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Port Workers' Safety Monitoring by RFID Technology: A Review of Some Solutions

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ABSTRACT

The paper reviews a number of working safety scenarios in harsh environments based on RFID (radio frequency identification) technology. Some of them are used at seaports, some in construction, and some in oil and gas industry. The advantages and disadvantages of these systems are analyzed in the context of their possible implementation in a developing seaport which operates in the transitional economy, i.e., in the Port of Bar (Montenegro). It is also given a proposal of on port workers safety model based on RFID technology, which should at a satisfying level meet the individual needs of the Port of Bar, and which is at the same time cost-effective, reliable, and scalable. Some directions for the future research work in this field are given, too.

1. Introduction

Work at seaports takes place through the day and night (24/7) in all types of weather conditions (HSE, 2011). It usually involves a number of different employers and/or contractors carrying out different activities: harbor authorities, stevedoring firms, haulers, ship's masters, and crews. This requires sound co-operation, co-ordination and communication between all involved parties. Besides, there are usually pressures to load or unload a ship's cargo quickly to catch a tide or to free up a wharf for another ship; or, visiting drivers want to pick up or drop off their cargo as quickly as possible and get back on the road.

Therefore, seaports are dangerous places for on port workers in terms of operational risks connected to (un)loading operations, managing on port traffic and transportation, handling manipulative equipment, warehousing, etc (Roberts and Gray, 2013). In parallel, seaports tend to be associated with emerging environmental problems (Darbra and Casal, 2004): water and air pollution, soil contamination, problems related to dust and noise, generation of waste, dredging operations, warehouse storage of hazardous substances, etc. All these make work at seaport challenging, but also potentially high-risk one.

Under the regulations, employers in seaports, people in control of premises, the self-employed and employees must ensure the health and safety of others and themselves. However, employers have duties concerning the provision and use of PPE (personal protective equipment) to their employees who may be exposed to risks to their health or safety at work (HCE, 1974). PPE can include items such as safety helmets, gloves, eye protection, high-visibility clothing, safety footwear, safety harnesses etc. In the paper, PPE of on port workers will be limited to so-called 3 Point PPE one: helmet, safety vest, and protective shoes.

The PPE equipped with passive or active RFID devices can help identifying each garment and examining its functionality. By the corresponding alarm system workers on port can be alerted, when they are in range of a reader, if some PPE garment is missing, or if some of RFID tags embedded/attached to the PPE don't function properly, that usually means that related PPE piece(s) is(are) damaged. In such cases workers are required to go to the central to wear or change the clothes (Musu,

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2015). Also, in the case of emergency, workers can be alerted to come to the appointment zone, which is well covered with the so-called anchor readers, where workers can be automatically identified, located, and the inspection of using and correctness of their PPE garments can be carried out.

It is worth to mention here that the idea to use RFID for controlling PPE items is registered as a patent in the USA in 2002 (Kimberly-Clark Inc., 2002). Since RFID technology has been more and more adapted in many sectors and identified as one of the ten greatest contributory technologies of the 21st century (Sun et al., 2013), there are a lot of literature recourses which concern it. We shall refer to a few of them (Ngai et al., 2008; Ferrer et al., 2010; Yang et al., 2011; Blecker and Huanng, 2008; Frinkenzeller, 2006; Garfinkel and Rosenberg, 2006), in order to avoid repeating some well-known facts about this emerging technology. Instead, we shall give an overview of existing RFID solutions for locating and tracking workers and monitoring their PPE at harsh environments, e.g., at seaports, construction sites, oil and gas industry. This overview is done with the aim to give an insight to the managers of the developing Port of Bar (Montenegro) into available safety solutions of such kind, and to encourage them to provide correct justification to the senior management and stakeholders to secure buy-in and implementation of the same or similar safety measures.

2. Scenario 1: Oil and gas industry

A cost effective RFID technology solution for locating and tracking personnel in case of emergency situations was deployed at oil and gas rigs in North Sea in the beginning of 2000s. This system is defined as an offshore emergency preparedness system, rather than personnel surveillance one. Its two key components are RFID interrogators (readers) and transponders (tags). In the event of an emergency, the system should be able to determine the current and past locations, and the identities of all personnel wearing an active RFID tag for the purpose of tracking. Of course, in addition to this emergency safety system, using PPE on oil and gas rigs is obligatory. Extended version of the personnel tracking system may also include employment of the environmental sensors, e.g., temperature, humidity, gas detection, etc.

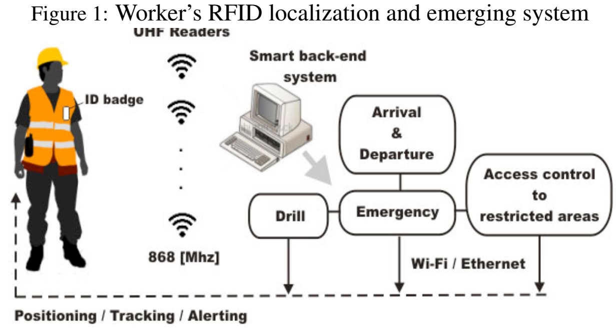
Platforms operating in an offshore environment typically employ hundreds of people. Some of them are connected via bridges which create a center that can hold up to 1000 persons. Each person on the rig has an ID badge (active RFID tag) which can be worn around the neck, attached to the clothing or placed in the pocket. The badge has a battery powered UHF (ultra high frequency) tag (868 [MHz] - EU standard) that transmits ID number at preset intervals. The tags can be read up to 500 [m] away. Back-end software stores data on each worker's name, shift, job, education, etc., which are contained into the unique ID number on the badge. When a reader captures a tag's ID number, it forwards that information via a wire(less) connection to a computer, which could then pass on that data, either to the company's back-end server or to a server on-site, as well as, off-site one via a Wi-Fi or Internet connection (Swedberg, 2011).

If there are several readers on the platform, the system can determine each employee's location, while the accuracy of position being determined depends on the number of readers used. The system typically tracks which zone an employee is in, rather than the person's specific location. The system also provides an alerting function, in the case that certain personnel are not allowed to enter specific zone. Basic scheme of this UHF RFID safety scenario is given in Figure 1.

The system can be used in normal, emergency, and drill conditions. During normal conditions, it allocates a tag to a person, while the person is picked from the POB (personnel on board) application; it is regularly tested to verify that system and POB application are synchronized; it de allocates personnel from the tag, etc. During an emergency/drill situation, the demand from the authorities is to ensure full control over the personnel within about 25 minutes after an emergency/drill situation has occurred. The system shall be in that case use to automatic muster personnel at muster stations or in muster zones (e.g., lifeboats, bridges, indoor and outdoor muster places, and emergency personnel meeting spots), manual muster of personnel, etc. Some more detail on these procedures and following measures can be found in (NOaGA, 2010).

This RFID locating, tracking, and alerting system in normal and emergency/drill occasions has been presented here on the basis of secondary literature resources, since it is a cost-effective and efficient for employing in harsh industry environment. It might be, in the same or similar form, adapted to the Port of Bar. However, the following two RFID safety solutions, that will be presented, can be used, as well, like models for improving health, safety and environment management in the considered developing seaport.

Figure 1: Worker's RFID localization and emerging system



Source: Adapted from (Swedberg, 2011; NOaGA, 2010)

3. Scenario 2: Construction industry

Access control is one of the main objectives of the personnel logistics at construction sites (Helmus et al., 2011). On large construction sites, there are usually a lot of workers and visitors accessing them. Unauthorized entry should be denied for safety reasons, theft, and illegal working protection. To ensure this, some construction companies (e.g., ThyssenKrupp, Essen, Germany) install smart entrance gates or containers at the construction sites (Kelma et al., 2013).

The entering person is prompted to log into the system by holding the site ID card near the RFID card terminal and perform an authentication by placing his/her finger on a fingerprint reader. At the same time, his/her profile is controlled by comparing the required PPE (helmet, safety vest and shoes) in profile and the actually identified PPE using RFID reader. By a positive controlling of the ID, the fingerprint, and the PPE pieces, the hub is released and the access to the site is allowed. The time of entering the site can be automatically registered. The process of leaving the site works similarly, but usually without PPE control (Figures 2).

At the container terminal of the Port of Bar recently has been implemented an RFID system for identifying workers at the entrance/exit of the terminal, and for determining the length of their working time, i.e., CHRONO ID system (CIKOM, 2015a). The back-end software is capable to calculate the workers' earnings automatically, as well. This system could be upgraded by the system for scanning PPE garments at the entrance, and allowed or prohibited the access accordingly.

4. Scenario 3: Seaport environment

A smart workplace safety solution employed in the Port of Cagliari (Italy) is presented here in brief. Each on port worker has wearable sensor network composed of RFID tags/sensors embedded into PPE.

Figure 2: Entrance turnstile with a card, fingerprint and PPE reader at the working site

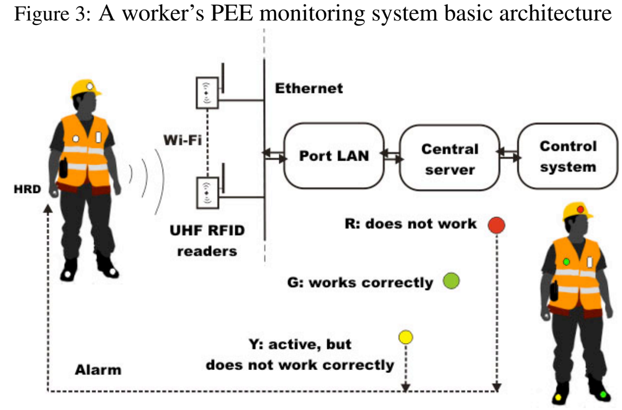
Source: Taken/adopted from (Helmus et al., 2011; Kelma et al., 2013)

The safety helmet is provided with a WISP (wireless identification and sensing platform) chip which combines RFID and sensor technology (Musu et al., 2014). Sensors can be temperature or light ones, or an accelerometer by which upright/proper position of the worker's helmet can be inspected. The WISP chip can communicate directly to an UHF RFID reader located at the strategic points at the port perimeter (gates, bus stops, etc). Workers' safety jacket and shoes are equipped with passive RFID tags which also directly communicate with fixed readers within the range of about 10-14 [m].

The UHF RFID readers work at 868 [MHz] and they are connected via fiber Ethernet to the back-end smart software system. This system includes CCTV (closed circuit television) as vision-based technology and it is used by the supervisors. The system is also connected with the Port of Cagliari Web GIS (geographic information system) and anchor readers for calculation of each worker's position by the location-based measurements via triangulation (Cheng et al., 2011). The pinpoint position of the worker is signed by the marker and presented on the screen in the central control room. Each worker's marker is associated with the signals of the sensors embedded into the PPE. The control system gets the information about the status of each sensor and passive RFID tag attached to the PPE, i.e., if they: work correctly (green), don't work correctly (yellow), or don't work at all (red). In Figure 3 is shown an example of the worker who does not have helmet on site, and whose shoe is damaged. In such situation worker has to be alerted via HRD (handheld radio device) by audio or flashing signal, or text message to go to the central for wearing/changing the PPE peaces.

This scenario of worker's on port PPE monitoring is adapted to the IoT (internet of things) concept. Besides ID, RF (radio frequency) functionality and gauged data (e.g., temperature, light, plantar pressure, worker's pose, and/or helmet position), each RFID tag/sensor embedded into worker's protective clothe has specific IP address which allows its RTL (real time locating) and other M2M (machine to machine) or P2M (person to machine) activities. It's important to mention that M2M and P2M include intelligent sensors and microprocessors embedded in the assets/devices (PPE garments), and a wireless communications modules that transmit and receive data to and from information management system, here smart centralized workers' safety monitoring system (Musu, 2015; Mobius Consulting, 2016).

Figure 3: A worker's PEE monitoring system basic architecture



Source: Adapted from (Musu, 2015; Musu et al., 2014)

5. Comparative analysis of the scenarios 1-3

In Table 1 are given some of the key features of the previously presented RFID based workers' safety monitoring, controlling, and warning systems in oil and gas industry, construction sites, and at the seaport environment. The first system (S1) being used in the oil and gas industry allows tracking workers along the rig zones (including arrivals and departures), and in emergency/drill situations. The system of visual and audio alarms is also available. It provides good coverage and communication to the off- and on-shore back-end ICT systems. The second presented system (S2) is employed at the construction sites and it provides workers identification double check by ID cards and fingerprints scanners at the entrance/exit, as well as PPE garments visual inspection by RFID smart readers at the entrance. The system is connected with the intelligent software which allows or prohibits turnstile activation. It also provides a visual alarm system. The third system (S3) is implemented in the Port of Cagliari and it is the most sophisticated. It includes real time tracking and monitoring on port workers and their PPE pieces presence, functionality, and proper using (e.g., helmet's position by means of an accelerometer). The system provides audio and text message alarms and interoperability at the IoT level. Some basic technical specifications of these systems are given below (Table 1). It is obvious that all considered systems use RFID technology, while the third one uses the supporting advanced systems like WISP, CCTV, Web GIS, IoT, etc.

In the next section, some objective requirements of the Port of Bar in terms of improving environmental management system and workers' safety, as its key segment are pointed. Also the previously presented safety scenarios are assessed in terms: how well they fit into the Port of Bar individual needs and its capabilities for adopting a new safety solution. In the first line, we have to bear in mind financial and human capacity barriers, since the port, as a transitional one, suffers during the years, from the rigid administrative structures and lack of investments.

Table 1: Combinations between number of Mama Vessels and number of barges

Features/Systems		S1	S2	S3
F1	Tracking workers in real time	/	/	x
F2	Registering workers at the entrance gate/periodically	x	x	/
F3	Tracking/ checking IDs and status of PPE in real time	/	/	x
F4	Checking IDs and status of PPE at the entrance gate/periodically on site	/	x	/
F5	Alarm system availability	x	x	x
F6	Access control to restrictive zones	x	/	/
F7	Emergency/drill control	x	/	/
F8	IoT concept deployment	/	/	x
Basic technical specifications		UHF RFID 868 [MHz]; active ID badge; passive PPE tags; supported by smart back-end software system.	UHF RFID 868 [MHz], or MW RFID 2.4 [GHz]; smart turnstile-site entrance gate (ID card, finger print, and PEE check).	UHF RFID 868 [MHz]; WISP chipped helmet; passive PPE tags; system is supported by WISP, CCTV; Web GIS; and IoT.

Source: Authors

6. Satisfying solution for the Port of Bar

With favorable geographical position, the railway line Belgrade-Bar, and the road network in its hinterland, along with the intermodal transportation and traffic links with Italian ports Bari and Taranto, the Port of Bar could provide good connections within the wide gravitational area.

It might be developed into the distribution center for the whole region. More about the Port of Bar can be found on its official web site and in the documentation of numerous regional and EU projects in which realization it has been involved (Bauk, 2015; Ten Ecoport, 2014; Ecoport 8, 2013).

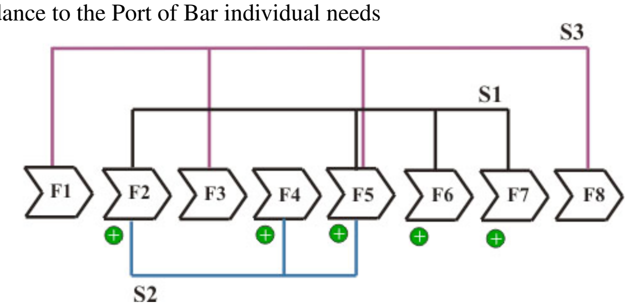
The projects Ten Ecoport and Ecoport 8 are of particular importance in the context of enhancing workers' on port safety and health conditions. During the realization of these projects and in the final reports, some recommendations for further actions towards improving occupational safety are provided. The most harmful environmental and workers' health and safety impacts are identified, as well. The working processes in the Port are analyzed in detail and the points with the highest level of risk to the workers employed directly on port are specified. For the purposes of the project Ten Ecoport realization, several in depth interviews with the managers in the Port of Bar are conducted (Bauk, 2014), and the highlights in terms of the most common risks are identified. These risks are: working outdoors at various (unfavorable) weather conditions (extremely high or low temperatures, rain, wind, etc.); exposure to the dust during the transshipment of bulk cargos (grains, all types of ores and concentrates, alumina, etc.); maneuvering with obsolete transshipment equipment and transportation devices; manipulating with damaged cargo (bags, pallets, packages, containers, etc.); exposure to the risk of fire (especially during the summer months), etc. In addition, workers on port are realizing mostly monotonous and repetitive operations what results in fatigue which increases the risk of accidents.

Nevertheless the range of negative working and environmental impacts in the Port of Bar is quite large, prospective employing PPE equipped with RFID tags, inspired by the previously presented solutions will strengthen the port workers' safety and increase the level of their corporate safety culture.

In that direction we made here a qualitative assessment of the features of the previously presented scenarios (see Table 1). In Figure 4 is given a scheme of the methodological approach in identifying features which are cost-effective, reliable, flexible, scalable, and at the same time affordable from the perspective of the Port of Bar.

According to the qualitative assessment, presented in Figure 4, it is obvious that the previously described workers' safety scenario S1 is the most suitable to be implemented in the Port of Bar. It implies providing the following features: F2 - registering workers at the entrance gate, or periodically; F5 - alarm system availability; F6 - access control to restrictive zones; and F7 - emergency, or drill control. Also, feature F4 - checking IDs and status of PPE at the entrance gate, or periodically on site (or, on port), which belongs to the previously presented scenario S2 is desirable in terms to be implemented in the Port of Bar. Feature F5 - alarm system availability, is common for all proposed scenarios, and within this analysis, it is the only one from the scenario S3 features set that can be objectively, at the present moment, adapted to the analyzed seaport.

Figure 4: Assessing features of the scenarios: S1, S2, and S3 in accordance to the Port of Bar individual needs



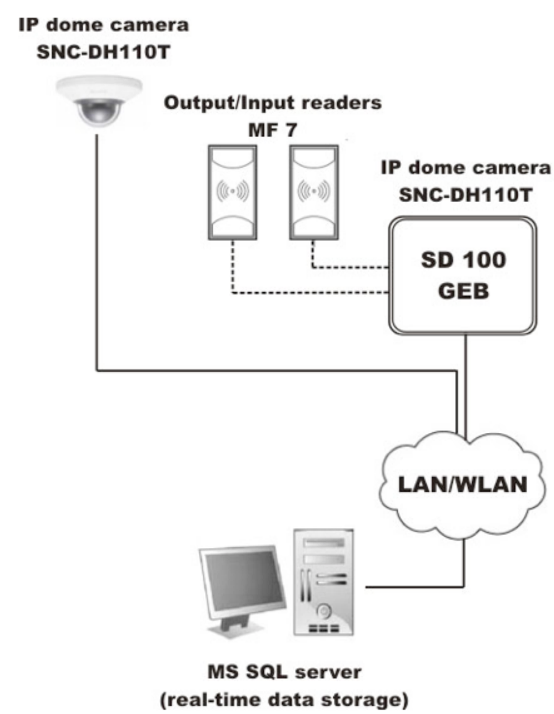
Source: Authors

Certainly, the final decision according to conceiving, developing and employing workers' safety model is to be done by the Port of Bar managers. They should once again, from their stand point, assess the reviewed solutions including the consultations with stakeholders and ICT experts who will be in charge of deploying an optimal satisfying solution.

At this point it is important to emphasize once again that at the container terminal and general cargo Department of the Port of Bar has been recently implemented CHRONO ID solution (CIKOM, 2015a; 2015b; 2015c). This is a system for access control and determining working time duration. It provides recording entrances and exits of employees, visitors, and vehicles in fixed, flexible, and multi-shift working schedules. Application software CHRONO ID works in Windows (MS Windows NT, XP, 2000, Server) and it uses centralized related data base (SQL Server). The central part of the system is responsible for workers' access control and measuring working time. It uses software applications for access control (Guard ID) and for recording working time (Web Chrono). These applications are supported by MS SQL database and real-time data about working time start/end, and workers' entries/exits. The system is scalable in terms of both employees number and access points and it operates within the port's LAN/WLAN infrastructure.

The access control device SD100 GEB is based on MIFARE (MF7) RFID output/input readers (Figure 5) that are installed close to the entry/exit in the server room in the administration building. If the worker approved his/her passing by inserting ID card in the field of reader, the SD100 GEB device sends a command to the electromagnetic lock to open the door. If the worker is not granted the right of access, the device holds the electromagnetic lock in the locked state. At the moment of worker's entry in the server room, the video sub-system for entrance verification (IP dome camera, SNC-DH110T) takes the worker's photo record and passes it to the server. On the basis of this photo record which is permanently linked to each passage, it is possible to check the entrances later by Guard ID software application. The SD100 GEB devices are powered by own batteries, which allow them autonomy to work a minimum four hours in the case of power supply failure.

Figure 5: CHRONO ID basic scheme



Source: Adapted from (CIKOM, 2015c)

Surely, it would be significant to consider the possibilities of upgrading this CHRONO ID system with the on port workers smart PPE (PPE equipped by RFID passive/active tags/chips) facilities. In this regard, it is of particular importance to inform managers of the Port of Bar and similar developing ports in the South-East Europe Region about the existing solutions in this field which will strengthen them to improve environmental management system in general, and particularly in the domain of on port workers' occupational safety.

7. Conclusions

The paper emphasizes the importance of securing measures of workers' safety in the seaports. Three scenarios, already applied with the aim of increasing workplace safety in harsh conditions (oil and gas rigs, construction sites, and seaport) are described. They can be used as certain benchmarks to the seaport managers in the developing environments. The Port of Bar is taken as an example of developing seaport which functions in transitional economy and which indeed needs conceiving and implementing new measures for improving workers' safety, and environmental safety measures.

Throughout the qualitative analysis of the three presented working safety solutions in invasive environments, some recommendations for planning and implementing a low-cost and in the same time reliable and scalable system are given. Namely, a safety system tailored to the individual needs of the Port of Bar should include at least the following possibilities: registering workers at the entrance/exit gate; alarm system availability; access control to restrictive zones; emergency/drill control; checking IDs and status of PPE at the entrance gate and/or periodically on site.

The future research work in the field should be oriented toward assessing managers and workers willingness to adopt such system, and readiness for providing funds and engaging ICT professionals for implementing the proposed scenario. Then, the preliminary safety model should be redesigned due to the expectations and needs of the port's personnel.

The possibilities of the system upgrading by providing real time monitoring of the workers and their PPE garments equipped with RFID tags and sensors have to be examined. Besides, deploying hierarchical networked RFID systems (Zhang, 2013), RTL (real time locating), and Web GIS are to be considered in the future within the wider context of IoT (Vermesan and Friess, 2014; Pramudianto, 2015). Providing scalability of the proposed scenario along with its semantic interoperability at the level of smart ports is to be taken into the consideration in the forthcoming research work. In addition, at the more profound level, performances of the proposed conceptual safety network solution are to be examined in the simulation environment (e.g., OPNET or OMNeT++) over the layout of the Port of Bar. This is necessary for establishing an optimal configuration of the network formed of the set of moving workers' wearable RFID tags/sensor sub-networks and fixed RFID readers located at the strategic points at the port perimeter. Different types of network protocols should be examined, like: UHF RFID, combination of HF RFID and ZigBee, Wi-Fi, White-Fi, etc. These simulation experiments should include primarily some physical and link layers analysis at the level of the channel between the transceivers over the analyzed seaport operational area including the obstacles and other noise and interfering factors commonly present at the highly dynamic and rough industrial and commercial seaport environment.

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