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The Challenge of Today's Industry: Safety and Reliability in Resilient Complex Systems

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In the most recent years, industry has been touched by the simultaneous introduction of 4.0 smart technologies and new elements of complexity mainly related to mutated interactions between humans and machines. This change has made the issue of safeguarding safety and reliability an increasingly central and challenging topic. At the same time, complex industrial systems need to be resilient, that is able to absorb shocks and facing changes or uncertainties, through adequate reaction and adaptation.
Technologies introduced by Industry 4.0 can increase workers safety and improve reliability and resilience of processes against system failures. However, new technologies have also introduced unexpected risks. Identifying critical components of an industrial system and considering its different elements with their dependencies can allow to balance safety advantages and risks while keeping resilience ability.
In the present study, the main 4.0 technological solutions for safety, their possible contraindications and the corresponding effects on the resilience capacity of the overall system are described and considered as distributed all along a specific company multi-level representation. The elements in the proposed model are firstly detailed for every identified company level; then, results are also synthesized in table form.

Keywords: Resilience, complexity, safety, Industry 4.0, smart technologies, risk.

1. Introduction

The introduction of new 4.0 technologies in the last decade has increased complexity in many industrial contexts, where new interconnected and integrated systems, which are well represented through the contemporary expression "Smart Factories", appeared.

In today's industry, the concept of "complexity" can be read according to different interpretative lines. First, traditionally complex sites are represented by high-risk industrial plants (e.g. Seveso Plants, nuclear sites), where the advent of Industry 4.0 added to the increasing importance assumed by Na-tech analyses for investigating the possible devastating effects of extreme phenomena on such critical plants at risk of major accidents and their surroundings.

Complexity typically arises also in constructions and in shipyards, where it is mainly related to the presence of many temporary workers. Even subcontractor networks can be considered as complex systems (Oedewald and Gotcheva, 2015). Anyway, nowadays complexity can arise in many other industrial fields.

From a general point of view, complex systems are characterized by many causal connections between technical, human and organizational elements (Carra et al., 2020), where the human component is becoming increasingly critical for the assurance of safety.

A part of the scientific world has recently introduced the additional concept of "Industry 5.0" in order to highlight the importance of sustainability, resiliency and human-centricity, but the idea of defining a real further phase of industrialization does not yet find a unanimous consensus in the academic community.

Technologies introduced by Industry 4.0 can increase workers safety in several working environments and improve reliability and resilience of processes against system failures. For example, machine-learning techniques can help in measuring and improving the adaptive capacity of systems (Salehi et al., 2020). This represents a big opportunity.

In parallel, a growing difficulty in managing such innovative and wide system is emerging. In modern productive systems, many science disciplines are involved, with consequent difficulties in identifying critical components and specifications of elements, which also have unknown dependencies (Bielefeld et al., 2017).

At the same time, in order to understand failures in complex systems, a vision of each system as a whole, supported by model-based integral approaches (Salzano et al., 2014), can generally help, while identifying their different internal elements with their dependencies.

Thus, it is necessary a better understanding of the whole system, in terms of causes and effects, and the use of model-based integral approaches, as through global system dynamics methodologies (Di Nardo and Murino, 2021).

The process of technological innovation is inevitably accompanied by many possible contraindications. In particular, new work risks have emerged, mainly due to unexpected organizational aspects, changes in social perceptions and an enriched scientific knowledge. In addition, some risks, already present previously, have increased, due to the increment in the number of sources of risk, in the exposure probability and in the extent of potential health consequences (Brocal et al., 2019).

For this reason, even risk assessment procedures must be updated, for example by highlighting new safety aspects to be taken into account when the machines with CE marking are equipped with Industry 4.0 enabling technologies (Monica et al., 2020).

In general, new system analysis methods, as well as updated organizational procedures, have to be implemented to face these new difficulties, with a new, but still effective, resilient attitude in absorbing shocks and facing changes or uncertainties through adequate reaction and adaptation. If the involved systems are analyzed in their entirety, it is possible to identify and, over time, optimize the reciprocal interconnections between productivity and safety guarantee, while keeping resilience ability. Some studies also calculated a Resilience Indicator for specific systems subjected to unexpected events (Di Nardo et al., 2020).

Previous literature researches already showed that different typologies of resilience can be distinguished at different company levels (from frontline activities to macro-level organization) (Macrae, 2019). The authors have also recently proposed a multi-level representation of the company decisional activity, expressly dedicated to establishing the feasibility of a collaborative use of machines (Carra et al., 2022).

Thus, the main aim of this work is to present a multi-level schematization of complex systems where recent safety 4.0 innovations, as well as their possible contraindications, new consequent emerging risks and resilience aspects are described, starting from an analysis of recent international literature.

This represents the premise for a better organization of procedures and solutions to be adopted in order to balance advantages and risks brought by new technologies in industrial safety and processes reliability.

2. Multi-Level Schematization of Complex Systems

Complex systems are characterized by multiple connections between many elements, including equipment, human factor, procedures. They can be subjected to unexpected perturbations that require a particularly adequate reaction and adaptation.

In this study, while taking into account these different aspects, we propose to schematized such industrial systems through three concentric layers, as a variation and extension of a similar structure recently introduced in literature in relation to resilience, where a situated resilience, a structural resilience and a systemic resilience were distinguished (Macrae, 2019).

Thus, complexity is here schematized as a three-level system:

- *Level a*: Front-line level;
- *Level b*: Process management level;
- *Level c*: Global and external level.

Level a concerns the complexity related to direct interaction between single operators and/or single machines (or their assemblies) at a front-line position. It therefore includes topics as human-machine interaction, behavioral analysis of operators and operating modes of single machines as well as communication tools between them.

Level b concerns the complexity at the level of a single industrial processes or, more widely, at the level of a company section constituted by several processes. It includes all technologies that allow an integration between physical objects and their mathematical models and, in general, all techniques of general modelling of the considered sub-system.

Level c concerns the complexity at the level of the global company, including control techniques of the whole system, from the point of view of their technological implementation as well as from that of their theoretical modelling. It is also strictly related to the integration between companies and external contexts, including other companies, other stakeholders and, more generally, even other cultures at international levels.

Amann et al. (2011) observed that, when companies have to operate across national borders, the complexity they need to manage escalates dramatically. Such escalation is mainly due to the diversity between their internal and external environments, but also to the very high communication speed required.

In the present manuscript, Sections 3, 4 and 5 analyze the innovations introduced by Industry 4.0 in each one of the above-mentioned levels, declining them in terms of safety. The analysis includes technological solutions for safety and possible arising issues or additional risks, as well as possible consequent implications in terms of resilience capacity.

Finally, Section 6 summarizes the results and presents a table where all such elements are listed and classified.

3. Front-line Level

The complexity related to the direct interactions between single operators and/or single machines at a front-line position in industries has been significantly increased by new 4.0 technologies. The advantages in terms of safety have been accompanied by new emerging issues and risks.

3.1 Technological innovations for safety

The collaboration between machines and humans is a pillar of today's industry. Their interaction has exponentially increased with the introduction of new technologies. In particular, collaborative robots are now able to share the work environment, without physical barriers, with humans. Robla-Gomez et al. (2017) proposed a classification of the main safety systems 4.0 in robotic environments, while distinguishing between separated or shared workspaces for humans and machines. Robots could also monitor workers, in order to limit or prevent human error.

Passive as well as innovative active exoskeletons can be useful for reducing muscular efforts and work-related musculoskeletal disorder, e.g. in lower back and shoulders.

Augmented reality devices can help in both education and workers training, with the final objective of increasing safety. Their design should always take into account ergonomics and comfort, since there is the need to ensure a continuous usage of the device by the operators in the real working conditions, even when workers have also to wear personal protection equipment (Bottani et al., 2021). Where troubleshooting became very difficult (e.g. when many stops and warnings arise), consulting the Instructions Manual is not sufficient more and augmented reality (as well as virtual or mixed one) can become a useful instrument.

The direct collaboration between humans and machines in Industry 4.0 is strongly characterized by the use of machine learning (ML), for example for fault detection or prediction (Di Nardo et al., 2022). ML consists in a process using algorithms rather than procedural coding that enables learning from existing data in order to predict future outcomes, as explained by ISO/IEC 38505-1:2017. Machine learning models learn from data based on pattern or inference without depending on rules. In contrast, knowledge-based models (learning from data following rules) and statistical models (formulating the relationships to develop knowledge from input data) can be also used (Arunthavanathan et al., 2021).

Innovation is also based on the use of wearable smart systems with R-FID, for a guided procedure against errors, e.g. when maintenance has to be carried out in presence of stored energy and non-insulated energy sources. Smart labels and tags also help in managing work equipment, even in terms of maintenance, or for behavioral safety in general (Vukicevic et al., 2019).

Prognostic models can derive causes and corrective interventions from anomalies, through artificial intelligence (AI), that is the capability of a functional unit to perform functions that are generally associated with human intelligence, as explained by ISO/IEC 2382:2015. For example, it is possible to have maintenance with virtual sensors predicting degradation based on past data.

3.2 Emerging risks and resilient attitude

Emerging risks at front-line level include both industrial risks and occupational risks, so the human factor and human-machine interaction has a central role.

The EU Agency for Safety and Health at work identified that there is an increased risk of mental and emotional strain on workers since complexity of new technologies produces a transformation of work processes, especially when accompanied by a poor design of human–machine interfaces (Adriaensen et al., 2019). The new direct human-machine interaction (HMI) can have important social implications, depending on the brain mechanisms that become central during this type of relationship.

An excessive gap between workers and managers, even from the point of view of safety awareness and culture, should also be avoided. Azadeh and Salehi (2014) report this subject for the case of complex petrochemical plants and propose a new framework, named integrated resilience engineering (IRE), for calculating the efficiency gap between managers and operators.

Difficulties can arise from problem solving capability in humans/machines, as well as from the previewed physical contact between humans and machines. Possible toxicity of wearable 4.0 technologies represents another unexpected risk.

Interconnecting old machines (i.e. arriving on market before 1996) to 4.0. technologies can be difficult, too, since they do not have an adequate internal technology. Even in case of machine "revamping" (modernization of a machine for a new productive life, usually with a new CE mark), it can be difficult to comply with product directives, social directives and technical standards at the same time.

4. Process Management Level

Industry 4.0 has furnished many innovative technological instruments for better managing safety while organizing and managing industrial processes in the company system. Anyway, new methodological and operational issues arise and additional risks have to be taken into account.

4.1 Technological innovations for safety

Control systems with ability to manage automatically unpredictable situations, in a resilient approach, can help in managing new complex processes. They can be supported by artificial intelligence. Approaches such as Alarm Management (AM) and the Safety Instrumented System (SIS) are able to alert the operators and take necessary actions for the system to reach a safe state (Arunthavanathan et al., 2021). Anyway, a manual intervention of the operator is needed. SIS system can include sensors, logic controllers and actuator devices controlling valves.

In general, modern process system researchers intend to apply machine learning algorithms for dynamic risk assessment (Paltrinieri et al., 2019). At the moment, the automotive and construction industries are leading this trend.

In the manufacturing sector, due to Industry 4.0 diffusion, there is a continuously increasing integration between physical and digital processes. In Digital Twins, digital models and physical ones share data and information reciprocally and some tools have been proposed. In particular, Agnusdei et al. (2021) introduced a "third dimension" specifically thought as a safety domain. It adds to the classical data systems, already dedicated to the transfer of data from the physical world to the digital one and to the information feedback towards the physical one.

Managing processes and their safety can be supported by Big Data system, which can more efficiently perform models and methods for fault diagnostic detection (Arunthavanathan et al., 2021). Feedback processes and automatic-controls schemes can help in highlighting complex interactions between variables and clarifying how to discern causes and consequent effects.

Real-time systems can be able to efficiently manage Big Data, together with cloud computing and system modularization. From the point of view of maintenance programming, new hybrid approaches based on data-driven models can support failure prognosis and the estimation of residual useful life, for a fault-free reliability of manufacturing processes. In this way, the maintenance interventions can be planned in advance, avoiding sudden stops and damages to the production processes.

Processes can be also monitored through Unmanned Aerial Vehicles (UAVs), i.e. drones for carrying out inspections, analyzing map terrain in hazardous or potentially polluted environments and activating emergency systems. They can be considered additional sensors with special features and they can help in guaranteeing safety.

4.2 Emerging risks and resilient attitude

The 4.0 smart systems that should be able to promptly send an alarm or react, correcting faults, need an adequate velocity of data processing. At the same time, data communication needs an increased reliability, for example for avoiding false alarms and computer problems or stops.

Availability and quality of sensors, real-time control systems and actuators, as well as communication devices and protocols, are therefore fundamental for resiliently react to unwanted events.

Moreover, in new 4.0 systems humans have a less direct vision of system failures, so machines need to be even more reliable in their ability to manage processes.

The concept of "assembly of machines" is extended towards a wider concept, so it is necessary to have an efficient interconnection between automatic cells level and managers level in order to guarantee safety as well as productivity.

5. Global and External Level

Resilience capacity of complex systems can be enhanced through a vision of systems as a whole, with a holistic approach (Adriansen et al., 2019).

In addition, globalization has produced an inclination of companies to communicate and interact more quickly with external contexts. At the same time, the recent worldwide pandemic experience has reduced the possibility of direct contacts and travels. Thus, 4.0 tools for remote communication and data exchange represent a vital instrument to overcome this obstacle.

In some cases, such communication channels are used to operate in favor of safety. Anyway, many new safety issues and risks can arise and they cannot be neglected.

5.1 Technological innovations for safety

The causal relationships between multiple factors that characterize complex systems at the time of Industry 4.0 can be represented through system dynamics models, which show causal interdependencies between technical, organizational and human components.

In particular, the graphical instrument constituted by Causal Loop Diagrams is often useful in order to represent a conceptual model of global company systems. Similarly, Bayesan nets can create simulated scenarios in order to analyze the uncertain dynamics of complex systems.

Communication channels and devices are central in managing internal as well as external information fluxes, especially for remote machine monitoring, diagnostics, remote maintenance.

New low-cost, miniature sensors can make these measurements simpler and quicker to implement. In the use of sensors, the communication via Wi-Fi network is gaining ground, but in some cases the use of clusters of cables, which are physically grouped and only subsequently connected to the cloud, is preferable as a more optimized solution.

Remote measuring through sensors can be also associated to the use of digital twin, creating a 3D model of the system and governing it remotely.

Such relationship are mainly realized through Web, telecommunications, 4.0 IoT technologies. A bibliographical analysis of industrial patents by Song and Su (2019) showed that Information Technology is a dominant trend in relation to the development of new technologies for work safety.

5.2 Emerging risks and resilient attitude

The global increasing complexity of new 4.0 working environments makes necessary to enhance the organizational resilience through more optimized and complete safety management systems (SMS) (Pera et al., 2020).

Since the internal and external communication fluxes of companies are actually strictly related to new technologies, their reliability appears more and more fundamental and has become more complex to be gained. Many technological factors have to be checked and monitored, e.g. the quality of vision systems and stability of connection speed.

Moreover, new dangers can come from outside, that is why it becomes fundamental to consider the risk of cyber-attacks, even for wireless communication layers. Cyber security is different from safety, but their relationship is important to be regulated. Cyber-attacks can touch even collaborative robotic cyber-physical systems, with causal effects on workers' safety during human-robot collaboration (Khalid et al., 2018).

New vulnerability points arise when information technologies converge with operational technologies such as edge computing infrastructures. Literature suggests to realize a complete secure re-engineering of the systems, starting with a well-defined segregation of the networks. IEC 62443 (the international standard for the security of industrial control systems) and ISO 27001 (giving requirements for information security management systems) can be useful. From a legal point of view, even a problem of liability (and possible failure to comply with the established service contracts) can arise from new IoT solutions.

Enhanced data communications can also produce a problem of privacy.

The continuously growing speed in both communications and production produces fast fluxes with consequent increasingly shorter product life-cycles. For this reason, it is necessary a very quick update of technical and organizational solutions (Amman et al., 2011). This means that an adequate and enhanced supply chain resilience will be probably necessary to follow contingencies.

In general, issues related to a possible negative environmental impact can also derive from new technologies, with a negative effect on safety in the broad sense of safety of the surrounding context.

6. Results and Limitations of the Work

Table 1 synthesizes the contents of *Levels a,b,c*, showing the main innovative solutions of industry 4.0 in terms of safety, together with their possible contraindications and effects on resilience.

Table 1. Safety in Industry 4.0: innovative technologies, emerging risks, effects on resilience.

	Technological innovations for safety	Contraindications, emerging risks, resilience needs
Level a	cobots in shared spaces; passive and active exoskeletons; augmented reality devices; ML and AI for direct humans/machine collaboration; wearable smart systems; smart labels and tags.	risk of mental and emotional strain in workers; social implications of HMI; need of avoiding poor design of human–machine interfaces; risks in new kind of physical contact humans-machines; possible toxicity of wearable systems; difficulties in interconnecting old machines.
Level b	process automatic control systems supported by AI; alarm management and safety instrumented systems; dynamic risk assessment with ML; Digital Twins, even including safety domains; Big Data managed by real-time systems; data-driven models for maintenance; monitoring activity through drones.	need of adequate velocity of data processing in alarm systems; need of increased reliability of data communication against false alarms and computer stops; need of high-quality sensors, control systems, actuators, communication devices; less direct vision of system failures by humans.
Level c	Causal Loop Diagrams and Bayesan nets; communication channels and devices (IoT); remote monitoring, through sensors and Digital Twins.	need of more adequate SMS; need of high-quality vision systems and stable connection speed; risk of cyber-attacks; possible failure to comply with established service contracts; privacy; need of enhanced supply chain resilience; possible environmental impact.

It appears evident that new technologies (sometimes even spread over more than only one of the highlighted levels, as in case of Digital Twins) are accompanied by many new requirements that a complex 4.0 system must meet. Being able to balance safety advantages and risks connected to the use of new technologies is in fact an important and actual challenge for industries and countries.

Resilience is mainly expressed in the capacity of guaranteeing high-speed communication and quick reaction, in the effective decision-making and control capacity of the new collaborative humans-machines systems, in the correct and regulated integration between old plants and new equipment and in the adaptive capacity of the entire supply chain.

The present work has still limited references to technical regulations and European directives, which always significantly influence actual companies activities. This gap will be filled in a forthcoming work, by integrating the concepts cataloged here with the multi-level decisional methodology proposed by Carra et al. (2022) for establishing the feasibility of the collaborative and safe use of machines according to regulations in force.

The theoretical treatment could also be supplemented by the analysis of empirical data collected from companies located in specific Italian areas, through access to their internal databases or through the realization of surveys based on questionnaires.

Conclusions

New technologies can be able to give a significant contribution to safety of people and processes in Industry 4.0. However, they can also introduce unexpected safety problems and risks that have to be known and managed. This need has also an impact on the resilience capacity of the system.

In this study, a multi-level schematization of complex systems is proposed. On the base of it, many 4.0 innovations for safety and their possible contraindications, have been identified, listed and catalogued, while taking also into account their effects on the resilience capacity of the system.

It appeared that linking quality and reliability in industrial processes is fundamental in order to achieve a complete resilient control capacity of complex system while assuring satisfactory production standards and high safety levels at the same time. New standardized procedures and updated organizational models for assessing and managing safety and reliability in the 4.0 industrial working contexts are therefore required and represent a priority for today as well as for the near future.

References

Adriaensen, A., W. Decré and L. Pintelon (2019). Can complexity-thinking methods contribute to improving occupational safety in industry 4.0? A review of safety analysis methods and their concepts. *Safety, 5(4)*, art. n. safety5040065.

Agnusdei, G.P., V. Elia and M.G. Gnoni (2021). A classification proposal of digital twin applications in the safety domain. *Computers & Industrial Engineering, 154*, art. n. 107137.

Amann, W., C. Nedopil and U. Steger (2011). The meta-challenge of complexity for global companies. *Journal of Database Marketing and Customer Strategy Management, 18(3)*, 200-204.

Arunthavanathan, R., F. Khan, S. Ahmed and S. Imtiaz (2021). An analysis of process fault diagnosis methods from safety perspectives. *Computers and Chemical Engineering, 145*, art. n. 107197.

Azadeh, A. and V. Salehi (2014). Modeling and optimizing efficiency gap between managers and operators in integrated resilient systems: the case of a petrochemical plant. *Process Safety and Environmental Protection, 92(6)*, 766-778.

Bielefeld, O., H. Dransfeld, N. Schlüter and P. Winzer (2017). Development of an innovative approach for complex, causally determined failure chains. *Management and Production Engineering Review, 8(3)*, 3-12.

Bottani, E., F. Longo, L. Nicoletti, A. Padovano, G.P.C. Tancredi, L. Tebaldi, M. Vetrano and G. Vignali (2021). Wearable and interactive mixed reality solutions for fault diagnosis and assistance in manufacturing systems: implementation and testing in an aseptic bottling line. *Computers in Industry, 128*, article number 103429.

Brocal, F., C. González, D. Komljenovic, P.F. Katina and M.A. Sebastián (2019). Emerging risk management in Industry 4.0: an approach to improve organizational and human performance in the complex systems. *Complexity, Vol. 2019*, Article number 2089763.

Carra, S., L. Monica and G. Vignali (2020). The critical role of human factors in safety of complex high-risk working environments. *Chemical Engineering Transactions, 82*, 139-144.

Carra, S., L. Monica, G. Vignali, S. Anastasi and M. Di Nardo (2022). Machine safety: a decision-making framework for establishing the feasibility of the collaborative use. *Proceedings of 32st European Safety and Reliability Conference*, Dublin.

Di Nardo, M., M. Clericuzio, T. Murino and M. Madonna (2020). An adaptive resilience approach for a high capacity railway. *International Review of Civil Engineering, 11(3)*, 98-105.

Di Nardo, M. and T. Murino (2021). The system dynamics in the human reliability analysis through cognitive reliability and error analysis method: a case study of an LPG company. *International Review of Civil Engineering, 12(2)*, 56-68.

Di Nardo, M., B. Piotr, M. Gallab, T. Murino and Y. Haoxuan (2022). The new safety trends: the challenges through Industry 4.0. *WSEAS Transactions on Environment and Development, 18*, 255-267.

Khalid, A., P. Kirisci, Z.H. Khan, Z. Ghrairi, K.-D. Thoben and J. Pannek (2018). Security framework for industrial collaborative robotic cyber-physical systems. *Computers in Industry, 97*, 132-145.

Macrae, C. (2019). Moments of resilience: time, space and the organisation of safety in complex sociotechnical systems. In Wiig, S. and B. Fahlbruch (Eds.), *Exploring resilience*, *SpringerBriefs in Applied Sciences and Technology*. Springer, Cham.

Monica, L., M. Madonna and S. Anastasi (2020). Risk assessment on machines with CE marking and with embedded industry 4.0 enabling technologies. *WIT Transactions on Engineering Sciences, 129*, 55-65.

Oedewald, P. and N. Gotcheva (2015). Safety culture and subcontractor network governance in a complex safety critical project. *Reliability Engineering and System Safety, 141*, 106-114.

Paltrinieri, N., L. Comfort and G. Reniers (2019). Learning about risk: machine learning for risk assessment. *Safety Science, 118*, 475–486.

Pera, F., M. Madonna and E. Del Prete (2020). Enhancing the organizational resilience through the safety management system. *Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference*, Venice, 3806–3812.

Robla-Gomez, S., V.M. Becerra, J.R. Llata, E. Gonzalez-Sarabia, C. Torre-Ferrero and J. Perez-Oria (2017). Working together: a review on safe human-robot collaboration in industrial environments. *IEEE Access, 5*, 26754-26773.

Salehi, V., B. Veitch and M. Musharraf (2020). Measuring and improving adaptive capacity in resilient systems by means of an integrated DEA-Machine learning approach. *Applied Ergonomics, 82*, article number 102975.

Salzano, E., M. Di Nardo, M. Gallo, E. Oropallo and L.C. Santillo (2014). The application of system dynamics to an industrial plant in the perspective of process resilience engineering. *Chemical Engineering Transactions, 36*, 457-462.

Song, B. and Y. Suh (2019). Identifying convergence fields and technologies for industrial safety: LDA-based network analysis. *Technological Forecasting and Social Change*, 138, 115-126.

Vukicevic, A.M., M. Djapan, M. Stefanovic and I. Macuzic (2019). SafE-Tag mobile: a novel javascript framework for real-time management of unsafe conditions and unsafe acts in SMEs. *Safety Science, 120*, 507-516.