Industry 4.0: technologies and OS&H implications

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The rapid spread of the Industry 4.0 technologies is deeply changing workplaces. In order to achieve the so-called Forth Industrial Revolution, several open issues have to be faced, concerning technologies, enterprise organization and knowledge. Automation systems are already replacing men in manual, repetitive tasks: both shop-floor and office operations are experiencing this kind of transformation. Therefore, the role of human operators is shifting from manual work to knowledge work: people will be increasingly required to manage and exploit technologies by interacting with automation devices. In order to fulfill such requirements, operators will need to own appropriate knowledge and skills, enabling them to profitably understand the feedback data and take complex decisions to guarantee high performance levels for the enterprise. Obviously, this change cannot ignore the need to maintain and improve Occupational Safety and Health – OS&H conditions, whose assessment and management are entrusted to specific analyses of each production context.
The paper proposes some applications on innovative technologies involved in Industrial production scenarios, highlighting also how a different and tailored analysis on Occupational Safety and Health – OS&H aspects are essential to both ensure and preserve safety and health of workers in a continuous working environment changing.
***Keywords**: Industry 4.0, Collaborative robotics, Lean Manufacturing, new technologies, OS&H.*

***Industria 4.0: tecnologie e implicazioni sulla OS&H.** La rapida diffusione delle tecnologie Industria 4.0 sta cambiando profondamente il luogo di lavoro. Per raggiungere la cosiddetta "Quarta Rivoluzione Industriale", devono essere affrontati diversi problemi aperti riguardanti tecnologie, organizzazione aziendale e conoscenza. I sistemi di automazione stanno già sostituendo gli uomini in attività manuali e ripetitive: sia le operazioni in officina che quelle in ufficio stanno vivendo questo tipo di trasformazione. Di conseguenza, il ruolo degli operatori umani si sta spostando dal lavoro manuale al lavoro di conoscenza: le persone saranno sempre più richieste per gestire e sfruttare le tecnologie interagendo con i dispositivi di automazione. Al fine di soddisfare tali requisiti, gli operatori dovranno possedere conoscenze e competenze appropriate, consentendo loro di comprendere proficuamente i dati di feedback e prendere decisioni complesse per garantire livelli di prestazioni elevati per l'impresa. Ovviamente questo cambiamento non può prescindere dall'esigenza del mantenimento e del miglioramento delle condizioni di Sicurezza e Salute del lavoro la cui valutazione e gestione sono demandati ad analisi dedicate di ogni contesto produttivo.*
Il documento propone alcune applicazioni su tecnologie innovative coinvolte in scenari di produzione industriale evidenziando anche come un'analisi diversificata e dedicata in materia di sicurezza e salute del lavoro – OS&H siano essenziali per garantire e preservare la sicurezza e la salute dei lavoratori in un ambiente produttivo in costante cambiamento.
***Parole chiave**: Industria 4.0, Robotica collaborativa, Lean Manufacturing, Sicurezza e Salute del lavoro.*

***Industrie 4.0: technologies et implications sur OS&H.** La diffusion rapide des technologies de l'industrie 4.0 modifie profondément le lieu de travail. Pour réaliser la "quatrième révolution industrielle", plusieurs problèmes concernant la technologie, l'organisation des entreprises et les connaissances ont été résolus. Les systèmes d'automatisation remplacent déjà les hommes dans des tâches manuelles et répétitives: l'atelier et les opérations de bureau connaissent ce type de transformation. En conséquence, le rôle des opérateurs humains passe du travail manuel au travail de la connaissance: les personnes seront de plus en plus obligées de gérer et d'exploiter les technologies interagissant avec les automates. Pour répondre à ces exigences, les opérateurs doivent posséder des connaissances et des compétences appropriées leur permettant de comprendre les données de retour de manière rentable et de prendre des décisions complexes pour garantir des niveaux de performance élevés à l'entreprise.*

1. Smart factory: the how and the why management's role changes

In a scenario characterized by increasingly aggressive international competition, small and medium-sized enterprises – SMEs – found themselves having to look for solutions to maintain a good level of competitiveness.

While many SMEs have decided to relocate production to countries with lower factor costs, other companies, on the contrary, have sought an internal response, questioning their organizational logic with a view to lean thinking. The Lean thinking is a new philosophy arisen from the Toyota Production System and defined in the 1990s as an approach supporting people development and continuous process improvement aimed to create value and growth with the minimum possible resources.

Womack, Jones e Roos, (1991) coined the term "Lean thinking" to make reference to a managerial model aimed at optimizing the company organization to obtain more and more using less and less resources: less human effort, less time, less space, less equipment and materials.

Move on to common management strategies to a Lean Management of the Company implies

Evidemment, ce changement ne peut ignorer la nécessité de maintenir et d'améliorer les conditions de santé et de sécurité sur le lieu de travail, dont l'évaluation et la gestion sont confiées à des analyses spécifiques de chaque contexte de production.
Le document propose des applications sur les technologies innovantes impliquées dans les scénarios de production industrielle, soulignant également comment une analyse diversifiée et dédiée sur la sécurité et la santé au travail - OS&H est essentielle pour garantir et préserver la sécurité et la santé des travailleurs dans un environnement productif en constante évolution.
Mots clé: *Industrie 4.0, robotique collaborative, Lean Manufacturing, Sécurité et Santé du travail.*

a profound change in the way of thinking and acting at different levels, from top management to workers, aligning the entire company organization on common projects and targets. Understanding the principles and applying them is not immediate: it is essential to analyze and mapping the flows of value, identifying the critical issues and setting up an operational action plan in the light of a continuous improvement.

This approach is often illustrated with the House of Lean (Fig. 1) showing key principles and how they work together as a complete system.

Management plays a very important role in the process and the presence of a close-knit leadership is a factor of success: the benefits of lean implementation in the organization are obtained only through an in depth analysis and a continuous revision of the system (Chiabert and D'antonio, 2018).

The Lean thinking allows organizing and managing an Organization on the base of a preliminary strategy based on the answer to three main questions:

1. *What problem are we trying to solve?*: it is essential to focus the Organization Commitment in order to achieve the targets as productivity increases, greater willingness to pay on the part of the customer and the reduction of operational and financial risks;
2. *How will we improve the work?*: this is the challenging task with the target to identify a set of methods, techniques and tools aimed at optimization of materials and information management activities within a productive context;
3. *How will we develop the people?:* the full involvement of workers and operators is of pivotal importance to work within a framework of quality standards, principles, policies and guidelines, promoting training and capacity – building activities of the Organization.

The difficulty in implementing lean derives from the fact that there is no pre-established model or schemes to adapt mechanically but the principles must be adapted to the reference Company context.

Given the complexity of the revolution process, companies encounter many difficulties and the probability of failure is high. The time needed to implement Lean transformation varies above all according to the Organization's Commitment: the benefits of work can be obtained in a few months, but the extension of positive performances to the entire Company is achieved only after a few years.

The management must not be in a hurry to obtain the results, but it will be necessary to "focus the attention and the efforts first on the processes and then on the results.

This passage will allow starting the change of culture and preparing the employees to face the great future transformations: the new philosophy will have to become an integral part of the processes.

2. Smart factory: how changes the view of the work(place) and operators' role

The current trend of automation and data exchange in manufacturing technologies includes

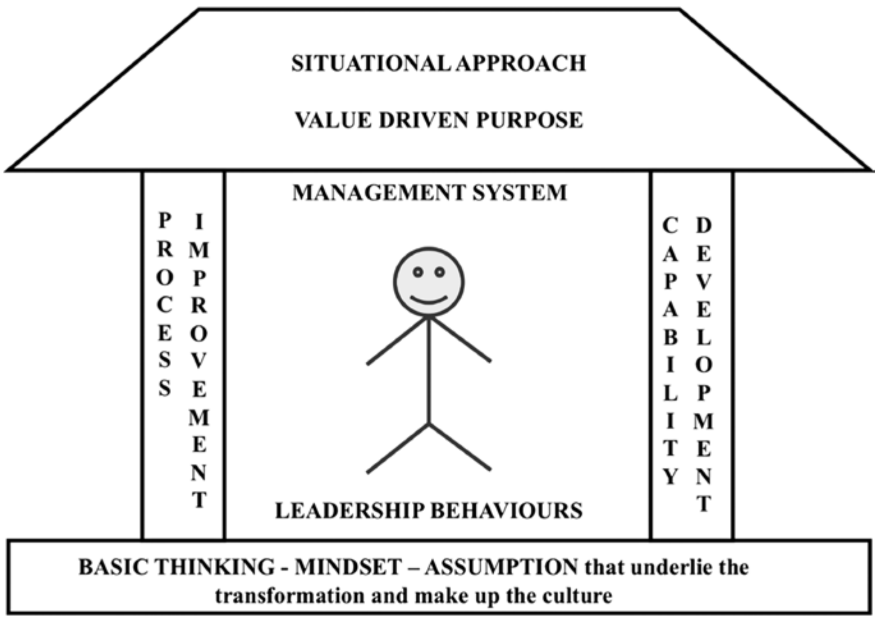

Fig. 1. House of Lean.
La casa del Lean.

integrated cyber-physical systems (i.e. cloud computing, and cognitive computing) supporting the companies in production and information management. The enabling technologies involved are designed and constructed to meet the main principles of Industry 4.0 scenarios:

- *Interoperability*: machines, devices, sensors, and people can collaborate and /or cooperate as a synergistic system;
- *Information sharing*: information systems are able to create a virtual copy of the physical world sharing output and feedback about processes in real time;
- *Technical facilitation*: assistance systems have a double role: first, they support humans for making informed decisions and solving urgent problems on short notice; second, they have also the physical ability to support humans by performing a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers;
- *Decentralized decision power*: systems make possible decisions on their own carrying out their tasks as autonomously as possible. Only in the case of exceptions, interferences, or conflicting goals, the tasks are delegated to a higher level.

This change in the working environment – obviously affecting the production process – solves two typical problem of common activities:

- Department separation: Industry 4.0 is breaking down the typical discretization of line production in the different departments (from the entry of raw materials to the quality control of the final product) within a production system. Employees are able to work in different location but with real-time data of every step of production when they need it, bringing departments closer together. Such data might include preliminary information about the status of a project, updates on a partner's requirements, or equipment maintenance schedules.
- Customized production: this is new age of an inversion of normal manufacturing. Manufacturers want to put their customers first, combining personalized manufacturing with the fast on-time delivery expectations of consumers. Intelligent and integrated systems play a pivotal role for delivering instructions to machines about specific customer orders as they progress along the production line.

This revolution implies scenarios that could become a "barrier" for a complete factory evolution, and insiders seem to be inclined to underestimate the implication of the reorganization of the operator's role and the related scale of the impact on those concerned. The operator continues to be functional for the production, but his role is shifted into another level because his tasks, his responsibilities, his skills and competences have to comply with the needs of the production. The main problem concerns the widespread lack of awareness of the leadership about using a 4.0 framework able to translate the global Vision into something that workers care about, encouraging a passive resistance to the transition. This is also due to the belief that their company will leave them because while the industry changes they are no getting a chance to follow newer technologies. Furthermore, the ageing of working population makes it necessary to re-evaluate the correlation between OS&H, work and job productivity by assessing the impact of the working life extension and the increasing number of workers affected by illness or disability. Recent studies are dealing with the assessment of how technical and technological changes can affect the response of workers, to the new workload from an ergonomic and psychological point of view. However, the nature of the problem is systemic: nowadays the major challenge is meeting all workforce generation needs: with an increasing number of older workers in the workplace is essential to take care about aspects such as eyesight, mobility, interactions, etc. together with the emerging importance of environmental and green design. Hence, the 4.0 revolution has to be global including Vision, OS&H, environmental and energy saving aspects in order to create a workplace for everyone, without physical and social barriers.

2. New technologies vs OSH aspects

Besides the workplaces, transformations are also undergoing in the way people are used to work, and safety management in industrial contexts needs to be updated as well.

Since, the cornerstones of European Directives on the protection and the improvement of Safety and Health at work (89/391 EEC and 89/392EEC, today 42/2006/CE) are still in force, the principia of Prevention through Design and System Quality Management have to be integrated both in the design and the management of working environment and new technologies involved by the development of Industry 4.0 innovations.

Among the enabling technologies of the Industry 4.0 paradigm, autonomous and cooperating industrial robots are playing a key role. Modern robots can be equipped with a variety of sensors to increase their awareness on the surrounding environment and to detect people close to the operative area.

This increased robot awareness enabled to lower the need of physical barriers: up to a few years ago, cages had to be installed around the robot to preserve the operators' safety. Cages had a twofold role. First, they enabled spatial separation: human operators and robots could be active at the same time in the shop-floor, with the cage sharply delimiting the space areas that could be used by each of them. Second, cages enabled temporal separation. The robot area, of course, could be accessed by operators, but the robot had to stop for safety reasons. Therefore, within the robot cell either the human or the robot could be active; they could not work at the same time in the same area. To fulfill with these requirement, appropriate sensors had to be installed in order to stop the robot operations as soon as the gate was opened (i.e. when a person was to enter the cage) (Unhelkar *et al.*, 2014).

The integration of sensors within the robot and the development of advanced control systems led to novel paradigms for human-robot interaction: new safety standards for the application of industrial robots have been set in the specific standard (ISO 10218:2011). This standard defined collaboration as the "state in which purposely designed robots work in direct cooperation with a human within a defined workspace". Different kinds of collaborations can be defined (as shown in figure 2, and each of them is provided with appropriate rules for risk reduction in the design phase:

– Safety-rated monitored stop, e.g. when the operator has to load parts or to set the workstation; in this case, no robot motion is allowed when the operator is in the workspace. As risk reduction measure is essential, the collaboration is limited with a robot in a standstill position whenever a worker is in collaborative workspace. Power is still enabled and the robot is ready to resume its activity.
– Hand guiding, e.g. when the device needs to be assisted or to coordinate manual and partially automated tasks; here, the robot motion can take place only through direct input of operator, and no active decisions are taken by the control system.
– Speed and separation monitoring, e.g. when the operator enters the workspace to replenish parts containers far enough from the robot; the robot cell must be equipped with sensors to detect human position, and is allowed to move (at a reduced speed) only when the mutual distance is higher than a given threshold. The minimum separation distance between worker and robot in collaborative workspace must also take into account the robot braking distance.
– Power and force limiting by inherent design or control; the robot itself must be equipped with sensors to detect contacts. When a contact is detected, the robot has to limit the applied force.

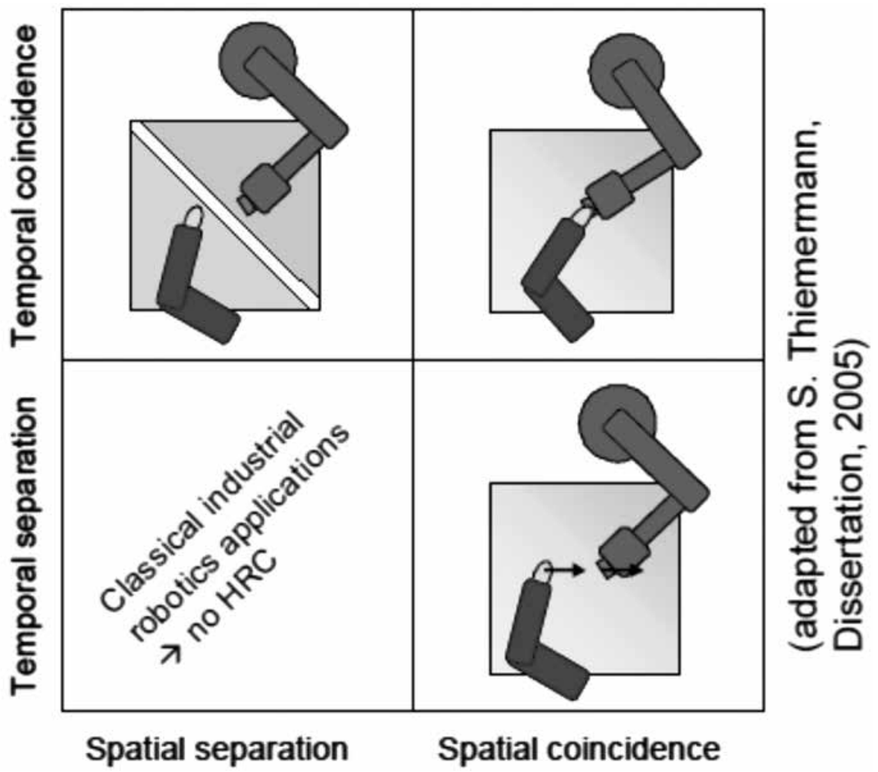

Fig. 2. Classification of human-robot cooperation (from S.Thiememann, dissertation, 2005).
Classificazione della cooperazione uomo-robot (da tesi S.Thiememann, 2005).

Robots compliant with the ISO 10218:2011 standard are flexible automation systems capable of reconfiguration in case of human proximity, but do not allow yet the temporary and spatial cooperation with operators. A step forward has been made by the standard on collaborative industrial robot systems and the work environment (ISO/TS 15066:2016). This document defined the requirements for human-robot cooperation through the following underlying idea: "Why a human-robot contact should be avoided if the result is no harm to the human?". The idea of cooperation must also take into account human factors: for example, when a contact – that is initially without pain or injury – becomes painful or no longer acceptable.

Further, the contact severity that can be accepted varies according to the involved body portion.

The possibility of exploiting both temporal and spatial cooperation promotes novel applications for robotics: besides being an automation system, collaborative robots can be used to support operators in reducing the complexity of their duties. Tasks can be shared, as well as the robot can be used to move heavy loads or pick the components necessary for the process – even from remote positions – and place them in a golden area for the operator. These applications can highly enhance the operators' safety and ergonomics, nonetheless the adoption of a collaborative robot does not ensure that the application is collaborative as well. The collaborative workspace is defined in the ISO/TS 15066:2016 as the "*space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation*". Therefore, a collaborative robot handling dangerous materials or equipped with a tool unable to preserve operators' safety leads to a non-collaborative operation.

Collaborative robotics is impacting processes (mainly, assembly processes) as well as logistics. In the last 30 years, great efforts have been spent in the development of Automated Guided Vehicles – AGV. Different technologies have been developed over time for vehicles guidance: initially, AGVs were used to travel on fixed paths. Magnetic sensors under the factory floor or colored bands glued on the ground were used to drive the vehicles. More recently, technologies for free navigation have approached the market: such AGVs are capable to map the available space and to autonomously choose the best route to achieve the targeted destination. The shop-floor portion traveled by the AGVs is of course shared with human operators; therefore, appropriate sensors for risk prevention and safe navigation must be adopted. AGVs are usually equipped with a laser scanner sensor capable to detect obstacles on the path to be traveled. In case the path is not free, the AGV reduces its speed or stops and evaluates whether a different path may be convenient. Passive devices for risk mitigation are also adopted: audio beeper in motion, flashing lights, emergency stop button are adopted and, in some cases, bumpers are also used (Ullrich, 2015).

The interest in wearable robotics is also increasing: they mainly consist in wearable suits (either powered or unpowered) fitted with motorized muscles to multiply the wearer's strength (Fig. 3).

Such devices are increasingly adopted in manufacturing and construction industries, although not yet widespread. They enable to augment human motion and allow for more lifting strength and for improved production on repetitive tasks like squatting, bending, or walking. The workers wearing the suits will also be less prone to severe injuries from accidents or overwork. Besides this, exoskeletons may also provide an ergonomic support to reduce fatigue of workers that have to adopt uncomfortable postures for a long time (Kong *et al.*,2018).

In order to identify the poten-

Fig. 3. Examples of exoskeletons supporting operators' ergonomics. Source: www.asme.org.
Esempi di esoscheletri che supportano l'ergonomia degli operatori.

tial occurrence of hazardous situations it is necessary to analyze the tasks that are to be carried out by operators of the robot system and its associated equipment. The integrator shall identify and document these tasks. The user shall be consulted to ensure that all reasonably foreseeable hazardous situations (task and hazard combinations) associated with the robot cell are identified, including also indirect interference (e.g. workers having no tasks associated with the system but having exposure to hazards associated with the system) in terms of volume and influence interferences (Labagnara *et al.*, 2016).

On this matter, it cannot be underestimated the inherent differences between operational characteristic of robots from other equipment. For example, robot are able to apply high energy movements through a large operating space, and these movements can vary, so it is difficult to predict different movements due to the change of operational requirements. The scenario ca be more complicated by the potential interaction of more than one robot whose operational spaces overlap each other's.

4. Conclusions

Industry 4.0 has led to profound changes in the way people work. The most demanding task, however, is entrusted technologies management that requires a different approach for OS&H aspects.

Different problem is the evolution of the role of the operator that for youngers is almost natural and intuitive, far from the workers almost retired, to those who are reinserted as a result of job changes or even worse for workers with disabilities.

The robot is simply a component of a chain of collaborative robot systems. It is not enough for a safe collaborative operation. These applications are dynamic and will be determined by the risk assessment during the application system design The crucial piece is the cooperation between Management and workers and the dissemination of the Culture of Safety at all level, in order to drive the continuous industrial change with a gradual process.

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