
✓ Additional information on working activities/workplace.	

Moreover, advantages and disadvantages of using smart PPE can be assessed, arbitrarily, with reference to every working phase of SWM (e.g. during the collection of waste, the use of GPS would be very useful, but in extreme environmental conditions there could be failures).

The evaluation of pros and cons of using smart PPE in each work phase of solid waste management is summarized in table 3. It considers several features: type of operations carried out, workplaces' conditions (e.g. on the road, outdoor, indoor, landfill, ...), proximity to dangerous equipment or machinery, presence of other workers nearby, type of PPE used, kind and level of protection needed, etc.

Table 5. Comparison between advantages and disadvantages of using smart PPE in each phase of SWM (C = Collection, T = Transport, R = Recovery/Sorting, D = Disposal, M = Monitoring)

Advantages	C	T	R	D	M
Health monitoring;	X	X			
Real time environmental monitoring;			X	X	
Wireless communication Device to Device (D2D);	X		X	X	
Wireless communication Device to Other (D2X);	X	X	X	X	
Checking correct use of PPE;	X		X	X	
Real time positioning in case of emergency;	X	X			X
Authorized access based on GPS/wireless technology;	X	X			X
Reacting to adverse climate conditions;	X	X		X	
Active reaction to hazards;	X		X	X	
Additional features linked to smart textile;	X	X		X	
Hazards forecast and warning;	X	X	X	X	X
Additional information on working activities/workplace;			X	X	X

Disadvantages	C	T	R	D	M
Complex training and use;	X	X	X	X	X
Respect of privacy rules;	X	X			X
Failures of complex technological devices;	X	X	X	X	X
Failures due to extreme environmental conditions (temperature, humidity, contaminants, etc.);	X	X			
Uncertainty of environmental and health measures;	X	X			X
Wireless communication depending on 3G/4G network;	X	X			X
Production of electromagnetic fields;			X	X	X
Reliability on wireless communication;	X	X			X
Low resolution of positioning GPS based;					X
High costs.	X	X	X	X	X

Current smart PPE in solid waste management

The most popular smart systems are based on the communication between PPE and smartphones or special receivers, using Bluetooth or RFID TAGs applied to PPE. The activities performed by this type of smart PPE are to: check the foreseen PPE and, when necessary, inhibit the beginning of the work; alarm in case of the PPE's non-detection; send real time alarms through an emergency button for the operator (indicating the GPS position and sometimes health conditions). A further system uses Radio Frequency IDentification (RFID) sensors to authorize access in hazardous areas, verify and certify the correct use of PPE and to define restricted areas.

Some systems perform Area control and Face recognition operations to control access / transit in specific areas and to verify the identity and authorization of workers, also connected with smart PPE.

Finally, an innovative system provides to anticipate possible accidents or near misses by using Physical Security Information Management (PSIM). SW platforms are able to receive and manage data coming from smart PPE and collective protection systems and to analyze them to avoid the occurrence of potentially hazardous situations (Situation Awareness).

Inail's project

Industry 4.0 should be an equal opportunity for innovation; however, it often creates differences among companies for resources and experience. In fact, adopting smart PPE is complicated, expensive and needs of IoT and IT experience. Small companies may have difficulty to find the many resources and teams necessary to manage and use a smart product.

For this reason, Inail is developing a new piece of smart PPE with few and relatively cheap components. The project concerns the use of a specific software and hardware in order to transform any standard PPE to "smart PPE". Unfortunately, the system is still under patenting, so the authors cannot provide the reader with all the details of the project. The project includes a small control unit connected to a series of sensors via physical or wireless connections. Sensors can detect different environmental parameters of the workplace, which are linked to some risks. Thanks to other devices, data obtained from the environmental sensors can be related to the parameters of the worker's health. Moreover, some accessories can be added to allow the system "reacting" to the risk. The reaction is stated on the information obtained and the "risk assessment", made by the control unit. Additional objects can be installed to prevent or protect the worker from possible hazards. Mainly, the system is able to produce acoustic and visual warnings, to send information to an emergency control room, to perform some simple actions such as heating or cooling a part of the PPE or to provide tactile feedback.

In the future, the system will merge different sensors and technologies to create a strong ecosystem providing a full suite of solutions to prevent workers from many risks. At the end of the project activities, both the software and the hardware will be available free of charge.

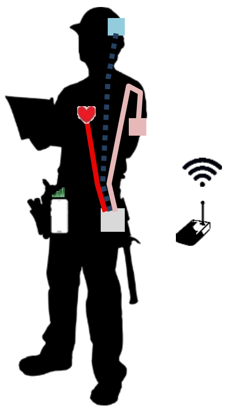

Figure 3: scheme of the Smart PPE that INAIL is developing

Conclusions

Each phase of waste management shows higher risks for workers than many other activities [14, 15], because of the contemporary presence of chemical/biological agents and dangerous environmental conditions due to the vehicles' circulation, traffic, etc. For this reason, the use of PPE is essential to prevent workers from injuries and professional diseases. Industry 4.0 applications and IoT allow employers and workers improving operational efficiency, optimizing productivity and, last but not least, increasing workers' safety [16]. These new technologies are spreading very quickly and their use in PPE is one of the most recent, with interesting applications.

INAIL is involved in studying the use of smart PPE in solid waste management, in compliance with European regulations: that is a great challenge for Italian researchers, because it is not easy to guarantee a better worker protection and, at the same time, the respect of other national laws about privacy, environmental issues etc. There is no doubt that employing new "smart" features in safety management allows an "active reaction" of PPE to hazards, which can result in giving additional information on many parameters (health, environment, activity performed, etc.) or monitoring the workers' health conditions.

Definitely, the interest in promoting the use of smart PPE in waste management is great because the last experimental activities show that they can make more sustainable waste management in terms of health and safety at work. IoT is changing how we think about PPE, as like as the introduction of Anti Block System (ABS) led us to new standards about driving safety. Smart technologies applied to occupational safety are our next future in the workplaces.

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