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Fourth industrial revolution and new challenges in post-pandemic world

Keywords

Fourth industrial revolution, COVID-19 pandemic, manufacturing systems, control systems, automation

Abstract

This chapter addresses current issues of the Fourth Industrial Revolution (4IR) in the situation of pandemic COVID-19 declining after necessary lockdowns that have been extremely burdensome for society and business in many countries. Valuable experiences have been gained at the national and international levels how to effectively fight pandemic and what to do in post-pandemic world to achieve new objectives. These issues are discussed in the context of the Great Deal and New Deal as well as New Green Deal proposed for realisation in the European Union. There are significant challenges concerning the societal and economic prosperity, business development, ecology, and quality of life of citizens. The recovery funds created in the European Union to be distributed among its members regarding some rules should effectively support the business rebuilding within a sustainable development strategy. It is postulated to shape properly the future of 4IR to offer advanced technologies supporting effectively required changes in post-pandemic world.

1. Introduction

Fourth industrial revolution (4IR) is happening right now. Its beginning is dated in 2012, when a final report of the Science Union on “Industrie 4.0” was published in Germany. Most of us are just experiencing presently results of this revolution and its scale and magnitude in coming years is not yet fully known (Schwab, 2016).

The cyber-physical systems (CPS) and advanced controlling of smart machines and manufacturing systems form the basis of the Industry 4.0. New concepts of software-intensive systems have been lately developed and using widely the Internet for communication make it possible to apply more effectively the IoT (Internet of Things) technology. There are numerous benefits expected when the Industry 4.0 technologies will be successfully applied in practice, especially those supporting the business management advanced concepts in coming the New Deal situation.

Special attention is paid in this chapter to the safety and security of the information technology (IT) and operational technology (OT). These technologies require appropriate convergence for carrying out effectively the business processes and controlling manufacturing processes regarding the quality, dependability, safety and security aspects.

This chapter addresses selected technological issues related to 4IR in the situation of COVID-19 pandemic and new challenges in post-pandemic world. The role of the automation and industrial control systems, and innovative technologies is emphasised.

The background of 4IR and semantics of word *revolution* is discussed in the context of new technological trends. RAMI 4.0 reference model is outlined to explain the levels in technological and management processes in manufacturing systems. The ISA95 reference model of the industrial control system is recommended for dealing with the functional safety and cybersecurity of the systems and networks of critical infrastructure.

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Observed and potential impacts of the COVID-19 pandemic on critical infrastructure objects and systems is also discussed. Recommendations for dealing with the pandemic situation that have been proposed in United States and Europe are characterised. New technological developments are also discussed, some of them are evidently accelerated by the COVID-19 pandemic. In the final part of this chapter the issue of a general resilience is raised that requires more attention of researchers and practitioners.

2. Background of fourth industrial revolution

2.1. Industrial revolutions

Revolution and *revolt* have a shared origin, both ultimately going back to the Latin *revolvere* "to revolve, roll back". According to the Merriam-Webster dictionary, when *revolution* first appeared in English in the 14th century, it referred to the movement of a celestial body in orbit. Then, that sense was extended to "a progressive motion of the body around an axis," and "completion of a course".

At virtually the same time, using of this word was extended to a different meaning, namely, "a complete change" apparently in reverse direction, implicit in the Latin verb *revolt*, which initially meant "to renounce allegiance". So, semantics behind the word *revolution* is intricated. Currently *revolution* is defined (see Merriam Webster Dictionary) also as:

- a sudden, radical, or complete change,
- activity or movement initiated to effect fundamental changes in a socio-economic system,
- a fundamental change in the way of thinking about or visualizing something, also a change of paradigm, e.g., the Copernican revolution,
- a changeover in use or preference, especially in technology.

Revolutions have occurred throughout history of regions and states when novel ways of perceiving the world trigger profound changes in social structures and economic systems directed towards developing more effective technologies to meet the needs of increasing population.

Lately, there is a significant interest in research concerning industrial revolutions that follow to get deeper understanding of the processes behind those changes, their causes, and effects. Four industrial revolutions have been till now distinguished and characterised by well known domain researchers (Schwab, 2016; Schwab & Davis, 2018).

Industry 1.0. The first industrial revolution (1IR, dated in 1765 in some publications) followed the proto-industrialization period, i.e., between feudalism and capitalism. It started before the end of the 18th century to the beginning of the 19th. The biggest changes came in the industries in the form of mechanization using water and steam as energy sources. Mechanization was the reason why agriculture started to be replaced by the industry as the backbone of the societal economy.

At that time people witnessed increasing extraction of coal along with an important invention of the steam engine to be used soon in the industry and transportation. It enabled speed up the manufacturing and development of railroads for more efficient transportation of people and goods, thus accelerating the economy in the situation of intensive population growth.

Industry 2.0. The second industrial revolution (2IR, dated in 1870 in some publications), so began almost a century later than Industry 1.0. It started at the turn of 19th century, with massive technological advancements in the field of industries that helped the emergence of new sources of energy, i.e., oil, gas, and electricity. The result of this revolution was the creation of an internal combustion engine that started soon to reach its full potential. Other important points of this revolution were the development for steel demand, chemical synthesis, and new methods of communication such as the telegraph and telephone. Finally, the inventions of automobile, and the plane in the beginning of 20th century were the reason why 2IR is considered by some researchers as the most important one. There are opinions that it provided a basis for modern and dynamic socio- economic development.

Industry 3.0.

The third industrial revolution (3IR, dated in 1969 in some publications) began in the second half of 20th century, when the emergence of yet another source of untapped energy, i.e., nuclear energy for commercial producing electrical energy in nuclear power plants, on a large scale, become economically justified. This revolution brought forth the rise of electronics, telecommunications, and computers used widely in the industry for automation of processes and controlling of distributed systems.

Through the new technologies 3IR opened the doors to space expeditions, and advanced research including nanotechnology and biotechnology. In the industrial applications, two major inventions, namely: programmable logic controllers (PLCs) and robots helped giving rise to a new era of high-level automation and supervising the production processes in industry.

Industry 4.0. The fourth industrial revolution (4IR) is happening right now. In Figure 1 this revolution is dated in 2012, when a final report of the Science Union on “Industrie 4.0” was published in Germany. Most of us are just experiencing it presently and its dynamics and magnitude in time is not yet fully known. The 4IR revolution began in the dawn of the third millennium with common worldwide using the Internet and development of new technologies, for instance, the internet of things (IoT), autonomous vehicles, 3D printing, materials science, nanotechnology, biotechnology, energy storage, quantum computing, etc.

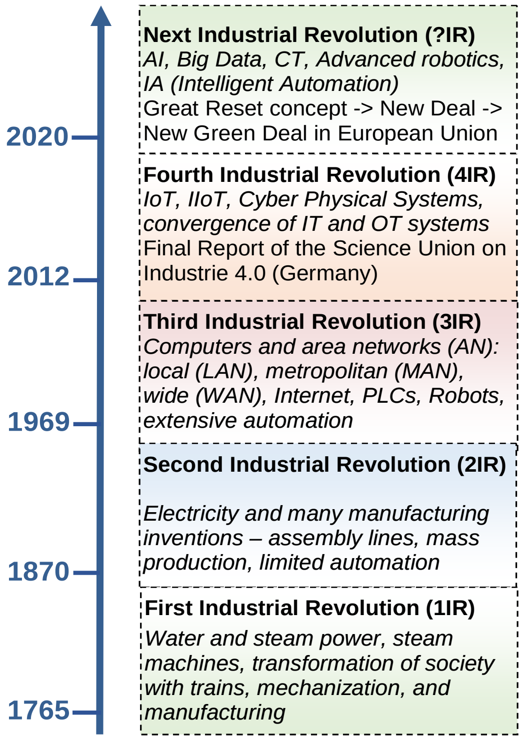

Figure 1. Consecutive industrial revolutions.

According to German “plattform Industrie 4.0” (https://www.plattform-i40.de; Fourth IR, 2021) the Industry 4.0 concept refers to an intelligent networking of machines and processes for industry with the help of information and communication technology.

Advanced wired and wireless technologies for information transmission have been developed for using worldwide advanced ICT (information and telecommunication technology) systems, based on distributed computer systems and data networks. The technology of cyber-physical systems (Lietão et al., 2016) is just under dynamic development and advanced implementations in distributed and interrelated industrial systems and networks.

Due to increasing ecological awareness of people worldwide, some crucial decisions have been undertaken at the international, regional, and national levels to react immediately to global warming and limit in coming years the emissions of warming gasses, mainly CO_2, mainly from the industrial and transportation sources. It will make revolutionary changes in energy systems to increase the role of renewable energy sources and shutting down in years to come the fossil-fuel power stations, especially the hard and brown coal-fired power plants.

The European Commission announced lately (EC, 2019) the European *Green Deal* for the European Union (EU) and its citizens. It resets the Commission’s commitment to tackling climate and environmental-related challenges that is treated as generation’s defining task. It is necessary due to observed already increasing climate changes with each passing year. One million of the eight million species on the planet are at risk of being lost. It is because the forests, seas, and oceans are menacingly polluted and destroyed.

The global problems are really challenging. The European *Green Deal* proposal is responding to current challenges. It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy promoting sustainable development and fulfilling an ambitious goal of net-zero emissions of greenhouse gases in 2050. There are increasing expectations that the EU recovery funds to be distributed, and innovative 4IR technologies will enable reaching these ambitious objectives.

It will surely lead to the revolutionary or at least dynamic evolutionary changes in manufacturing systems and other supporting systems to recover the socio-economic situation in the EU countries after lockdowns due to the COVID-19 pandemic. Therefore, in Figure 1 above the 4IR block an additional block is placed symbolizing a next stage “?IR”. How to name this block it is an open question if one come back to the semantic issues outlined at the beginning of this section, i.e., *evolution* or *revolution*? It is discussed in conclusions to this chapter.

2.2. Dynamic changes and uncertainties

As it has been outlined by Schwab (Schwab, 2016) in his widely known book *The Fourth Industrial Revolution*, based on works and opinions of experts from a think tank of the *World Economic Forum* (acquiring knowledge, and elaborating conclusions), we are witnessing profound shifts across society, economy, and all industrial sectors. New business models are emerging that reshape the production, and influence the consumption expectations, transportation systems, and the delivery chains. On the societal front, a paradigm shift is underway in how people work and communicate, as well as how they express expectations and opinions, communicate, and entertain themself.

Also, many institutions are being reshaped, as the systems of education, healthcare, transportation etc. New ways of applying new technologies to change the systems for manufacturing and production, distribution, and consumption, offer significant potential for the regeneration and preservation of natural environment. The changes are historic in terms of their size, dynamic, and scope (Rasmussen & Svedung, 2000).

While significant uncertainty is surrounding the development and adoption of emerging technologies, we do not yet know how the transformations driven by industrial revolution will unfold. Their flexibility, usefulness and interconnectedness across sectors imply that all stakeholders of global society – governments, business, academia, and civil society – have an opportunity ns responsibility to work together to better understand possibilities of emerging trends (Schwab & Davis, 2018) and influence them to increase social profits and reduce risks.

Shared understanding is particularly critical if we want to shape a good collective future that reflects common objectives and values. We should have a comprehensive and globally shared view on how technology is changing our lives and those of future generations, and how it can reshape positively the economic, social, cultural, and human context in which we live.

Mentioned above trends have potentially a dramatic effect on the necessary approach to model and understand systemic behaviour in some fundamental respects, and they rise the problems of modelling by structural decomposition versus functional abstraction and the problem of cross-disciplinary research versus multi-disciplinary co-operation (Rasmussen & Svedung, 2000).

We need more studies on the interactions among levels to be distinguished and evaluated in a socio-technical system with reference to the nature of the technological hazard they are assumed to control in the context of potential ecological consequences for some deteriorating phenomena and the risk of major accidents.

2.3. Industry 4.0 concept and technologies

As it was mentioned the Industry 4.0 concept is used interchangeably with the fourth industrial revolution (4IR) and represents a new stage in the organization development and manufacturing control in an industrial company.

The 4IR has been also perceived as current trend of automation and data exchange in manufacturing technologies using the cyber-physical systems, the Industrial Internet of Things (IIoT), cloud computing and cognitive computing for creating the smart manufacturing system/factory (Felser, et al., 2019; Kosmowski, et al., 2019).

The goal is to support autonomous decision-making processes, monitor assets and processes in real-time, and enabling operation of value creation networks through early involvement of stakeholders, and vertical and horizontal integration (Li et al., 2017; Fourth IR, 2021).

In an initial report ‘Industrie 4.0’ elaborated by a workgroup and published in 2013, some basic principles and foundations are specified that include:

- horizontal integration across value-added networks,
- vertical integration and networked/connected production systems,
- the technologies for CPPS (cyber-physical production systems),
- the consistency of engineering across the entire value chain,
- the new social infrastructures of labour/work.

Mentioned above integrations of systems and processes can be characterised as follows:

- a vertical integration of the systems in the traditional automation pyramid: from a field level and control level to production level, operations level, and an enterprise planning level,
- a horizontal integration which concerns mentioned end-to-end value chain: from supplier and the processes, information flows and IT systems in the product development and production stage to logistics, distribution and ultimately to the customer.

Two original concepts of the architectural frameworks have been initially proposed for further developing of advanced communication and control technologies (Fourth IR, 2021):

- Industrial Internet Reference Architecture (IIRA) proposed by the Industrial Internet Consortium, and then
- Reference Architectural Model Industrie 4.0 (RAMI 4.0) developed by German "Plattform Industrie 4.0".

The 3-dimensional RAMI 4.0 model emphasises that the production object must be tracked across its entire life cycle. This model describes the key elements of manufacturing system based upon the use of structured layers with distinguishing three axes (Fourth IR, 2021):

- architecture axis (layers in Figure 2) of six different layers indicating the information depending on the view to the asset,
- process axis (value stream) for including the various stages within the life of an asset and the value creation process based on the IEC 62890 standard,
- hierarchy axis (hierarchy levels) for assigning the functional models to individual levels based on IEC 62264 and IEC 61512.

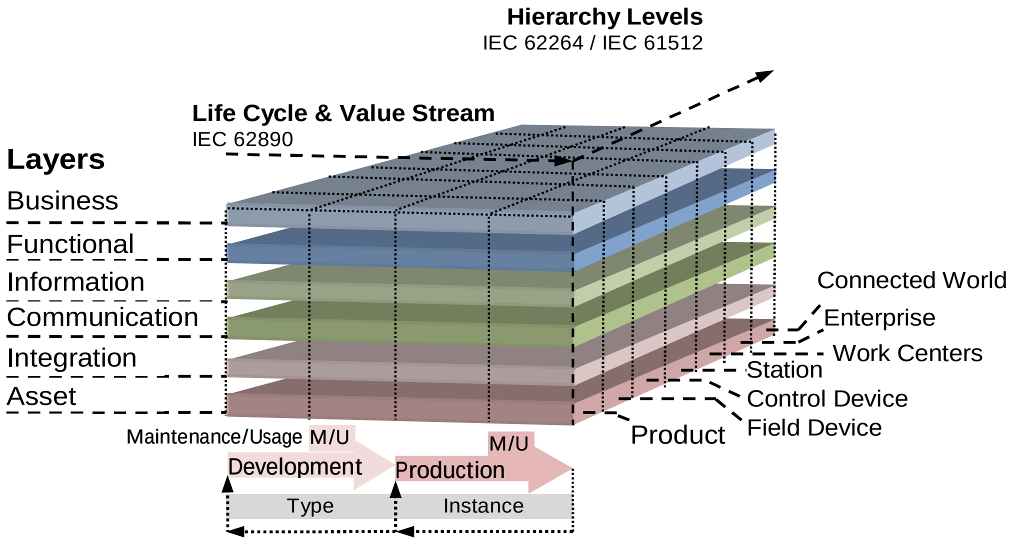

Figure 2. A reference architecture model RAMI 4.0, based on (Fourth IR, 2021).

The security related aspects should be carefully considered for these levels, value stream, and hierarchy levels as follows:

- layers – security related aspects apply to all different levels; the risk evaluation must be considered for the object / asset as a whole,
- value stream – the owner of the object must consider security across the entire life cycle,
- hierarchy levels – all objects / assets are subjected to security considerations (risk analysis) and need to possess or provide relevant security characteristics for fulfilling their tasks (providing protection).

As it is shown in Figure 2 the hierarchy dimension consists of 7 aggregation levels:

- the connected world,
- the enterprise,
- work centres,
- stations (or machines),
- control devices,
- field devices (sensor and actuators), and
- products.

It is worth a note that while traditionally these levels are seen as a "real hierarchy" and depicted as a pyramid, in Industry 4.0 they are more conceived and depicted as a mesh within a reality of ubiquitous connectivity of everything, including processes, devices, products, organizations, ecosystems and so forth (Fourth IR, 2021). The life cycle and value stream dimension cover some data mapping stages across relevant life cycles in RAMI 4.0 and across the entire value chain and the various processes, and stakeholders.

The third dimension, the architecture layers, consists of 6 components: business, functional, information, communication, integration, and asset. In fact, we should consider:

- the enterprise and its business processes,
- functions of assets,
- required data,
- communication as access to information,
- integration as, quote, transition from real to digital world, and
- assets as physical things in the real world.

Considering described above three dimensions together we obtain a three-dimensional (3D) production and service-oriented architecture.

Industry 4.0 refers to the convergence and application of following digital industrial technologies (Felser et al., 2019; Kosmowski, et al., 2019, Fourth IR, 2021):

- advanced robotics (cooperating industrial robots, integrated sensors, and interfaces),
- additive manufacturing (3D printing, e.g., for spare parts and decentralized facilities to reduce transport distances and inventory),
- augmented reality (for maintenance, logistics, and verifying all kinds of SOP – standard operating procedures),
- simulation / digital twins (for simulation of value networks, and optimisation based on real time data from intelligent systems),
- horizontal and vertical integration (cross company data integration, precondition for fully automated value chain from supplier to customer),
- industrial IoT (network of machines and products, multidirectional communication between networked objects),
- CT – cloud technology (management of huge data volumes in open systems, real time communication for production systems),
- cybersecurity (operation in networks and open systems, advanced networking between intelligent machines and systems),
- dependability and safety (OT dependability, functional safety of safety-related ICS – industrial control system, process safety),
- AI&ML – artificial intelligence and machine learning (value creation using smarter information for limited evidence or knowledge, improving machine-to-machine interaction, diagnostics of systems and processes, enhancing attack resilience and increasing cybersecurity of IT and OT),
- big data & analytics (evaluation of available data, e.g., from MES, ERP, SCM – supply chain management, and CRM – customer relationship management), data mining,
- block chaining (for growing list of records / blocks of data linked together with cryptography, e.g., for marketing and logistics, historical data processing to support decision making, SCM in time, audits and change management, insurance related data records in life cycle).

There is increasing interest in using advanced methods of bigdata analysis (BDA), and the artificial intelligence (AI) methods for supporting on-line and off-line decision-making. In business related activities and decision making in time the blockchain method and relevant software is nowadays of special interest for secure handling in time of interrelated blocks of data using advanced cryptography methods.

All of that require advanced knowledge and skills of managers and personnel to be consistent with the technological developments and changing conditions. Therefore, the expectations concerning effective training programs and practical exercises using relevant methods and supporting tools are increasing.

2.4. Hierarchical model of industrial control systems

The 4IR concept is based upon data models and data mapping across the mentioned end-to-end product life cycle and value stream. All the technologies in Industry 4.0 need to be seen in that perspective whereby integration is a key.

A first integration concerns convergence of the information technology (IT) and operational technology (OT) as illustrated in Figure 3. The hierarchy levels proposed are compatible with ISA95 reference model (IACS Security, 2020; Kosmowski et al., 2019). A cloud technology (CT) is increasingly used to support the business management regarding distributed data gathered and coordinated systemic control of installations and processes including optimisation, diagnostics ana maintenance.

It is worth a note that ISA95 model is more suitable for dealing with safety and security aspects of hazardous industrial installations, and the critical infrastructure systems and objects (ENISA, 2016). In such model usually five levels are specified, numbered in Figure 3 from 1 to 5:

1) field level (installations, sensors, actuators, EUC – equipment under control, drives, auxiliary equipment, etc.),
2) control level (I / O – input / output devices, PLC – programmable logic controllers, ICS – industrial control systems for control and protection, HMI – human machine interface; CC – continuous control, DC – discrete control, BC – batch control),
3) production control (DCS / SCADA / HSI – distributed control system / supervisory control and data acquisition / human system interface, AS – alarm system, DSS – decision support system),
4) operations level (MES – manufacturing execution system, QM –quality management, EN – environmental management, MOM – manufacturing operation monitoring, CME – current maintenance execution),
5) enterprise planning level (ERP – enterprise resource planning, BCM – business continuity management, CMP – computerized maintenance planning).

The information technology (IT) includes levels 4 and 5, whereas the operational technology (OT) encompasses levels 1, 2 and 3. Within OT the safety functions (SF) are defined to be implemented in a safety-related system (SRS). They are subjected to periodical testing (T) to diagnose potential danger failures within SRS (Kosmowski, 2013; IEC 61508, 2016) regarding a preventive maintenance (PM) strategy developed. The RAMSS (reliability, availability, maintainability, safety, and security) methodology is often useful to integrate the dependability, safety, and security analyses of OT (Kosmowski, 2021).

Historically, the standards concerning OT have been elaborated by the International Electrical Commission (IEC). The IT, on the other hand, is rather the domain of the International Telecommunication Union (ITU) and International Standardization Organization (ISO), which takes over most of the standards in the communication field from IEEE Standard group 802. The convergence of OT and IT, e.g., on an Ethernet network, with time sensitive networking (TSN) is an example of technology for real-time applications in manufacturing installations (Felser et al., 2019).

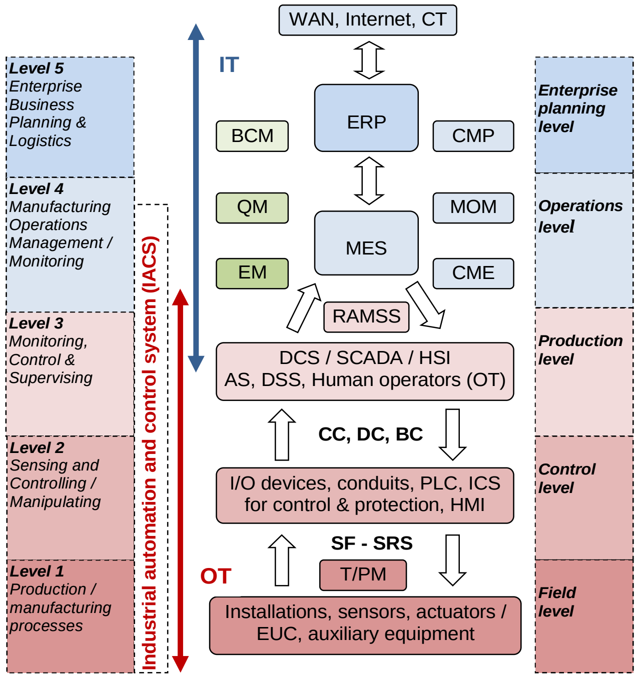

Figure 3. Reference model for operational management and control of an industrial manufacturing system, based on ISA95.

The safety functions must be defined and implemented in a safety-related ICS to limit risk of death or injuries during operation of machinery or accidents in the process industry installations. The architecture of these systems is designed regarding a functional safety concept for determined safety integrity level (SIL) based on the risk evaluation results (IEC 61511, 2016; IEC 62061, 2005).

The Industrial Automation and Control System (IACS) plays an important role in a process plant. It is designed and operated regarding the security-related principles (IEC 62443, 2018) specified for given domain regarding the security level (SL) and defined security assurance level (SAL). These aspects are discussed in detail in the publication (Kosmowski, 2020). It was proposed to integrate the safety and security-related analyses (Kosmowski, 2021).

In Figure 3 the IACS is represented using the distributed control system (DCS), and the supervisory control and data acquisition (SCADA) system with relevant interfaces: a human system interface (HSI) and human machine interface (HMI) at the lower level of IACS hierarchy (ENISA, 2016).

Lately, applying of an industrial protocol concept OPC UA (open platform communications, unified architecture) is of increasing interest to provide advanced communication from the factory automation and control systems to the CT infrastructure. This issue is related to the AutomationML concept implementation in the 4IR solutions (Kosmowski et al., 2019).

A concept of intelligent automation (IA) has been lately developed. The IA is a combination of artificial intelligence (AI), machine learning, and process automation that are used to create smart business processes and workflows that can learn and adapt to specific situation. The IA is also considered as advanced combination of the robotic process automation (RPA) and artificial intelligence (AI) technologies (Lee et al., 2018) that together empower rapid end-to-end business process automation and accelerate digital transformation processes.

2.5. Industry 4.0 benefits and performance indicators before pandemic era

There are numerous benefits expected when the Industry 4.0 technologies will be successfully applied, also those at the development stage to be soon implemented in industrial practice. They stem from achieving in near future following objectives (Fourth IR, 2021):

- productivity (thanks to advanced control and automation reducing production time, better asset utilisation and inventory management),
- flexibility (using a set of machines and robots for various products),
- quality (using sensors and actuators that monitor current production in real time that enable quickly intervening in case of errors and inadequacies),
- speed (from prototype to final product through consistent data and / or simulation).

These depend on the site manufacturing conditions and can improve:

- dependability of equipment thanks to the use of advanced protections,
- security of industrial computer systems and networks,
- safety through advanced automation and using safety-related ICS (industrial control systems) i.e., implementing verified and validated functional safety solutions,
- innovative capability (through applying new technological possibilities in manufacturing / production),
- environmental protection (through optimized use of resources and reducing energy consumption for processes and drives of machinery, and reducing risk of accidents),
- working conditions (through ergonomically optimised stands, workstations, and advanced HMI / HIS interfaces),
- training and collaboration (through acquiring knowledge and advanced design of production systems, and availability of consistent data).

As it was mentioned the horizontal integration in Industry 4.0 solutions refers to the integration of IT systems for and across the various production and business planning processes, from supplier to consumer, end-to-end integration of IT and OT systems, and the information flows and analytics of available data. The life cycle and value stream dimension of RAMI 4.0 is of interest for planning early data collection and provisioning.

The entire internal development, production, and business processes, from suppliers to consumers, can be characterized as follows (Fourth IR, 2021).

Development:

- market analysis, design, proof of concept,
- prototyping, pre-production, market launch.

Production:

- production planning, operation assets,
- materials, procurement, staff,
- manufacturing parts, automation,
- production performance, assembly,
- quality control.

Logistics:

- warehouse management, transporting and packing, preparation for shipping,
- reception of goods, planning of demand.

Distribution:

- (demand management, processing of quotes, processing of orders,
- delivery / shipping, tracking, return management.

It is expected that horizontal integration will help with horizontal coordination, collaboration, cost savings, value creation, speed (as an enabler of smooth service and operations but also of faster time to market and worker's efficiency) and some possibilities to create horizontal ecosystems of value, based on knowledge and information available.

In a wite paper prepared for the World Economic Forum three key technology megatrends transforming production are indicated (WEF, 2019):

- connectivity (creates links between network nodes, increasing visibility),
- intelligence (automates event recognition and translation for decision-making), and
- flexible automation (incorporates response mechanisms, automation, and remote movement).

The Industry 4.0 companies differ in practical approach to business and applying innovative technological solutions from the continuous improvement efforts that have characterized factories for decades. It is expected to be not purely incremental but involves rather a step-by-step change in resetting benchmarks. So called companies-lighthouses employ different use-cases to transform their operations (WEF, 2019).

Table 1 consists of selected key performance indicators (KPIs) that present the impact of the 4IR solutions in the lighthouse factories. For instance, in some factories a high productivity increase was observed (up to 160%), and time to market was reduced (up to 90%).

Table 1. Impact of 4IR solutions on selected KPIs in lighthouse factories (WEF, 2019).

Aspect	KPI evaluated	Impact range observed
Productivity	Factory output increase	10-200%
	Productivity increase	5-160%
	OEE increase	3-50%
	Quality cost reduction	5-90%
	Product cost reduction	5-40%
Agility	Energy efficiency	2-50%
	Inventory reduction	10-90%
	Lead time reduction	10-90%
	Time to market reduction	30-90%
	Change-over shortening	30-70%
Customization	Lot size reduction	50-90%

Adoption of 4IR technologies at suitable scale can have a radical impact upon companies. A close look at mentioned three megatrends makes it clear just how powerful the effects can be. An analysis McKinsey Global Institute projects a remarkable gap between companies that adopt and absorb artificial intelligence (AI) within the first five to seven years and those that followed later or lag. The analysis suggests that AI adoption in "front runners" can anticipate up to a cumulative 122% cash-flow change, while "followers" will see a significantly lower impact of only 10% cash-flow change (WEF, 2019).

It shows the importance of early adoption of new technologies, since companies that postpone important decisions may risk missing a large share of the benefits. Company leaders who move to the implementations earlier, rather than waiting for decreased technology and related transition costs, will realize the greatest benefit.

3. Infrastructure and human factors

3.1. COVID-19 pandemic impact on critical infrastructure objects and systems

The COVID-19 pandemic impacted remarkably some important systems of the critical infrastructure. Figure 4 illustrates average daily total load of the electric grid in selected European countries across peak hours (2020 as % of 2019) from 2nd of March to 3rd of April 2020.

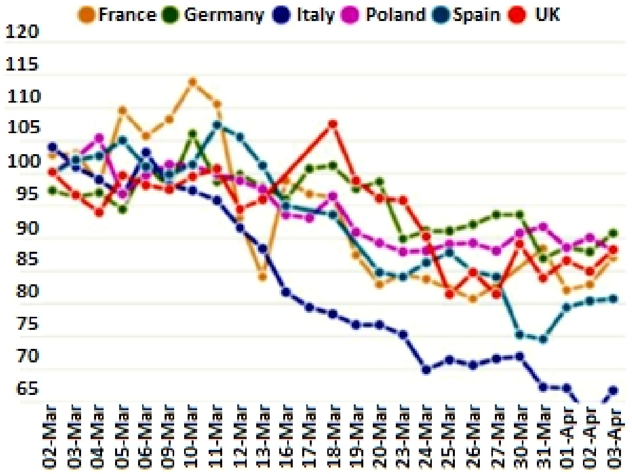

Figure 4. Daily electrical energy load drops in some European countries during pandemic (Uzelac et al., 2020).

As it can be seen in Figure 4 at the beginning of April 2020 the electric grid load drop was to the level of about 90% in Poland, 80% in Germany, and about 70% in Italy. It indicates significant lowering of the industrial production in that period due to lockdowns in some sectors because the production output in most countries is almost proportional to the electric grid load.

Most industrial facilities throughout the world have had to make substantial adjustments to their operations due to the COVID-19 pandemic. They faced problems due to:

- reducing staff involved in certain operations, for a few weeks and sometimes much longer,
- shut down their site installations completely for weeks or months during national, regional, or local lockdowns,
- re-organizing operations to ensure proper social distancing, enforce mask-wearing, etc.
- experiencing dramatic economic impacts, such as lower earnings because of the production shortage, or
- substantially exhausting activity because of increased demand due to the pandemic.

Therefore, it is justified to obtain an overview of good risk management practice and to gain insights on:

- how industrial sectors have been coping with these changes?
- how competent authorities have tried to support them?
- how competent authorities perceived that the pandemic has influenced risk at hazardous sites?

The OECD Working Group on Chemical Accidents (WGCA) approached following the fatal accident in India in May 2020 and asked if a response information could be provided. The Bureau of the WGCA agreed to write a note addressing this accident and issues related to start-up following lockdown. The EU JRC (Joint Research Center) Major Accident Hazards Bureau agreed to publish the content, as this was the fastest way to bring attention to the issue (Wood et al., 2021). Finally, two accidents in India and Italy have been analyzed.

Visakhapatnam, India, 7th-8th May 2020

Leak of hazardous gas from a polymer plant, Visakhapatnam, Andhra Pradesh India of 7th-8th May 2020. A leak of hazardous gas led to the death of at least 11 people and injuries to hundreds more. The authorities have reported that a release of gas from styrene tanks occurred in the early hours of the morning (around 3 am) on 7th May 2020. The polymer plant was restarting following shutdown due to the COVID-19 pandemic. Media reports and the official investigation report suggested that the styrene had been stored for a long time (Wood et al., 2021).

Ottaviano, Italy, 5th May 2020

An explosion at a plastics factory killed one person and injured two others and resulted in shelter-in-place of residents in vicinity. The factory reopened on 4th May after the government eased the lockdown following the coronavirus pandemic.

Typical process safety advice given by authorities during the COVID-19 pandemic are as follows (Wood et al., 2021).

Staffing issues:

- operators must assure minimum workers are present to keep the site running safely,
- operations should be stopped if not enough staff,
- maintenance activities (e.g., continuity, staffing),
- availability of professional competences for specialized tasks,
- managing fatigue should be monitored and managed,
- companies should plan for shut down and startup,
- specific guidance on planning turnarounds,
- batch process recommended to reduce disruption.

Compliance and enforcement:

- legislative requirements still should be respected,
- discretionary enforcement and compliance guidelines (e.g., administrative requirement delays, equipment certification),
- operators must notify the authorities when restarting.

Safety management system issues:

- change management processes for reduced staff were followed,
- SMS was adapted to reflect new arrangements,
- measures in place for also resuming normal operations post-COVID-19,
- sites should plan for possible delays in obtaining safety critical components and spare parts,
- several respondents noted that reduced staffing levels should already have been part of the SMS (e.g., in case of worker strike),
- template for evaluating the site’s pandemic response and lessons learned,

- site must confirm that "all necessary measures" have been taken to prevent incidents.

There are challenges and recommended priorities for high hazard site inspections due to the COVID-19 pandemic. Everyone's top priority should be to maintain high levels of protection on site while reducing exposure of personnel and inspectors to the risk of contracting the virus (Wood et al., 2021). Some challenges were specified as follows:

- re-organizing and adapting inspections,
- maintaining morale of the inspection staff when they could not do their jobs,
- supporting sites that were critical to the normal functioning of society and ensuring that their critical staff could keep working (healthcare, childcare, etc.),
- testing the internal and external contingency plans in a pandemic context,
- limited inspection of the physical site,
- varying ability of some sites to correspond effectively in digital mode.

There are some important lessons to be learned for the risk management of chemical accidents concerning:

- management of organizational change and its importance to maintaining site safety in transition times,
- management of staff changes, working with staff turnover, staff reductions, and other constraints,
- the automation contribution and limitations for the foreseeable future, because it is now still very fragmented and only suitable for certain operations,
- the importance of the IT systems for communication and OT systems including protections for safe and secure operations,
- the issue when required onsite inspections can be replaced with remote inspections, and priorities for onsite inspections,
- how the remote inspection methods can make inspections better, and on which aspects they should be focused?

3.2. Shaping human and organisational factors in socio-technical systems

It is well known that human and organisational factors significantly impact the dependability, safety, and security of any technical system (Kosmowski, 2003, 2013, 2021). When this impact is crucial, it is justified to examine a socio-technical system. An interesting monograph was published by Rasmussen and Svedung (Rasmussen & Svedung, 2000) devoted to the proactive risk management in a dynamic society in relation to technical systems. Several nested levels and factors were considered that potentially influence the decision making within risk management. In any hazardous process installation some categories of factors, called environmental stressors, can be identified with relevant domains or disciplines specified as follows:

- work (mechanical, chemical, and electrical engineering),
- staff / personnel (psychology, human-machine interaction / interface (HMI), work conditions, human factors, ergonomics),
- decisions and controls (planning of production, control of processes, quality criteria, proactive maintenance),
- company management (company policy and economics regarding the decision theory, organisational sociology; key performance indicators – KPIs; management processes and procedures, etc.),
- regulators (regulations and standards concerning inspections and maintenance; environmental and site requirements; safety and security criteria),
- state governance (law and ordinance, standardization and legal procedures for the design and operation).

In the Formal Safety Analysis (FSA) methodology of the International Maritime Organisation (IMO) (FSA, 1993), several levels of factors influencing relevant risks, including the human and organisational factors, are specified. For insurance purposes following two levels with relevant influence factors have been considered depending on the risk evaluation objectives (Kosmowski & Gołębiewski, 2019).

Direct level:

- human (competences, training, experience, motivation, HMI, etc.),
- technology and software (quality of materials, aging properties, construction, systems architecture, HIS, network / software functionality, safety, and security-related technologies),
- environment and infrastructure (environmental conditions, potential influence of neigh-

bouring installations, availability of media source, etc.),

Organizational level:

- management processes and procedures (quality & updates, strategy for business continuity management – BCM including inspections and testing of protections),
- emergency procedures (internal and external communication, training, exercises, sources of information),
- organisational culture (leadership, , safety & security culture, awareness and staff involvement),
- management of changes (formal description, frequency, and audits, etc.),
- maintenance and diagnostics (preventive maintenance, supporting tools, spare parts, administrative control, and inspections),
- competences & communication (personnel training programmes, certification, etc.).

Relevant factors for a site considered can be placed in hierarchical influence diagram (HID) as shown in Figure 5 that potentially impact a scenario of interest in the risk evaluation for specific industrial plant and environmental conditions (Kosmowski, 2003).

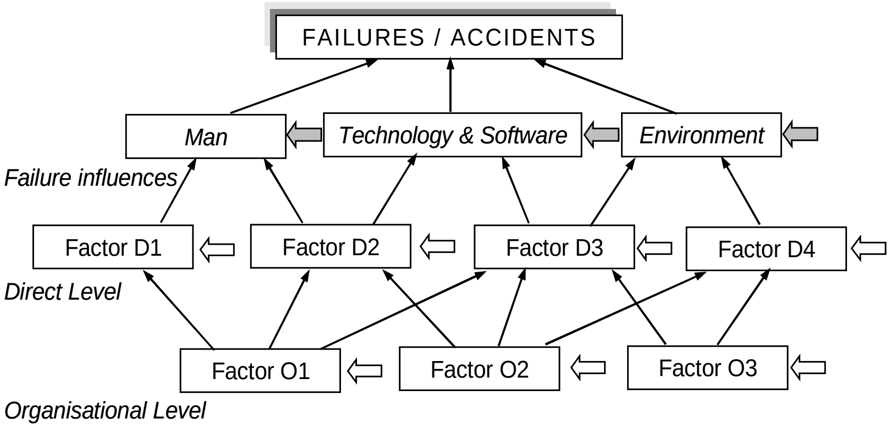

Figure 5. Influence diagram for including human and organisational factors in technical system evaluation.

The number of levels in a plant specific HID can be assumed depending on the purpose of evaluation in the probabilistic modelling and information available, including expert opinions. Aggregating of qualitative and quantitative information used in the HID is based on normalized ratings (r) and weights (w) of relevant factors to be aggregated at consecutive levels (Kosmowski, 2003).

Such formal representation of relations between relevant factors is useful in the probabilistic modelling and the risk evaluation, similarly, how it is done in the FSA methodology (FSA, 1993). Some vectors of the influencing factors with specific rates and weights can be modified for some environmental conditions, e.g., for pandemic situation.

It seems to be justified to postulate that the pandemic in relation to a socio-technical system can contribute to a macro common cause failure (CCF). Thus, it can significantly increase the risk of a forced industrial installation outage or an accident with major consequences.

In the publication of Solarz and Waliszewski (Solarz & Waliszewski, 2020) a holistic framework is proposed in which pandemic COVID-19 is treated as a systemic risk. Some researchers (Sasangohar et. al, 2020) propose a concept of the disaster ergonomics for dealing with human factors in the COVID-19 pandemic situation for emergency management.

These issues require further research in the context of a generic system modelling of defined category, and then evaluation of specific system to be treated as the socio-technical system when justified. Its safety and security properties in the context of proposed interfaces and protection functions needs to be carefully considered.

3.3. Critical infrastructure sectors and recommendations for pandemic situations in United States and Europe

The issue of pandemic COVID-19 activities to limit risk of potential consequences will be discussed on examples of United States and Europe.

There are differences in various countries in defining the critical infrastructure and indicating responsible institutions for their developing and current operation.

For instance, in the United States the Centre for Disease Control and Prevention (CDC) defers to the Cybersecurity and Infrastructure Security Agency (CISA), which is considered as the nation's risk advisor, responsible also for defining critical infrastructure sectors (Krebs, 2020).

These are organizations whose assets, systems, and networks – whether physical or virtual – are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on national public health or safety. CISA 3.0 and the CDC define a critical infrastructure worker as a worker employed in the following sectors:

- healthcare and public health,
- law enforcement, public safety, and other first responders,
- food and agriculture,
- energy,
- water and wastewater,
- transportation and logistics,
- public works and infrastructure support services,
- communications and information technology,
- other essential functions,
- critical manufacturing,
- hazardous materials,
- financial services,
- chemical,
- defense industrial base,
- commercial facilities,
- residential shelter facilities and services,
- hygiene products and services.

In CISA's latest guidance (the 4.0 memo issued on August 18, 2020) the education workers are added as critical infrastructure workers, and the organizations that provide transportation, operational, and administrative support for education facilities.

Specified above CISA categories are then broken down into descriptions of workers and the tasks they perform in the critical infrastructure objects and systems. To determine whether business considered belong to the critical infrastructure regarding the CISA and CDC guidance, its employee must perform one of the tasks described in each category (Krebs, 2020).

Some examples of the categories, tasks, and business or professions that would be considered as the critical infrastructure are following.

Healthcare and public health:

- researchers (i.e., in laboratories),
- healthcare providers (i.e., physicians, dentists, nurses, pharmacists, and their assistants and aids, administrative professionals, and similar workers), and
- healthcare support services (i.e., third-party transportation services for healthcare, laundry services, billing, IT, childcare services, manufacturers, and healthcare vendors and suppliers).

Food and agriculture and energy / water:

- sellers of food or beverages (i.e., grocery stores, restaurants, convenience stores and other retail that sells food, whether human or pet, online ordering services),
- manufacturing and distribution (i.e., manufacturers or energy providers, and their suppliers, vendors, farmers, and supply chains and the support services for those supply chains, security), and
- manufacturing and maintenance of equipment or services (i.e., machine shops, repair shops, parts vendors, supply vendors).

Public works and infrastructure support services / communication and technology / other essential functions / critical manufacturing:

- these categories are broad, and include nearly any business that supports the response to the COVID-19 pandemic, or
- supports other categories of critical infrastructure with logistics, personnel, IT, transportation, manufacturing, or any other services that critical infrastructure businesses need to perform their functions as required.

Addressing confirmed COVID-19 cases and exposure to COVID-19 in critical infrastructure will be an issue for the foreseeable future, and one should review and update the COVID-19 mitigation and contact tracing policies to comply with the latest CDC guidelines.

To ensure that response is consistent with current guidance, if there is any doubt as to whether business is classified as critical infrastructure by CISA, or before continuing to operate in one of the states that do not defer to CISA's guidance, one should seek the advice of counsellor.

Challenges and priorities for operators due to the

COVID-19 pandemic have been specified also in Europe (European Commission) for three following issues (Wood, 2021).

Managing safety:

- ensuring adequate supervision on site,
- handling maintenance activities, risk-based decisions (postpone or go ahead?),
- shutdown and start-up, having backup plans for critical infrastructures,
- adapting the SMS, management of change, e.g., to changes in staff, emergency planning, maintenance, IT security, etc.

Managing staff:

- protecting staff from exposure to the virus, ensuring that sick employees stay at home,
- managing labour shortages and surpluses, and employees working from home,
- having access to specialized competences and certifications.

Survival:

- keeping the sites open, especially sites important to society, despite reduced staff,
- kaintaining the installations with respect to input and output of raw material, energy, products and waste, spare parts,
- financial and economic survival.

Almost all operators have made enormous efforts to adapt quickly to the new situation and to take the necessary measures, presumably without postponement of maintenance activities. No incidents so far were caused due to using the pandemic measures (Wood, 2021). Some examples of good practices have been noticed including:

- good communication with authorities, and sites in similar situation,
- agreements between neighbouring Seveso sites on exchanging experience and support during similar incidents,
- development of quality guidelines and procedures for the COVID-19 situation and the post covid strategy in one establishment,
- creation of safe operating programs due to deferred maintenance turnaround, informing about cases of successful turnarounds,
- execution of high-level management of change evaluations, stopping of production lines to review risks, etc.,
- systematic approach to maintenance including expert consultation to determine which to postpone,
- continue strict enforcement of pandemic measures, rapid adaptation of workspaces and schedules.

4. Fourth industrial revolution and post-pandemic challenges

4.1. Great reset and new deal

Schwab and Malleret (Schwab & Malleret 2020) in their monograph *The Great Rest* began with the statement that the macro reset would occur in the context of the three prevailing secular forces that shape our world today: interdependence, velocity, and complexity. They claim that this trio exerts its force, to a lesser or greater degree, on us all, whoever or wherever we may be.

Such world can be a world of deep systemic connectivity, in which all hazards and threats, and related risks affect each other through a web of complex interactions. In such conditions, the assertion that an economic risk will be confined to the economic sphere or that an environmental risk will not have repercussions on risks of different nature (economic, geopolitical, and so on) is illusory and no longer tenable.

Lately, a European *Green Deal* for the European Union members and their citizens was announced. It resets the Commission’s commitment to tackle climate and environmental challenges. The atmosphere is warming, and the climate is changing with each passing year. One million of the eight million species on the planet are at risk of being lost. Forests and oceans are being polluted and partly destroyed.

The European *Green Deal* is a response to these challenges. It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from conventional energy sources.

It also aims to protect, conserve, and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related impacts and risks. It must put people first, and pay attention to the regions, industries and workers who will face the greatest challenges.

Since it will bring substantial change, active public participation and confidence in the transition is paramount if policies are acceptable and workable. A new pact is needed to bring together citizens in all their diversity, with regional, local, and state authorities as well as civil society and industry of distributed ownership.

The *Green Deal* is considered as an integral part of Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals with priorities to be announced. The objective is to put sustainability and the well-being of citizens at the centre of economic policy.

It is almost inevitable that the pandemic will prompt many societies around the world to reconsider and redefine the terms of their social contract. We are just witnessing the fact that COVID-19 has acted as an amplifier of pre-existing conditions, bringing to the fore long-standing issues that resulted from deep structural frailties that had never been properly addressed before (Schwab & Malleret, 2020).

4.2. Post-pandemic recovery and challenges

The social expectations are still high in many countries, partly due irresponsible promises during elections. Opinions are expressed (Klaus & Malleret, 2020) that in the post-pandemic era, according to current projections, the new economic "normal" may be characterized by much lower growth than in past decades. As the recovery begins, quarter-to-quarter GDP (Gross Domestic Product) growth may look impressive (because it will start from an exceptionally low basis), but it may take years before the overall size of most nations' economy returns to their pre-pandemic level.

In Figure 6 some global economic prospects are expressed in terms of the GDP in OECD countries. As it can be noticed the prognosed economic situation in these countries is expected to be slightly improving in coming years, but continued divergence is expected across countries (OECD, 2020). This is also because the severity of an economic shock inflicted by the coronavirus will conflate with a long-term trend: declining populations in some countries and ageing (demographics is a crucial driver of GDP growth). Under such conditions, when lower economic growth seems almost certain, many people may wonder whether "obsessing" about growth is even useful, concluding that it does not make sense to chase ambitious target of ever-higher GDP growth (Schwab & Malleret, 2020).

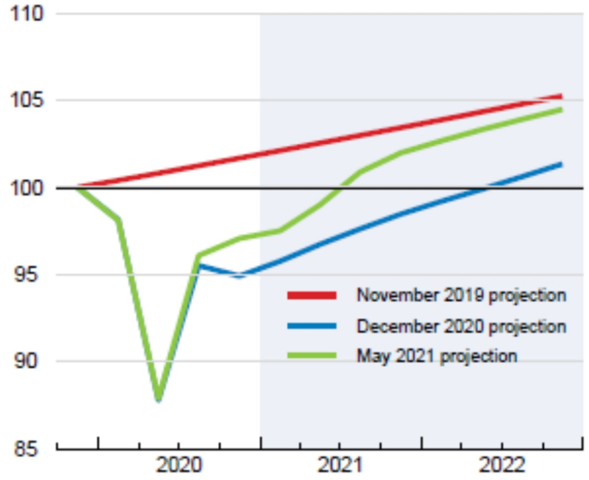

Figure 6. Global economic prospects expressed in terms of GDP (index 2019Q4 = 100) in OECD countries (OECD, 2021).

Nevertheless, the situation concerning business seems to be rather optimistic in some countries in near future if expressed using the global or local composite PMI (Purchasing Managers' Index). This index treated as an economic indicator, is being derived from monthly surveys of mainly private sector companies. PMI data are presented in the form of a diffusion index. If PMI index is equal 50.0 it means that the business situation is unchanged, a number over 50.0 indicates an improvement, while anything below 50.0 suggests a decline.

In Figure 7 two curves of the global composite PMI are presented for the input prices and output prices in 2020 with a projection to 2021. As it can be seen the business situation was improving in a second half of 2020, but then due to next lockdown the situation was worsening.

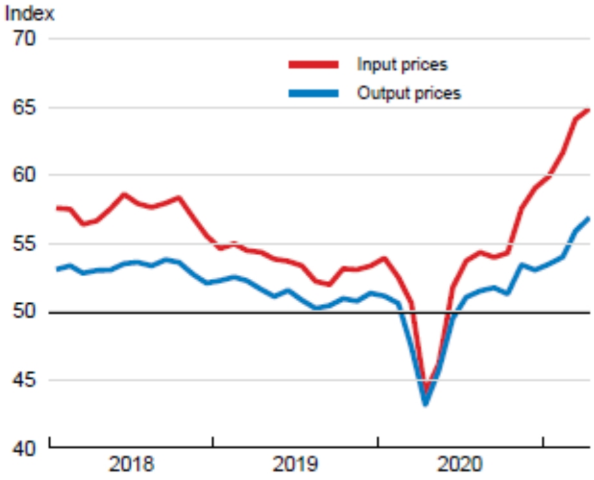

Figure 7. Global composite PMI during pandemic (OECD, 2021).

In second quarter of 2021 the business situation started to be rather optimistic. The IHS Markit Poland Manufacturing PMI rose sharply to 57.2 in May of 2021 from 53.7 in April, well above market expectations of 54 and the highest level registered since the survey began in 1998 (see Poland's Manufacturing PMI on the Internet for Trading Economics).

The difficulties tend to be greater for small businesses that, on average, operate on smaller cash reserves and thinner profit margins than large companies. Moving forward, most of them will be dealing with cost–revenue ratios that put them at a disadvantage compared to bigger companies. But, as it is known, being small can offer some advantages in today's world where flexibility and celerity can make all the difference in terms of adaptation.

The COVID-19 crisis has laid bare the inadequate state of most national health systems, both in terms of treatment costs of patients and shortages of the medical staff including nurses, doctors, and supporting paramedics. In some countries, where tax-funded health services have suffered for a long time from a lack of resources, e.g., in the UK and Poland, due to political concerns about rising taxes, calls for more spending (and therefore higher taxes) will get louder. It becomes evident that postulated "efficient management" cannot compensate the investment shortages and necessary treatment and rehabilitation expenditures, including COVID-19 health consequences.

Another aspect that can be critical for social contracts in Western democracies pertains to guarantee of liberties and freedom. There is currently growing concern that the fight against the COVID-19 pandemic (and potential future one) will lead to the creation of societies subjected to permanent surveillance.

Some political theorists emphasize that extraordinary powers require authorization from the people through the democratically elected parliament and must be limited in time and proportion. This issue requires special attention during realization of *Great Reset* activities in the EU countries regarding the recovery funds foreseen for New Deal including those for the technological and infrastructural development and local expectations.

An important issue is honest accessibility to the European recovery funds to be gradually spend and supervised in coming years in a democratic way. Member States have prepared the national recovery plans pledging to the reform of their economies and to unlock allocated share of funding, which will be distributed from 2021 to 2023. An access to sufficient financial resources from external and internal sources, and effective funding of many projects is at present a key issue in many European countries.

The European *Green Deal* accepted and unprecedented crisis triggered by COVID-19 require enormous funds to make realistic revitalizing economies of the EU members. European leaders agreed on 21 July 2020 on a package worth €1,824 billion. It combines the EU's 2021-2027 budget amounting to €1,074 billion and an additional package for Next Generation EU recovery plan of €750 billion.

The Next Generation EU recovery plan "aims to address the damage caused by the pandemic and invest in a green, digital, social and more resilient EU", as well as reducing risks of further EU fragmentation. EU's Recovery and Resilience Facility (RRF) is considered as "the key recovery instrument at the heart of the Next Generation EU which will help the EU emerge stronger and more resilient from the current crisis".

We are still in early days of the post-pandemic era, but new or accelerating trends have been already initiated. For some industries, these will prove to be a boon, but for others a major challenge. However, across all sectors, it will be up to each company to make the most of these new trends by adapting with celerity and decisiveness. The businesses that prove the most agile and flexible will be those that emerge stronger for the future (Schwab & Davis, 2018).

Like other crises, COVID-19 has revealed both the shortcomings of the EU's capacity to respond to the crisis posed by the pandemic and subsequent economic collapse. Now the resilience of the EU countries and their economies are becoming key issues to be build up regarding the experiences gained during pandemic. A solidarity policy and lessons learned on how to make the budgetary and financial rules more flexible should be profitable. So, the crisis due to COVID-19 pandemic and coordinated counteractions undertaken can be also treated as an opportunity.

4.3. Towards effectiveness and resilience

The COVID-19 pandemic has also an impact on the way the EU and its members think about the security issues. Published recently document outlines the EU's approach to security. The EU Security Union Strategy gives a lot of attention to COVID-19. This document states that the COVID-19 crisis has reshaped the notion of safety and security threats and corresponding policies. It highlights the need to guarantee security in both the physical and the digital environments and underlines the importance of strategic autonomy for supply chains in terms of critical products, services, infrastructures, and technologies.

Resilient supply chains are also crucial from the Industry 4.0 point of view. The very nature of global supply chains and their innate fragility means that arguments about shortening them are becoming crucial now to create effective solutions in international trade. They are also difficult to monitor in terms of compliance with environmental standards and labour laws, potentially exposing companies to reputation risk and damage to their brands.

In the post-pandemic era, it is necessary to make "end-to-end value optimization". Such idea includes both resilience and efficiency alongside related costs that will undoubtedly prevail. It can be epitomized rather in a new formula that "just-in-case" will eventually replace "just-in-time" (Schwab & Malleret, 2020).

Another problem is related to the governments and relation of the business processes in public and private sectors. The COVID-19 pandemic has rewritten many (of not fully known) rules of the game between the public and private sectors. In the post-pandemic era, business will be subject to much greater government interference than in the past. Possible greater intrusion of governments in the activities of companies and conducting of their business are country and industry sector dependent, therefore can take many different guises. There are three notable forms of impact that will emerge with force in the early months of the post-pandemic period including: (1) conditional bailouts, (2) public procurement, and (3) labour market regulations. They should be supervised and controlled to achieve short- and long-term profits in a country development (Schwab & Malleret, 2020).

There are statements concerning 4IR that technology and digitization will revolutionize almost everything, making new solutions more effective for people, states, and international society respecting ecological constraints. Technological innovations will support expected changes throughout the world. The experiences till now are optimistic as the technological progress has moved impressively fast.

AI is now all around us, from drones and voice recognition to virtual assistants and translation software. Our mobile devices have become a permanent and integral part of our personal and professional lives, helping us on many different fronts, and anticipating our needs. Automation and robots are reconfiguring the way businesses operate with staggering speed and returns on scale inconceivable just a few years ago (Schwab & Malleret, 2020).

An interesting view concerning waves of innovations through industrial history was published recently by Newman (2020). His insights are illustrated in Figure 8. The 6th wave was triggered by the COVID-19 pandemic, and it was named in short, the ***renewable energy***.

Thus, new opportunities and emerging developments are foreseen, some of them being accelerated by the COVID-19 pandemic. Below some examples are specified:

- spread out of distance meeting and learning.
- massive home office,
- the growing popularity of e-shopping,
- intensifying the data transmissions using 5G,
- intelligent towns and rural districts for smart co-operation,
- smart control of renewable energy sources,
- remote health monitoring, advanced diagnostics for computer-aided treatment,
- intelligent traffic control for conventional and autonomous vehicles,
- advanced manufacturing based on secure IoT and IIoT technologies,
- remote 3D construction technologies,
- applications of safe and secure drones in various industrial sectors and transportation,
- setting up post- COVID-19 supply chains,
- application of AI methods (Lee et al., 2018), big data analytics, data mining, machine learning, and AI for decision making,
- integration of WAN, MAN, CT, and Internet for creating advanced technologies of CPS

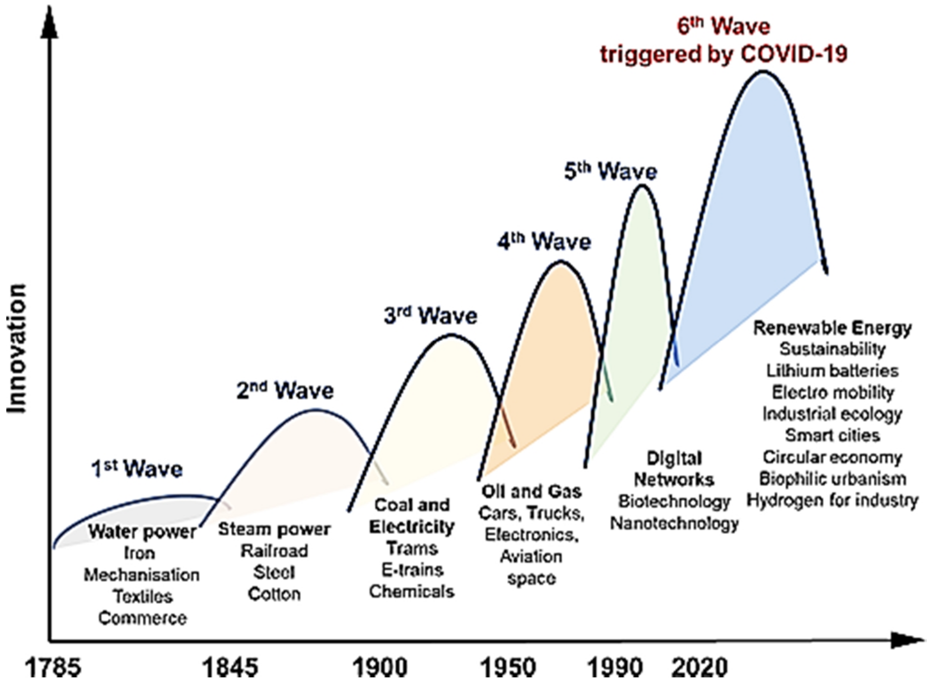

Figure 8. Waves of innovation through industrial history and into the future (Newman 2020, wileyonlinelibrary.com)

(Cyber physical systems) including smart and secure interfaces based on cognitive methods,

- advanced automation (AutomationML based on secure OPC UA protocol), and intelligent automation (IA) technologies.

Thus, it is expected that the automation and control systems will play increasing role the post-pandemic world together with advanced monitoring and management systems. Evaluation of increased costs concerning some 4IT technologies are presented in Table 2.

Table 2. Estimation of increased cost of technologies used in 4IR, based on (Lawrence, 2020)

Technology and related activities	Increased costs
Automation and control systems	54%
Monitoring/management systems	54%
Infrastructure and networks security	43%
Staff salaries (overtime & bonuses)	34%
Additional cloud capacity	31%
Disaster recovery services	29%
Additional operations personnel	21%
R&D (safety & security)	20%
Training & certification of personnel	25%

Three areas will be of special interest for people and decision makers in the post-pandemic era: high tech, health, and wellness. The banking, insurance and automotive sectors are three different examples of industries that should immediately build greater resilience to pass through the deep and prolonged recession caused by the health crisis due to COVID-19 pandemic.

The key issue in post-pandemic world will be resilience that can be perceived in various dimensions including people, individuals, business, economics, constructions, technologies, safety, and security. The functional safety and cyber security issues of the industrial automation and control systems (IACS) that require integrated evaluations are discussed in the report (CISA, 2020) and publications (Kosmowski, 2020, 2021) regarding relevant international standards (IEC 61508; IEC 63074; IEC 62443; ISO / DIS 22301; ISO / IEC 24762; ISO / IEC 27001; ISO / IEC 27005; NIST SP 800-82r2).

It is emphasised often (OECD, 2014, 2020) that the security and especially digital security is a borderless issue, requiring a combination of the inter- and intra- sector and country collaboration. The private and public sectors partnership is needed to effectively address threats. A strategic approach is required to move collaboration beyond the law enforcement, intelligence agency and information security 'circles of trust' that exist today, which focus mainly on operational and tactical threat information sharing.

5. Conclusion

A deep crisis provoked by the COVID-19 pandemic has given us plenty of opportunities to reflect on how our economies and societies work and some ways for improvements. Will the experience gained during pandemic and lockdowns open the door to a better future? Resetting is an ambitious task, perhaps too ambitious, but we should try our utmost to make it. As it was emphasized by Schwab & Malleret (2020) there are new challenges to create the world less divisive, less polluting, less destructive, more inclusive, more equitable and fairer than we left it in the pre-pandemic era.

This chapter addresses selected issues of the 4IR in the situation of COVID-19 pandemic declining after lockdowns that have been extremely burdensome for society and business in many countries. Valuable experiences have been gained at the national and international levels how to effectively fight pandemic and what to do in post-pandemic world to achieve in coming years corrected socio-economic objectives.

These issues are discussed in the context of the Great Deal and New Deal as well as New Green Deal proposed for realization in the European Union countries. There are significant challenges concerning the economic prosperity, business, ecology, and quality of life of citizens. The recovery funds created in the European Union and already distributed in its member states should effectively support required changes.

It is postulated to shape properly the future of 4IR to offer innovative technologies supporting effectively necessary changes in post-pandemic world. Special attention is paid in this chapter to the safety and security of industrial automation and distributed control system.

The background of Fourth Industrial Revolution and semantics of word *revolution* is discussed in the context of new technological trends. The RAMI 4.0 is outlined to explain the levels in technological and management processes of manufacturing systems. The ISA95 reference model of the industrial control system is recommended for dealing with the functional safety and cybersecurity of the critical infrastructure systems and networks.

It seems to be justified to write an acronym 5IR (Fifth Industrial Revolution) in an upper block in Figure 1 that means a next “revolution” to be aimed at sustainable development (SD) regarding socio-economic and ecological (SEE) aspects. It can be considered locally or regionally (in some countries, e.g., the EU members).

There are many hot topics behind of global and geo-political nature including natural and drinking water resources, social well-being, and social justice to be discussed at international levels and shaped in interested countries regarding local situation and accepted values.

Observed impact of COVID-19 pandemic on critical infrastructure objects and systems is also discussed. Recommendations for dealing with pandemic situation that have been proposed in United States and Europe are characterized. General resilience problem is raised that requires more attention of researchers and practitioners.

There are still many substantial problems to be gradually solved at the international and national level, for instance to successfully shift Poland to net-zero economy (Bukowski et al., 2019). It requires more active involvement of scientific community in verifying proposed climate policy in cooperation with experts representing relevant international organizations.

Next necessary step is to undertake research aimed at acquiring multidisciplinary knowledge concerning COVID-19 pandemic to be useful for decision making in the process of implementing advanced technologies in practice (Gajewski & Paprocki, Ed. 2020). The Industry 4.0 technologies discussed in this chapter have significant potential to help in gradual solving of many existing and emerging problems.

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