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Occupational health and safety in the industry 4.0 era: A cause for major concern?

Adel Badri[a,b,*], Bryan Boudreau-Trudel[c], Ahmed Saâdeddine Souissi[d]

[a] Industrial Engineering Department, School of Engineering, Université du Québec à Trois-Rivières, Trois-Rivières, Quebec G9A 5H7, Canada
[b] Research Institute on SMEs, Université du Québec à Trois-Rivières, Canada
[c] Department of Management, Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, Quebec J9X 5E4, Canada
[d] Advanced Sciences and Technologies Department, National School of Advanced Sciences and Technologies of Borj Cedria, Ben Arous, Tunisia

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ABSTRACT

Real-time communication, Big Data, human–machine cooperation, remote sensing, monitoring and process control, autonomous equipment and interconnectivity are becoming major assets in modern industry. As the fourth industrial revolution or Industry 4.0 becomes the predominant reality, it will bring new paradigm shifts, which will have an impact on the management of occupational health and safety (OHS).

In the midst of this new and accelerating industrial trend, are we giving due consideration to changes in OHS imperatives? Are the OHS consequences of Industry 4.0 being evaluated properly? Do we stand to lose any of the gains made through proactive approaches? Are there rational grounds for major concerns? In this article, we examine these questions in order to raise consciousness with regard to the integration of OHS into Industry 4.0.

It is clear that if the technologies driving Industry 4.0 develop in silos and manufacturers' initiatives are isolated and fragmented, the dangers will multiply and the net impact on OHS will be negative. As major changes are implemented, previous gains in preventive management of workplace health and safety will be at risk. If we are to avoid putting technological progress and OHS on a collision course, researchers, field experts and industrialists will have to collaborate on a smooth transition towards Industry 4.0.

1. Introduction

Industrialisation has undergone remarkable transformations since its beginnings in the 18th century. Following the introduction of machinery powered by local generation of steam, which uncoupled production from the limitations of human manual effort (Industrial revolution 1.0), the next paradigm shift came in the 19th century with the introduction of electricity, which allowed the broad distribution of power from a central facility. Thanks to electricity, machinery became less bulky and ran faster (Industry 2.0). The 20th century brought powered assembly lines, and with the development of electronics, manufacturing became more and more automated (Industry 3.0) and focused on performance. With automation came opportunities to optimise manufacturing processes and improve productivity through the design of more flexible, ergonomic and safer machinery (MESI, 2016).

In comparison, the term "Industry 4.0" was coined very recently. As might be expected, it refers to the convergence of manufacturing with the digital revolution, artificial intelligence, the Internet of things and with every device called "smart". Its goal is to allow manufacturers to meet ever-changing demand more efficiently using adaptable and responsive machinery. This idea goes beyond the design of single machines and now encompasses a broadened vision that can best be described as a global revolution in manufacturing. Conceived in Germany, this vision has spread to several other industrialized countries, some of which have been investing heavily in order to catch up to the innovators (MacDougall, 2014; MESI, 2016). Real-time communication, Big Data, man–machine cooperation, remote sensing, monitoring and control, autonomous equipment and interconnectivity are all considered as non-negligible assets in industries that face fierce competition and seek to improve productivity and reduce costs.

The fourth industrial revolution goes well beyond concepts such as interconnectivity and digital manufacturing. In Industry 4.0, businesses digitize their physical assets and integrate them into digital ecosystems throughout the value chain. Industry 4.0 promises increases in productivity through the integration of digital systems of production with analysis and communication of all data generated within an intelligent environment.

In examining these transformations, we note a co-evolution of manufacturing philosophy and the approach to occupational health and safety (OHS). Industrialisation created an urgent and growing need for

* Corresponding author at: Industrial Engineering Department, School of Engineering, Université du Québec à Trois-Rivières, Trois-Rivières, Quebec G9A 5H7, Canada.
E-mail addresses: adel.badri@uqtr.ca, badri.adel@gmail.com (A. Badri).

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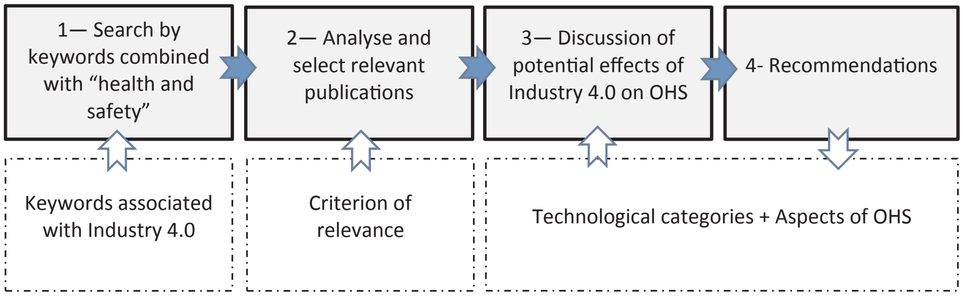

Fig. 1. Methodological steps.

labour and led to the rise of deplorable working conditions in which men, women and children risked life and limb to earn their keep. The inexperience of the labour force and the ignorance of employers regarding what we now call OHS inevitably took a brutal toll, and under the resulting public pressure, legislators were forced to intervene. Labour unions, labour laws, regulations and standards began gradually to emerge in industrialized countries. Although some alarming statistics persist, it is now safe to say that workplace conditions have improved tremendously. Notwithstanding continued criticism, we can also point to improved involvement of employers and workers in the solving of problems related to OHS. Today, we refer to integrated OHS management, sophisticated tools and standards for the management of occupational risks, equipment that is safer to operate, and especially working environments and practices that are better supervised and controlled.

It should be emphasized that evolution in the realm of OHS has always followed revolutionary developments in industry. Reaction to technological progress, changes in work methods and the real consequences of these on OHS have provided the impetus for the implementation of reliable and sustainable solutions to problems. In most industrialized countries, reactivity is now yielding to proactivity, which has advanced considerably during recent decades but has also benefitted from legislation, regulation and standards that have brought to the forefront both occupational risk and the duty to eliminate danger at the source. Prevention is no longer just a word. Industrial businesses today now understand that the health and safety of their workers is a major component of financial success, like total quality, productivity and cost reduction. A healthy business is now one in which OHS is regarded as an imperative.

As Industry 4.0 becomes more and more a reality, it appears inevitable that it will lead to a new series of paradigm shifts. We are starting to see the implementation of new industrial concepts based on decentralising of information and decision-making. Industrialists are starting to evaluate the positive repercussions on the responsiveness, autonomy and flexibility of manufacturing facilities. New generations of interconnected and autonomous equipment such as cobots (collaborative robots) are emerging (MESI, 2016; Beetz et al., 2015). All of this is intended to meet human needs that never cease to diversify. This is observable at the numerous congresses, trade shows and workshops that promote this industrial effervescence and further stimulate competitiveness.

As this trend gathers momentum, we must ask whether or not we have we given sufficient thought to new OHS imperatives. Have we evaluated the OHS consequences (positive and negative) of this industrial revolution? Will we lose the gains made through proactivity? Will OHS considerations have any moderating influence on all this effervescence? Are there reasonable grounds for apprehension? By raising such questions, our intention in this article is to initiate reflection with regard to the integration of OHS into Industry 4.0. We shall begin with a description of our research methodology in the next section, followed by the results of our analysis of the literature relating to OHS in the context of Industry 4.0. In the fourth section, we present a broader discussion of the potential effects of Industry 4.0 technologies on OHS, we list some of the recommendations found in the literature and we point out the current limitations of research in this area, including our own. In the fifth and final section, we present our conclusions.

2. Methodology

2.1. The context

The term "Industry 4.0" thus refers to the fourth industrial revolution. Other expressions such as "industrial internet" or "digital manufacturing" refer to similar ideas but do not convey the whole picture. In fact, the disparity of the usable terms is the first obstacle to overcome in carrying out an exhaustive search of the literature. For this purpose we consulted a list of equivalent terms published recently (Danjou et al., 2017), from which we selected those that appeared to be the most widespread, namely: "industrie 4.0", "industry 4.0", "manufacturing 4.0", "smart production", "smart manufacturing", "smart factory", "smart industry", "factory of the future" and "advanced manufacturing".

2.2. Steps of the review

In order to achieve our objective, the review was carried out according to the steps shown in Fig. 1.

The first step consisted of a systematic search for publications using the selected keywords. During this step, we used only the keyword "health and safety" since it is the most representative and inclusive term in the OHS field. This keyword was combined (OR, AND) with the terms most widely associated with Industry 4.0, as mentioned above.

The fields of text searched included the title, the abstract and the keywords of peer-reviewed articles published since 2012. For this purpose, we used only the cross-disciplinary database Scopus, which is the largest database of peer-reviewed publications and includes scientific reviews, collections of works and conference proceedings.

The second step consisted of selecting publications focused on OHS in the context of Industry 4.0. Each researcher analyzed independently each of these articles, and all findings were discussed in a meeting in order to establish their reliability, which was judged according to the vested interest the authors might have had in discussing OHS through the developments they achieved in association with Industry 4.0.

The third step was devoted to complementing the initial literature search results with a broader discussion of the effects (positive or negative) of Industry 4.0 on worker health and safety in view of the technological categories listed in Table 1, namely Big data, Internet of things, cyber-physical systems, computer networks, cobotics, artificial intelligence and computer simulations (Danjou et al., 2017; Hermann et al., 2016). This discussion was based also on four aspects of OHS, namely: (1) organisation of work, (2) OHS legislative and regulatory framework, (3) OHS management systems and (4) management of occupational risks. In order to support the ideas formulated during the discussion, more extensive literature published since 2010 was

Table 1
Technological categories relevant to Industry 4.0.

Category	Definition
Big data	Datasets so large that they exceed human intuitive and analytical capacities and even those of conventional computing tools for database and information management.
Internet of things	Exchanges of information and data coming to the Internet from devices performing real tasks in the physical world.
Cyber-physical system	A system in which computerized elements collaborate to monitor and control physical entities.
Cobotics	Emerging branch of technology devoted to robotic design based on combining information sciences, human factors (behaviour, decision, robustness and error monitoring), biomechanics (modeling of behaviour and of movement dynamics) and robotics.
Artificial intelligence	The multidisciplinary theories, techniques, concepts and technologies implemented in order to develop machines capable of simulating intelligence.
Simulation	Representation of the behaviour of an industrial process by means of a computer model in which the parameters and variables are reflections of those of the process being studied.

included.

Finally, numerous recommendations regarding the implementation of OHS measures in the context of Industry 4.0 were formulated and discussed.

3. Results

The concept of "Industry 4.0" first appeared in 2011 and is now one of the most discussed subjects in manufacturing technology circles and business groups (Rojko, 2017; Qin et al., 2016). It is easy to show that this concept is attracting more and more attention of researchers and experts in several fields. For example, if we search the Scopus database alone using the keywords "Industrie 4.0" and "Industry 4.0", we find considerable growth in the numbers of publications (peer-reviewed articles, conference papers, notes and short surveys) between 2012 (1) and 2016 (240).

In spite of the huge increase in the number of scientific publications on the subject of Industry 4.0, we note that few of these raise OHS issues in any helpful way. In fact, we found only 11 peer-reviewed articles that meet the criterion of presence of obvious interest to discuss OHS (Table 2). Of these publications, 7 are conference articles and 4 are review articles. It should be noted that none of them cite research focused on integrating OHS into manufacturing in the Industry 4.0 context and that most of them are focused on new technologies with only a brief mention of worker health or safety. The details will be provided below, as our discussion unfolds.

Kaivo-Oja et al. (2015) studied the effects of the Internet of things, Big data and other key technological waves of the fourth revolution (robotics, artificial intelligence, etc.) on managerial practices in organisations. The authors regard these technological factors as means of reinforcing production but recommend new approaches to organisational analysis in order to adapt their managerial practices more effectively, including those associated with health and safety. The recent development of intelligent sensors, the Internet of things, cyber-physical systems and advances in computing have led to numerous attempted applications to OHS.

A recent review of the literature (Podgórski et al., 2017) reveals a large range of personal protective devices that use these technologies. The use of intelligent devices of this sort apparently has modified work methods and added further complexity to production processes. As a solution to these incipient problems, the authors of this review propose a more dynamic OHS conceptual framework based on a new, more personalized and dynamic risk management paradigm.

Fernández and Pérez (2015) note that advanced manufacturing processes can generate new OHS risks but that conventional tools of occupation risk analysis appear incapable of identifying these emerging risks. In order to address this problem, the authors propose implementing new models of risk analysis capable of monitoring all OHS risks (conventional and emerging).

Meanwhile, the use of cyber-physical systems offers the promise of adapting industrial systems to changing environmental conditions thanks to autonomous decision-making (Kuschnerus et al., 2015). In industrial process automation, the search and adoption of a cyber-physical system must take into account safety restrictions that reduce technical risks to a tolerable level, which must be defined in up-to-date standards (e.g. IEC 61508) for better adaptation to an autonomous and intelligent environment.

The most important message of the study by Siemieniuch et al. (2015) is that OHS in the Industry 4.0 context requires significant input from ergonomics and human factors research. This could be based primarily on considerable advantages associated with cyber-physical systems. The authors emphasize the major role of ergonomists and engineers in the design and operation of new systems and processes as well as in the reduction of undesirable effects brought by industrial paradigm shifts. In the same context, Beetz et al. (2015) raise the problem associated with the use of cobots and the close interaction thereof with workers in support of difficult and dangerous tasks. They highlight the importance of developing safety-conscious robots that recognize actions that could cause injury or threaten worker safety. For safe and effective interaction, such robots must be equipped with complex programs that allow them to reason and to understand the intentions of workers in their proximity.

Table 2
Selected publications.

Keywords combined with "health and safety"	Review article	Technological categories	Conference article	Technological categories
Industrie 4.0 OR industry 4.0 OR manufacturing 4.0	Siemieniuch et al. (2015)	Internet of Things, Artificial Intelligence and Simulation	Mattsson et al. (2016)	Big data and Internet of things
Smart AND production	Podgórski et al. (2017)	Internet of Things and Cyber-physical system	Kaivo-Oja et al. (2015)	Big data and Internet of things
Smart AND manufacturing	Vogl et al. (2016)	Robotics and Simulation	Lira and Borsato (2016)	Big Data and Cyber-physical system
Smart AND Factory	–	–	Kuschnerus et al. (2015)	Cyber-physical system
Factory OR factories AND the future	Gisbert et al. (2014)	Internet of Things	Beetz et al. (2015)	Robotics and Artificial Intelligence
			Palazon et al. (2013)	–
Advanced AND manufacturing	–	–	Fernández and Pérez (2015)	Simulation
Total	**4 (36%)**		**7 (64%)**	

Mattsson et al. (2016) emphasize that the Internet of things and *Big Data* raise enormous challenges where the goal is to analyse and use information circulating in a factory. They raise questions regarding the most appropriate way of using and integrating such information and new technologies in order to improve performance and accident prevention. However, they also see numerous opportunities to automate the monitoring of a broad range of workplace information (e.g. pulse, emotions, activity, temperature, etc.).

Palazon et al. (2013) suggest that wireless communication has a significant role to play in improving work conditions. Wireless sensor networks with well-designed and properly integrated technological support prevent accidents in autonomous and intelligent industrial settings. Along the same lines, Gisbert et al. (2014) maintain that information technologies and wireless communication are becoming capable of detecting dangers effectively and continually in the workplace and that in order to ensure the reliability of these systems, common technological platforms capable of monitoring the functioning and performance of all networks and linking sensors to remote control centres need to be implemented. These platforms will reduce occupational risks by facilitating the integration of general surveillance applications.

Recent technologies associated with smart production offer opportunities for the maintenance and management of assets through the development of new decisional strategies (Lira and Borsato, 2016). Information technologies and communication provide means of analysing *Big Data* faster, autonomously and in real time. By combining historical data with current data, real-time decision-making throughout the manufacturing process can be improved and will have a positive impact on the performance, safety, reliability and sustainability of industrial systems (Vogl et al., 2016).

4. Discussion

It is helpful to begin with a concise overview of the potential advantages and drawbacks of the six technological categories in terms of impact on OHS. Table 3 below summarizes some of these with regard to the introduction of such technologies (Podgórski et al., 2017; Mattsson et al., 2016; Lira and Borsato, 2016; Vogl et al., 2016; Beetz et al., 2015; Fernández and Pérez, 2015; Kaivo-Oja et al., 2015; Siemieniuch et al., 2015; Kuschnerus et al., 2015; Gisbert et al., 2014). The drawbacks could *become* emergent risk factors that could in turn lead to occupational injuries or illnesses and hence deterioration of OHS performance in the industrial setting.

No modification of an industrial manufacturing system should be contemplated without discussing at length the potential effects on worker health and safety. In general, the consequences of change will be studied from several perspectives. In the present article, we shall focus on gathering and analysing the potential consequences of using the technologies driving Industry 4.0 (Big data, Internet of things, cyber-physical systems, computer networks, cobotics, artificial intelligence and simulation) in terms of work organisation, OHS regulatory and legislative framework, OHS management systems and occupational risk management systems (Fig. 2).

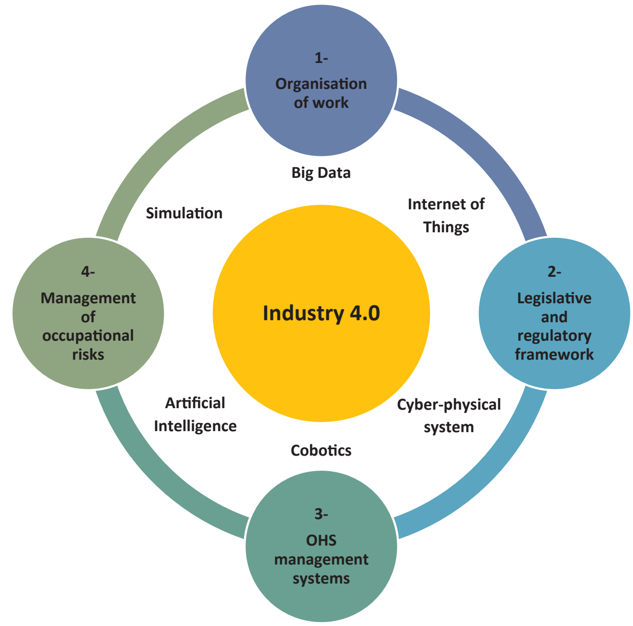

Fig. 2. Industry 4.0 technological categories and aspects of OHS.

4.1. Challenges associated with new organisation of work

Industrialists who implement smart factories wish to limit the risks inherent in planning, to identify the effects that the new setup will have on workers, to avoid having to redesign equipment, to optimise utilisation of resources, to eliminate wastage and to increase performance and flexibility (Simons et al., 2017; Brettel et al., 2016; Neal et al., 2016; Abersfelder et al., 2015). According to the consulting firm CIMdata, efforts undertaken in the field of smart production allow reductions of 30% in time to market, decreased expenditure on planning, reductions of 40% in equipment costs and production increases of 15% (Proto lab, 2016). These analyses do not necessarily imply gains in OHS, especially in the case of a radical change in work organisation (Bücker et al., 2017; Kiel et al., 2016; Reuter et al., 2017; Van Lier,

Table 3
Potential impact of technological categories relevant to Industry 4.0.

Category	Advantages	Drawbacks
Big data	– Unlimited gathering of data – Reduced uncertainty – Improved capacity for analysis of behaviour and anticipation of errors	Issues associated with: – Data reliability – Data selection criteria – Personal data confidentiality
Internet of things Cyber-physical system	– Improved interaction between equipment/machinery and detectors of anomalies – Improved process monitoring and control – Remote monitoring and control	Issues associated with – Network reliability – Cyber security
Cobotics	– Improved flexibility and accessibility	– Unpredictability of worker reliability, proximity and interactions with devices – Absence of standards
Artificial Intelligence	– Learning and quick recognition of hazards – Timely decision-making	– Uncertain reliability – Potential drift (calibration) – Absence of standards
Simulation	– Improved evaluation and comparison of work scenarios and methods – Prevention at the source	– Uncertain reliability and robustness of the models

2014).

Industry 4.0 production systems are constantly increasing in complexity (Waschneck et al., 2017; Block et al., 2015). This is especially apparent in terms of increasing interaction between work content (variety, cycle, skills, uncertainties, exposure, etc.), organization (team scheduling, overtime, rush orders, etc.), management (responsibilities, communication, roles, relations, problem solving, etc.) and other organizational factors (promotion and pay raises, job security, social value of the work, etc.). Leka and Jain (2010) note that these interactions underlie several types of workplace hazards, in particular those in the psychosocial category. Engineers and designers of advanced manufacturing systems often overlook risks of this type, which may become the most important to be managed. It should be noted also that psychosocial risks have already become a major challenge in terms of legislation and OHS management systems.

Smart automation and integration of new technologies into the business value chain cannot be achieved without introducing new organizational constraints (Reuter et al., 2017; Kiel et al., 2016). Insufficient expertise and workers on learning curves amplify production problems. Another major issue facing Industry 4.0 businesses in this regard is that of training existing workers and recruiting new workers who are better equipped to learn (Lorenz et al., 2015, European Commission, 2013). In the meantime, a wide variety of occupational risks will abound.

In order to function effectively in Industry 4.0, workers will have to acquire a wide range of quite specific skills. They will have to combine conventional task-associated expertise with computer skills (Lorenz et al., 2015, European Commission, 2013). The acquisition of such skills can be complicated for an aging labour force that does not have at least minimal scholastic training (Lorenz et al., 2015). Workers will have to be more motivated and open to change. They will have to be more flexible in order to collaborate more effectively and will have to accept continuing education (Moniri et al., 2017).

Suitably adapted planning and organisational models should serve as the new basis for the management of this growing complexity (Waschneck et al., 2017; Kress et al., 2016; Toro et al., 2015). Innovative tools are required in order to develop such models, and ought to be made available to industrialists (Uhlmann et al., 2017), who are in a position to apply the findings of scientific research, even though their goal is not likely to be advancing Industry 4.0. In this situation, there is a danger of new tools and untested industrial models being implemented at the expense of worker health and safety.

Although increased interaction and collaboration between workers and machines is the basis for Industry 4.0 (Bonini et al., 2015), this does not mean simply more human–machine control interfaces but new ways of sharing tasks in order to complete complex operations more rapidly (Waschneck et al., 2017; Christiernin and Augustsson, 2016; Gattullo et al., 2015). In order to avoid creating unforeseen dangers in the manufacturing setting, more careful planning of tasks and more complete clarification of the limitations of each participant will be necessary.

4.2. Legislative and regulatory frameworks are lagging behind

Current OHS law and regulation is in large part the result of expert inquiries and recommendations made following major industrial accidents. This framework plays an important role in obliging industries to meet health and safety standards. It also encompasses a vast body of knowledge and know-how that is generalizable throughout the industrial sector, notably in small and medium-sized businesses that would not otherwise have the means to acquire such assets.

In spite of criticism, the presence of such framework favours successful implementation of OHS management (MacEachen et al., 2016; Manzoli et al., 2015). Many of the measures enforced oblige businesses to evaluate risks, to implement standardized work procedures and to provide training that reduces the frequency of workplace accidents (Badri et al., 2012a). From a legal perspective, these obligations represent commitments as well as an audit reference used to levy sanctions against non-compliant companies.

However, even though the legislation establishes mechanisms of participation intended to eliminate the source of threats to worker health, safety and physical integrity, it does not specify standard procedures or even provide an explicit definition of the integration of OHS into operations. This openness to interpretation is not likely going to help maintain the gains made once the radically new conditions that characterize smart industry are in place throughout industry (Jones, 2017; Gaudet, 2004). There is currently no widely accepted and internationally recognized regulatory framework, this being due notably to the tripartite approach to prevention (Froman et al., 2002). However, as hazard identification, system compliance and in-house monitoring mechanisms all improve, systematic management of OHS will provide advantages in both the operational and the strategic phases of business in the era of digitization and interconnectivity.

Laws, regulations and standards historically have come into existence on a reactive basis (OIQ, 2009). They follow events, social change and technological progress and even new models of business administration and management. There is no reason to expect this to be any different for the new industrial revolution currently underway or for the implementation of new industrial systems based on autonomous, smart or networked machinery. Once again, the regulatory and standardization framework will not arrive in time to save all workers from the consequences (Jones, 2017). Unlike for regulations and standards, the consequences of this delay will not be as great as for more general legislation. In spite of the rapid progress of technologies used in smart production, most authors are of the opinion that current legislation will continue to function adequately and remain valid for the next few years.

If a review of OHS legislation were in order, standards rather than law or regulations would be the most judicious starting point. In view of the time that the bureaucratic process takes to change laws, it would be more realistic and more effective to review specific standards (Provan et al., 2017; Hasle et al., 2012). The absence of a standard or an update in response to technological progress can have major repercussions in terms of OHS. An industrial system incorporating a remote control process (cloud computing, Internet of things, etc.) or sensors that increase machine autonomy for the first time will no longer be subject to the standard applicable to the previous generation. The designers will be able to assert that the new system is compliant until experts in the field have debated and cast doubt on the adequacy of the current standard. Under these conditions, in the absence of real social pressure, thousands of potentially dangerous technological innovations could be installed in many industrial sectors throughout the world. The cost of retrofitting such machines in order to achieve compliance with updated standards could become huge (Pettitt and Westfall, 2016).

In cases where the equipment designers or users have the benefit of an in-house framework for monitoring OHS, timely detection of deficiencies associated with a new technology might be expected. However, such initiatives appear limited when we examine an industrial sector as a whole. What appears obvious to a business that performs admirably in terms of OHS might not register in another business. An influential business in a network of industrial collaborators (client – suppliers) may more easily insist that safe technologies be used (Manu et al., 2013; Dumas, 2011) and contribute to developing or updating industrial regulations and standards so that these take new implications for OHS into consideration. In general, there are no definite rules to ensure proper integration of a new technology into an industrial process. As the wait continues for standards organisations to move forward on this issue, the status of OHS will depend on corporate goodwill or isolated initiatives (Burke et al., 2011).

4.3. OHS management systems to be re-examined

OHS management frameworks have been developed to guide practices in the business sector (OHSAS 18001, CSA Z1000-06, Z1002-12, etc.). It should be noted that the inspiration for these frameworks came primarily from the concept of total quality. This model proposes a general guide for managing accident prevention, training, emergencies and regulatory requirements specific for industrial activities. By definition, based on a continuous improvement model, these frameworks should be more flexible and hence better suited to following the changes brought by Industry 4.0.

Documented experience shows that integration of OHS has an overall favourable effect on productivity and cost in industry (Von Thiele Schwarz et al., 2016; Van Holland et al., 2015). We also note a positive correlation between productivity and the implementation of OHS measures (Productivity Commission, 2010). It should be emphasized that increased industrial system productivity and efficiency (the goal of Industry 4.0) is not in any fundamental conflict with the implementation or maintenance of OHS management systems. Furthermore, most businesses that have begun to set up smart and connected production facilities already have a well-established culture of accident prevention. This is the case for automobile manufacturers (Renault, Volkswagen, etc.), who are building smart construction plants around the world. Their turn towards OHS integration and sound management of the environment began long ago in all their logistic chains (Frost & Sullivan, 2015). Within a rigorous legislative framework, these gains in OHS will not be lost easily in spite of the possible flaws in the new technologies.

OHS management standards will undoubtedly help industrialists convert smoothly to autonomous and smart systems. Among the advantages to be realized are reduced documentation and increased synergy between all managerial processes (Muzaimi et al., 2017; Dahlin and Isaksson, 2017; Chovancová et al., 2016). This will help overcome obstacles such as errors in prioritizing risks and difficulties organizing preventive actions in automated and dynamic management systems. OHS management systems have a reputation as insufficiently flexible frameworks. Researchers will have to turn their attention to improving the agility of these systems in order to make them adaptable to increasingly complex, flexible and autonomous industrial processes.

4.4. Rethinking occupational risk management

OHS risk management, including the phases of identification, analysis and evaluation, may be viewed as a decision-making tool used to improve anticipation of risks that are known and likely to have an impact on business goals and controls already in place. Although risk can be evaluated at all stages of an industrial system life cycle, risk identification is always more relevant and more profitable when it is incorporated into the very design of the industrial project, new technology, equipment, process, procedure and so on (Badri et al., 2012a). In fact, the more a project matures, the less decisional latitude managers have for processing risks and consequently the greater will be the financial cost of this processing (Pettitt and Westfall, 2016). Finally, the option chosen will depend on what the directors wish to achieve through the initiative, on what level of detail is sought and especially on the availability and reliability of the data used. According to ISO/IEC standard 31010, the technologies used must in all cases be suitably adapted to the context of that particular business and provide readable, traceable, reproducible and verifiable results.

As new control devices, on-line data analysis and the Internet of things continue to make machinery and industrial systems more and more autonomous, many industry experts and providers of technologies are reassuring us that process errors will be eliminated (Yaqiong and Danping, 2017; Ubisence, 2016). With extensive and ultimately complete automation of factories, it becomes possible to reduce both OHS risks and deficiencies or flaws in the value chain (ABB, 2014). These systems will be equipped with technical means of monitoring all parameters that have any bearing on the process (Podgórski et al., 2017; Mattsson et al., 2016; Beetz et al., 2015; Palazon et al., 2013). Machines will thus be more apt to respond appropriately the instant any dysfunction occurs. They will have more and more self-monitoring capability as well as the ability to monitor their surroundings and send information to diagnostic centres that will determine whether or not further intervention is necessary (Zhang et al., 2017; Tantik and Anderl, 2017; Scholz et al., 2016).

Some smart machinery is now capable of precise interpretation of human emotions and hence facilitated interaction with workers (Khatchadourian, 2015). Autonomous vehicles could soon replace many heavy equipment operators and avoid many forms of error and accidental interactions with workers (Scholz et al., 2016). Robots are getting faster and more precise as well as taking up less and less space. They will soon have the ability to move about, handle materials, respond to dynamic surroundings (Nielsen et al., 2017; Bonini et al., 2015), follow intuitive protocols and utilise cutting-edge navigation and perception technologies to recognize their tasks and their surroundings (Beetz et al., 2015). Machinery downtime and servicing could be reduced considerably if intelligent systems were to predict maintenance needs (Lira and Borsato, 2016). Costs and errors could be reduced as a result of simulating processes more accurately before building the production system. Production could be defined to meet real rather than projected demand, thus reducing wastage, work-related stress and consequently occupational injuries (Shibin et al., 2016).

Counterbalancing this optimism are questions regarding the emergence of and interaction between technical risks in such a complex environment (Badri et al., 2012b). Researchers and experts have been warning us for decades about the potential risks associated with new technologies (Brocal and Sebastiána, 2015; Geraci, 2010). One of the most widely documented problems concerns the ergonomics of control interfaces and human–machine interactions. Until recently, robots were confined to protected spaces and moved according to programmed and previously tested and validated sequences. The associated risks were relatively easy to identify and control. In comparison, more flexible and mobile cobots performing all sorts of tasks in close interaction with workers represent a much broader range of much less predictable risks. In spite of the autonomy and presumed intelligence of smart equipment, we could find ourselves expanding the continued discussion on the causes of human error to include “smart machine error”. It must be emphasized that the reliability of such devices becomes more and more difficult to predict as the complexity of the surroundings increases.

Before the digital era, field experts in accident prevention gathered data, observed operations and analysed behaviour in order to improve work conditions. In practice, the starting point of preventive initiatives is always human needs as perceived in the opinions of workers and managers. In the digital era, data gathering should only be easier, since equipment is now able to log and archive huge amounts of information. However, the task remains of determining which data are actually useful for improving accident prevention. Before undertaking a preventive or corrective action, hazards must be identified through rigorous management of information (Ross et al., 2005). Numerous sources of data of different types must be analysed. This management is often delegated to a team made up of experts in different fields, who must collaborate. One of the challenges of Industry 4.0 risk management will be overcoming the difficulties of correct identification of risk factors and maintaining the availability of experts in OHS, who will be less and less present on the shop floor.

The concept of risk management in real time will also become highly relevant in very dynamic industrial settings (Podgórski et al., 2017; Niesen et al., 2016; Malinowski et al., 2015). This concept will draw upon data gathered from multitudes of networked devices, often delocalized and accessible via internet, which raises serious issues of cyber-security management (He et al., 2016; Pontarollo, 2016; Wang et al., 2016). In this context, artificial intelligence could play an important role by assisting decision-making and thereby decreasing occupational risks due to the sheer complexity of the new environment (Ahmar, 2017; Percy, 2017).

4.5. Recommendations

It is clear that if the technologies driving Industry 4.0 develop in silos and the OHS initiatives of manufacturers are fragmentary, hazards will multiply and some of the gains made in accident prevention will be lost. Researchers, field experts and industrialists will have to collaborate on the implementation of measures based on a comprehensive vision of managing change in order to ensure a smooth and safe transition to the new paradigm.

Kagermann et al. (2013) and the European Commission (2013) have proposed various recommendations to implement in order to maintain or improve the status of OHS in the Industry 4.0 context. We note and add in particular those listed below:

- More interdisciplinary research is needed in order to improve the integration of human labour with intelligent equipment.
- There is a need for more research focused on emergent occupational risks at all levels of production, on improving the social responsibility of businesses, on workplace design and configuration and on the effective use of information technologies.
- There is a need to carry out research on the consequences for the work organisation and the associated psychosocial risks.
- There is a need to develop new standards or update existing ones in order to adapt to the new reality and improve the use of the new technologies.
- Business management models need to be re-examined in light of changing human and social factors.
- For the purposes of automation, the distribution of tasks among workers and intelligent devices such as cobots must take all relevant adjustable physical and cognitive factors into account.
- The equipment configuration and the effort required to operate it must be adapted to the physical and cognitive capacities of the workers.
- The design and configuration of new work environments must remain focused on humans and their safety and comfort.
- Worker expertise and motivation need to be reinforced in order to promote safe collaboration between workers and cobots and make new technologies safer.
- Future OHS integration initiatives must combine at the outset virtual task analysis, dynamic evaluation of occupational risks, cognitive analysis of workload, and skills management tools.
- Adaptive interfaces and emotion sensors need to be developed to monitor workers and ensure their safety continuously. Modeling of human behaviour, intentions and reactions to stress, difficulty and uncertainty is needed.
- Means of protecting against unauthorized access to logged data and information circulating in a production system need to be upgraded on a continual basis.

4.6. Limitations of this work

The small number of publications retrieved on the subject integrating OHS into Industry 4.0 should raise concerns, given that a cross-disciplinary database spanning a wide range of document types (Scopus) was queried, and that much the same result would have been obtained by consulting other databases.

We examined the potential consequences (positive and negative) of the fourth industrial revolution from four perspectives, namely work organisation, OHS regulatory and legislative framework, OHS management systems and occupational risk management systems. This was not based on any known scientific principle but rather on the authors' knowledge and experience with the study of OHS. These four perspectives summarize the aspects of OHS that are taken into account in a typical manufacturing business.

5. Conclusion

The term "Industry 4.0" referring to a fourth industrial revolution is a very recent neologism. The rise of digital technology, artificial intelligence, the Internet of things and networked, "smart" and responsive devices is seen more and more as providing means of responding to changing consumer demand more quickly and efficiently. This vision has gone well beyond equipment in factories and is becoming a global revolution that will soon transform the very notion of what constitutes a manufacturing facility.

Although scientific publication on the subject of Industry 4.0 is quite effervescent, the number of articles that raise the question of how to incorporate OHS remains small. Most articles are focused on the new technologies driving this revolution and mention worker health and safety only briefly. Published research on the integration of OHS in the Industry 4.0 context is cited rarely.

It is clear that if the technologies driving Industry 4.0 are developed in silos and manufacturers' OHS initiatives remain isolated, workplace hazards will multiply during the transition period and some previously improved accident prevention records will be tarnished. Researchers, field experts and industrialists will have to collaborate on the implementation of measures based on a comprehensive vision of managing change in order to ensure a smooth and safe transition to the new paradigm.

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