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Results of the implementation of a virtual control approach to improve the effectiveness and quality of Safety and Health inspections at workplaces

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ABSTRACT. During the last years, a significant technological and organisational evolution is taking place in the industrial activities, thanks to Advanced Manufacturing together with a more and more widespread use of Cloud Big Data Analytics. With special reference to the OS&H (Occupational Safety and Health), these changes involve a new attention, both to the technological and employee's level. The paper discusses the characteristics, and the possible original use of a new methodology, based on virtual reality and digital checklist. This methodology can be used both to easily carry out surveillance activities and checks at workplaces, and to create a virtual itinerary of the area under investigation, in which checks and operative instructions can be virtually introduced for workers in charge of particular machinery or operations. The main results obtained thanks to the implementation of the methodology are: a reduction of the remedial actions' duration on non-compliances brought into evidence, and the deriving possible increase in the frequency and efficiency of inspections. Moreover, this approach intrinsically favors the involvement of workers and staff in charge of activities related to Prevention and Protection, supporting a process of continuous improvement and of general spread of the Culture of Safety in the Company.

Key words: *Occupational Health and Safety, Safety inspections, virtual Safety control.*

RIASSUNTO. Risultati dell'implementazione di un approccio di controllo virtuale per migliorare l'efficacia e la qualità delle ispezioni in materia di sicurezza e salute sui luoghi di lavoro. Negli ultimi anni si è assistito in ambito industriale ad una sostanziale evoluzione tecnologica e organizzativa, resa possibile dalle Advanced Manufacturing associate ad un impiego sempre più pervasivo di Cloud Big Data Analytics. Nell'ambito della Sicurezza e Salute del lavoro questi cambiamenti rendono essenziale una nuova attenzione, sia dal punto di vista tecnologico sia per quanto concerne il personale. Pertanto, in questo articolo, sono discusse le caratteristiche e le possibilità di impiego di una applicazione di una nuova metodologia, basata sulla realtà virtuale e su una checklist digitale, utilizzabile per effettuare in modo semplice le attività di sorveglianza e verifica nei luoghi di lavoro, consentendo di creare un percorso virtuale nell'area in esame, nel quale sono inseriti in maniera visuale gli accertamenti da eseguire e le istruzioni operative per addetti a particolari attrezzature od operazioni. I principali risultati ottenuti grazie all'applicazione sul campo della metodologia sono: riduzione del tempo di intervento su una non conformità e conseguente aumento della frequenza dei controlli e della loro efficacia. L'approccio favorisce

1. Introduction

Starting from the beginning of the '80s, the scientific cooperation of experts of Polytechnic and University of Turin focused on the new approach to Safety and Health some years later officially adopted in the Economic and Social EEC Directives (1,2). The main result was a shared and well tested Risk Assessment and Management methodology, a valuable reference to comply effectively with the requirements of the new safety regulations, leaving aside the obsolete prescriptive approach of proven poor efficiency (3).

As summarized in Borchiellini et al., 2018 (4), the implementation of the methodology made it possible to draw up Guidelines internationally and nationally officially approved, initially specific for mining activities (5-7). The Guidelines have been gradually extended to a number of NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) sectors characterized by particular criticalities (e.g. construction (8-10), important public structures (11-12), etc.), and systematically updated in coherence with the research activities of the Occupational Health group (13-14).

In coherence with the original approach, which made possible the development of the methodology, the multidisciplinary research group, which includes the authors and other professionals, currently operating at the headquarters of Occupational Health, Turin University, focused on the following goals:

- Setting, in close cultural synergy, of theoretic applicative research and of methodological in-depth analysis on Occupational Health and Safety. Some recent results are discussed in (15-26);
- Dissemination of the Culture of Safety, that can play a key role in the reduction of risks of workers. Indeed, this is an essential goal that still now needs substantial development, based upon in-depth analysis of its multiple aspects (27-29). Educational processes should be specially tailored for different groups of people identified on the basis of some common characteristics, this also includes the optimizing of the university education at various levels, from degree programs to masters and specific courses for PhDs (30-33), and renowned international Masters (e.g. the ITC ILO Master on

intrinsecamente anche la partecipazione di lavoratori e preposti alle attività legate a prevenzione e protezione, favorendo un processo di miglioramento continuo e di generale incremento nella disseminazione della cultura della sicurezza in azienda.

Parole chiave: Salute e Sicurezza nei luoghi di lavoro, ispezioni di Sicurezza, controllo virtuale della Sicurezza.

Occupational Safety and Health (34)), in addition to the collaborations for research and formation at public and private Institutions and Organizations (35).

This cultural synergy made the research group able to study new Industry 4.0 challenges and risks. Nowadays, the Industry 4.0 development is basically modifying the workplaces, in terms of reorganization of processes and activities (36). The progressive introduction of Enabling Technologies (37) in the productions systems and their management is taking on fundamental importance. Both processes and employees are becoming of systemic relevance, conditioning the possible enhancement in the efficiency of production and support systems in almost all the economic NACE sectors (38). The technological and organizational evolution, possible thanks to Advanced Manufacturing Solutions (39), is associated to a growing use of Cloud Big Data Analytics (40) and makes necessary to reshape the cultural approach of the workforce, supporting its adjustment to the new tasks. In addition, with the transformation in terms of 4.0, today it is possible to manage nets and interconnections of equipment to optimize processes, and to develop mutual process – product information exchanges. However, the more a system becomes articulated and complex, the more chances of deviation can increase. These chances are not simple to identify at the design phase and can result in scenarios for which processes of self-test and self-correction were not implemented. The well-known Swiss cheese model proposed by J.T. Reason (41-42) can be a useful benchmark also in this case. It is then clear how absolute is the necessity of adjustment within a rigorous System Safety approach of all the phases of work-related Hazard Identification, Risk Assessment and Risk Management (given the GAH-EEC recommendation (43)). The rapid improvements of techniques and technologies not always correspond to adequate developments of the Assessment and Management of OS&H risks: the current situation sometimes stays anchored to approaches that are no longer coherent with the needs of an evolving world (44-46), particularly with reference to: performances of completeness, efficiency and promptness (47); coherence to the modern vision of OS&H as a subpart within a quality system (48-49); and ability to make full use of the current technological resources and information management techniques, coherent to the expectations and capabilities of digital generations.

Moreover, the Employer's task is more demanding: the complexity of technologies, the systems three-dimensional extent, the behavior of physical and chemical pollutants in articulated systems make necessary both abilities to exhaustively identify and analyze these criticalities, and to define suitable control measures (50); planning and advanced technological options should be implemented in a scenario of exasperated contraction of the production times, which in terms of OS&H means being able to recognize and quickly prevent critical situations; OS&H management must involve experts in different fields, such as engineering, occupational health, metrology, computer science etc., and it is certainly now more necessary than ever to adopt the approach of cultural synergy recommended since mid-20th century by CECA (see Fiches thématiques sur l'Union européenne - Santé et sécurité au travail, (51)) (Figure 1).

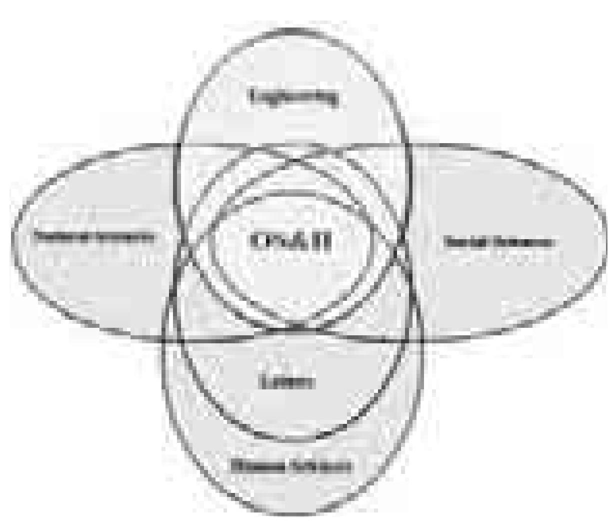

Figure 1. ***Multidisciplinary structure of Safety sciences (C.E.C.A. documentation). Translated from the original in French***

Therefore, an updated commitment to satisfy these needs is necessary and can contribute to the economic efficiency of a company. Such efficiency is achieved only by considering OS&H as *"a factor of a well working system"* (52).

The use of checklists –strictly derived from a preliminary dedicated and rigorous analysis- is often recommended, given their advantages in terms of efficiency and flexibility, coherently with the recommendations in the document of GAH_EEC. The user friendliness of the checklist technique makes possible to commit the infield activities to operators with a basic formation, leaving the decisional interventions to OS&H experts. Moreover, the approach makes also possible to enhance the frequency of review inspections, with both "technic" and psychological advantage, as discussed in Borchiellini et al., 2017. However, given the criticalities mentioned above, the huge amounts of data and information deriving from inspections are today difficult to manage using common paper checklists. In this respect, virtual reality (VR) can be useful to supply information in a more natural and effective way if combined with a digital checklist. VR is a mature technology, that add digital information to reality, already applied to a series of services within the factory. Moreover, VR is already a technological base for the development of digital environments, monitoring/control, and training (53). VR applications have been reported in literature also for virtual prototyping, web-based virtual machining, assembly, fault diagnosis, and various types of manufacturing operations (54). Thus, the aim of this paper is to illustrate the results of a new methodology, based on VR and digital checklist and coherent to the current technological evolutions and principles of management quality, tested in the field of OS&H management. This new methodology can constitute a modern and time / moneysaving approach, which allows effective autonomous guided assessments, the reduction of the persistence in time of non-conformities and the velocity of implementation of corrective actions.

2. Materials and Methods

2.1. Definition of the requirements

To design a successful methodology, the first step was the identification of the requirements, which was performed by setting up a focus group. The focus group included seven experts, from consulting firms and institutions, requested to talk about the requirements that an improved methodology should have to optimize the general and timely verification of safety conditions in the workplace. This technique refers to that used in the field of Quality to determine customer requirements for products (55).

The requirements identified by the focus group were:

- To reduce the amount of paper documents (by providing a computerized support);
- Small and light enough to carry around easily;
- Easiness of operation, even though small in size;
- Availability and storage of a wide range of implementing possibilities of schemes, pictures and videos, observation, and annotations directly on the ground;
- Possibility to online contact with the expert and rapidly receive indications and suggestions;
- Providing a tool of information and (interactive) formation for the employees;
- Capability to memorize the history of the results of routine checks and improvement interventions;
- Generation of reports of the verification operations and the interventions carried out;
- Flesibility in terms of updates.

2.2. Identification of the technology which fulfils the requirements

The second step was the identification of the technology that could fulfill the general requirements identified. It was chosen a technology already known to the focus group for

the identification of the controls to be performed by the operators during the different work phases and for Lean Manufacturing - 5S, in particular for the "Seiketsu - Systematize or standardize" phase (56). That technology was also used in formation and training (e.g. for training courses on specific risks in production activities and for training on the job through mobile devices) thanks to the possibility of creating courses with the insertion of multimedia content and learning tests.

The technology is composed by:

1. a web platform for the creation and storage of Virtual Tours[1], consisting of a set of multiple flat or panoramic photographs up to 360°, connected and navigable (Back-office) for navigation and interaction of the virtual tours themselves and for report management (Front-end). In particular, in each virtual tour "clickable" points called "hotspots" of various types can be inserted, including:
   - hotspot navigation to check the accessibility of each desired point during the tour;
   - information hotspots where it can be uploaded instructions or procedures in video and audio;
   - "pdf" hotspots to attach documents that can be consulted during the tours;
   - "link" hotspots for entering internet addresses, etc.;
   - interaction hotspot, to make it possible to introduce answers and comments, upload video and audio photos as well as choose answers proposed from the drop-down menu.
2. an app for iOS and Android systems, for browsing and interacting with virtual tours on mobile devices, both online and offline (with download of virtual tours on the device: this is particularly useful both in areas where there is no data or wireless network coverage). It can also generate reports and performs statistical analyzes on the data collected.
   There are two access levels:
   - User level: used by those who perform virtual tours in situ.
   - Super-user level: used by subjects who, in addition to being able to perform virtual tours, are enabled to view the reports and act at a decision level.

Table I illustrates how the technology can operate.

2.3. On-field implementation

The third step was the implementation of the methodology to the management of Occupational Safety and Health. The platform and app were adapted for equipment maintenance checks, for verification safety devices and equipment, and fire prevention and protection devices, with the possibility of generating replacement reports of the register (as required by the Italian official regulations (57-59)).

Using the platform and app of the technology selected, it was possible to organize a checklist management technique. This technique was implemented in 21 companies (through voluntary participation) divided into the following sectors: one in the publishing sector, one in the rubber processing sector, two in the chemical and pharmaceutical sector, three in the construction sector, four in the food industry sector, six in the metalworking sector and four from the service sector (Figure 2). The technique was

[1] The process of creating a virtual tour is already consolidated in popular applications such as Google Street View.

Table I. ***How to access the platform/app based on user level***

Modality	Activity	Access
Back-office	- Virtual tours' creation and management; - Reporting system's creation and management; - Creation and management of personal settings.	- From PC / MAC (browser); - With authentication.
Front-end PRIVATE	- Archive of reserved virtual tours; - Navigation of reserved virtual tours and report generation; - Report view.	- From PC / MAC (browser) or mobile (browser or APP); - With authentication.
Front-end PUBLIC	Virtual tours freely available in which navigation hotspots, information, video / audio, and pdf can be inserted, but not interaction hotspots.	- From PC / MAC (browser) or mobile (browser or APP); - With no authentication.

set and improved alongside the surveys in the 21 companies, and organized starting from the development of a dedicated radar image on which the observation points (navigation hotspots) were positioned for each area (e.g. workplaces, departments, etc.). Thus, a unique reference for the planned inspection path was available (Figure 3), and it was guaranteed that a 360° panoramic view was associated with each observation point (Figure 4).

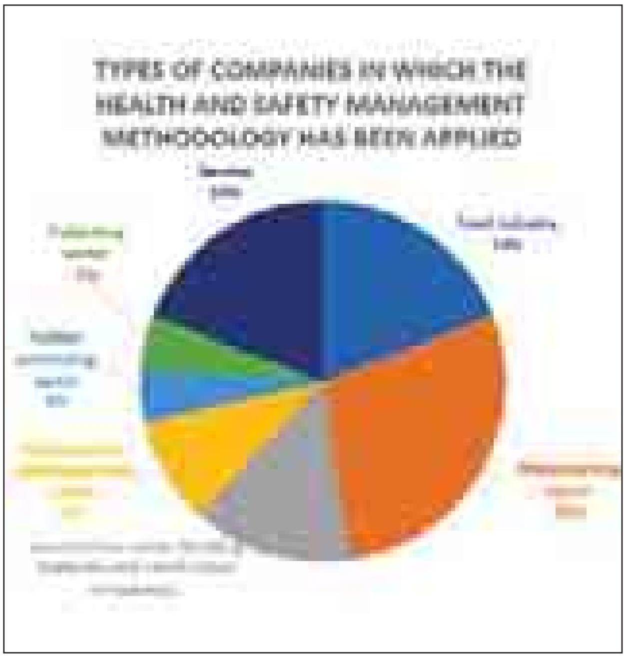

Figure 2. ***Main types of activities in which the health and safety management methodology has been applied***

Figure 3. ***Example of a radar image that allows to move virtually in the premises and areas of the departments***

Figure 4. ***Example of a pre-recorded overview on tablet, depicting what is visible during the investigation by the employee with visible interaction hotspots***

The various types of hotspots were operated as follows:

- the information hotspots were used to insert instructions and procedures that needs to be followed, in the form of video and audio supports;
- the "pdf" hotspots have been used to attach reference documentation on instructions or safety procedures that can be consulted during the tours;
- the "link" hotspots have been used for the insertion of internet addresses which give the possibility to open the destination page in a browser window;
- the "interaction" hotspots were used to highlight any "non-conformities" found, by proposing ad-hoc questions during navigation that provide for binary (YES / NO) or textual answers (known fields), or insertion during virtual tours of photographs, audio or video or even answers from preset drop-down menus.

The basic questions - which were implemented during the surveys in the 21 companies - referred to the basic criterion discussed in Borchiellini et al., 2016, summarized in the diagram illustrated in Figure 5.

The controls were divided into macro categories and subcategories (Table II) so that by filtering the results the report analysis phase becomes easier.

Figure 5. ***Approach for the assessment and management of OS&H risks***

Table II. ***Macro categories and examples of subcategories***

Structural characteristics	**General support services (including emergency management)**	**Equipment (plants, machines, work tools, ...)**	**Operations (e.g. organisation including materials and workers)**
Examples doors, walls, windows, floors, mezzanines, step and ladder stairs and other architectural elements; luminous and non-luminous horizontal and vertical signs and parabolic or hemispherical mirrors; asbestos: periodic inspection of asbestos-containing artefacts, encapsulated and confined artefacts[2].	Examples firefighting: surveillance of devices and equipment such as fire extinguishers, hydrants, alarm buttons; evacuation: security doors and opening devices, emergency signs and light signs; intervention devices: such as first aid kits, medication packages, defibrillators and medical rooms; Special PPE (Personal Protective Equipment); Emergency response teams: training on the intervention procedures provided for in the corporate emergency plan.	Examples electrical equipment: switchboards, sockets, cables and connections, extension cables; equipment: safety devices, immaterial barriers, microswitches, fixed and mobile guards, stop buttons, etc.; compressed air distribution systems, gas distribution systems (flammable, oxidizing, inert, medical, etc.) including valves; liquid distribution systems (fuels, lubricants, water, steam, superheated water) including valves and gate valves; walkways, passages, ladders, railings serving production lines and plants; portable electric appliances; centralized and localized suction systems; room lighting, safety and emergency.	Examples working and lifting equipment (check before use and functional checks) transportation (checking the vehicle before use and checking the load) control of processes and work phases, control of the construction site and safety documents inspection audits; business documents; external company documents DUVRI (Italian document for the assessment of interference risks); Correct implementation of COVID-19 contagion containment protocols.

[2] In this regard, the proposed system can operate in symbiosis with the approach discussed in Cina et al., 2019 (60).

The report and statistical sections have been respectively structured to make it possible to:

- send immediately reports containing indications of any discrepancies to the super user at the end of each tour;
- analyze of the evolution of reports and types of discrepancies in subsequent tours and comparison of the same also between virtual tours conducted in different offices or departments of the same company.

The data collected during the inspections in the 21 Companies were subsequently analyzed in terms of:

- time savings compared to the traditional paper approach;
- reduction of the non-given answers (using the report and statistical sections);
- reduction of reported non-conformities resulting from the direct solving of the identified criticalities (using the platform/app statistical section and also the 2 proportions test in Mintab®).

3. Results and Discussion

The following bullet points summarize the main results obtained thanks to the in-situ implementation of the methodology:

- The percentage of the reduction of the time used to compile the check list, compared to the traditional paper approach (the percentages also take into account the time necessary to report any non-conformities to the manager in charge and the time storage) was almost 80%;
- The remedial actions' time (time that elapses from the moment in which a non-conformity is detected to the moment in which it is resolved), is significantly reduced compared to an approach based on traditional paper checklists, thanks to the direct and immediate communication from who detects to who has the task of solving the non-conformity;
- As a direct consequence of the time reduction needed to carry out all the activity of control and correction of any deviation and the possibility, thanks to the guided performing of the controls, to also include personnel who is not highly qualified, the frequency of checks can be considerably increased. For example, with reference to a sample company, the increase was almost 600% (value due to the widespread use of the app from a single department to the whole company) the first year, 2018, and 26% the second year, 2019, as shown in Figure 6;
- Reduction of the non-given answers following a greater awareness and increase of the safety's culture by those who carry out the control tours (Figure 7);
- Reduction of reported non-conformities resulting from the direct solving of the identified criticalities. The examples of Figure 8 and 9 suggest that in a department of a sample company there was a general decrease of non-conformities over the years.

In addition, the 2 proportion tests were performed with data illustrated in Figures 8 and 9, by using the total yes responses (compliance) as number of Events and the sum of the total responses (yes, no and no response) as number of trials N. This test determines whether the population proportions of two groups differ, by comparing the p-value to the significance level. A significance level of 0.05, which indicates a 5% risk of concluding that a difference exists when there is no actual difference, was chosen for this test. The p-value was calculated using the normal approxima-

Figure 6. ***Annual trend (2017 is the reference year without the application of the methodology) of the number of Virtual Tours performed in a sample company (graph generated in the statistics section). Translation from the original Italian output***

Figure 7. *Virtual Tour annual trend of control in a sample company: (graph is generated in the statistics section). Translation from the original output in Italian*

Figure 8. *Annual trend of compliance and non-compliance percentages relating to a department of a sample company (graph is generated in the statistics section). Period from 03/05/2018 to 10/05/2019. Translation from the original output in Italian*

Figure 9. ***Annual trend of compliance and non-compliance percentages relating to a department of a sample company (graph is generated in the statistics section). Period from 03/05/2019 to 10/05/2020. Translation from the original output in Italian***

tion method and Fisher's exact method in Minitab®. The Minitab® output of the test is illustrated in Table III below:

Table III. ***Minitab® output of the 2 proportions test***

Test and CI (confidence interval) for Two Proportions			
Method			
p_1: proportion where Sample 1 = Event			
p_2: proportion where Sample 2 = Event			
Difference: p_1 - p_2			
Descriptive Statistics			
Sample	N	Event Sample	p
Sample 1 (data from Figure 8)	1890	1586	0.839153
Sample 2 (data from Figure 9)	1575	1441	0.914921
Estimation for Difference			
Difference	95% CI for Difference		
-0.0757672	(-0.097312; -0.054222)		
CI based on normal approximation			
Test			
Null hypothesis	H_0: p_1 - p_2 = 0		
Alternative hypothesis	H_1: p_1 - $p_2 \neq 0$		
Method	Z-Value	P-Value	
Normal approximation	-6.89	0.000	
Fisher's exact		0.000	

Because the p-values for both methods are less than 0.001, which is less than the significance level of 0.05, the decision is to reject the null hypothesis (the difference between the population proportions (p_1– p_2) equals the hypothesized difference (0)) and conclude that the difference between the proportions of the two periods, is statistically significant.

4. Conclusion

The substantial changes of recent years in the technical and organization system of industrial production in many NACE sectors, and the changed roles of all the people involved, make necessary new approaches to the Occupational Risk Assessment and Management. Systematic checks and continuous improvement of the situation, special for the changed context, play a basic role, and a quality approach becomes even more important.

The development of this original application for OS&H can contribute to evolve and modernize the infield inspection and control phases, with undeniable advantages in terms of efficiency and effectiveness. Obviously, also in this case the quality of the result depends, as for any Checklist, on the reliability of the Occupational Hazard Identification and Risk Assessment preliminary phases.

However, it is not a system control software, and does solve the identified non-conformities. This goal, currently covered by a different software special for maintenance, will in future be implemented, so that, based on reports and statistics generated by the platform, the superusers will also charge specific subjects of the management of non-conformities and record the closure of the problem, within the same IT environment.

Moreover, a nearly completed *"internal video call to the application"*, will enable an operator carrying out a control tour to contact a referee or consultant without exiting the tour, and to receive information and support. This will become a particularly significant feature in case of maintenance activities: the maintenance crew will find, in the same environment, checklists, manuals and procedures. Moreover, video call capabilities will make possible to remotely ask for technical information, and forward frames of the faulty component for immediate support.

The application for the OS&H checks in companies discussed in this paper, constitutes a modern and time / moneysaving approach, and allows effective guided independent inspections or, if necessary, verification interaction and real-time implementation by experts. The possibility to directly forward reports makes possible the just in time management of occasional non-conformities, the verification of the layout of working areas, the revision of the training of workers charged of specific tasks, and comparative assessments of the various situations over time or in departments or similar production units.

The reduced duration of each inspection makes moreover possible, within the same budget, a substantial increase of the inspections' frequency, reducing the possibility of persistence of non-conformities.

In addition, the approach intrinsically favors the participation of workers and supervisors in the prevention and protection activities, promoting a process of continuous improvement of their expertise, and contributing to the effectiveness and quality of the OS&H audits.

The proposed technique can then contribute in innovative terms to the actions aimed at promoting the dissemination of the Culture of Safety.

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