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SMART MANUFACTURING AND PROJECT MANAGEMENT

MONOGRAPH

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INTRODUCTION

The key technologies of the digitalisation, Third and Fourth industrial revolutions, supported by Internet of Thnings (IoT) and AI are setting the stage for what is being called Industrie 4.0 (I 4.0). The concept is geared towards the integration of intelligent machines and AI systems into manufacturing processes and supply chains. With the promotion of the I 4.0 concept, companies have started to build smart manufacturing (SM). However, in order for companies to establish SM, a number of projects need to be developed and implemented. The work of people on production lines is being displaced by technology. Workers' positions are reorganised according to the needs arising from changes in technological (production) processes. Projects are implemented not only in the production halls, but also outside them. In the smart factory, the configuration of the production cycle will be determined by intelligent technologies and products, making their own selection of the locations of the next processing steps and submitting to the subsequent processing operations thus determined, resulting from the current state of product processing. Project Management (PM) has a new goal of success called 'Smart Manufacturing'. As defined by the PM methodology manual BOK – A Guide to the Project Management Body of Knowledge (2012) USA, Publisher: PMI: project management focused on the effective achievement of a project objective, within a defined timeframe and with a fixed budget and high quality. In an environment of accelerated commercialisation of new I 4.0 technologies, the number of projects in companies is growing rapidly. There is an overlap of ongoing projects and employees and project teams are constantly involved in improving project results. The opportunities for investors to build a smart environment seem endless. Companies that are on the path to I 4.0 are struggling to manage SM projects. At the project implementation stage, questions are being formulated: which project management methodology to use (cascading or agile)? How to organise the project team? How to protect intellectual property? How will the human factor cope with change? The list of questions is open-ended and is constantly being expanded with more questions. As technology evolves and more (next) projects are implemented, companies identify new issues in SM project management.

The authors of this monograph wanted to add to the knowledge of project management new aspects concerning the development of smart manufacturing projects (SMPs). Due to the wide range of changes in PM, the monograph is only an introduction to project management (PM) in SM. The monograph consists of four chapters dealing with aspects of SMPs. Chapter one deals with the essence of the I 4.0/SM concept. The second chapter contains knowledge about PM, which is enriched with information about patent procedures in Poland and the USA. The

Human Factors (HF) is devoted to the third chapter. The last chapter deals with the Lean philosophy in smart manufacturing.

The monograph complements the knowledge of students and practitioners about PM in the smart environment. To increase the readership, the book has been prepared in English. The authors hope that the monograph will be well received by the Readers.

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1

INDUSTRIAL MEGATRENDS AND SMART MANUFACTURING

1.1. CHALLENGES OF THE TWO LAST INDUSTRIAL REVOLUTIONS

In the history of industrial development, so far, there have been four revolutions. The first and second revolutions are historical, while the third revolution and the fourth revolution are current. Figure 1.1 shows the industrial revolutions and their key achievements. The last two revolutions are strongly changed manufacturing processes. Their caused changes based on strong interactions of automation of activities, data collection and data processing and exchange in processes, and smart technologies with humans, which, step by step, are changing manufacturing into smart manufacturing.

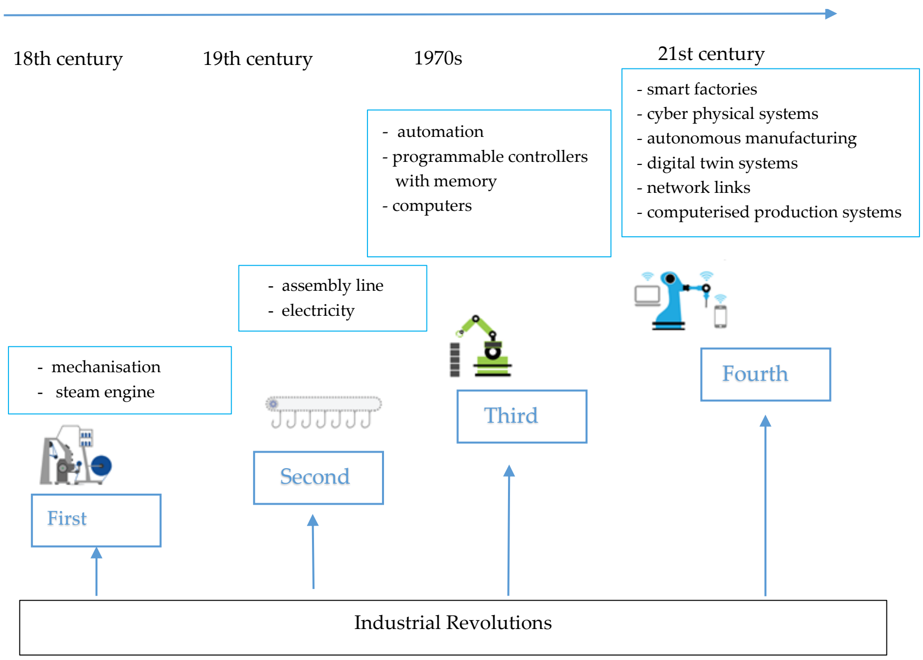


Fig. 1.1 The history of industrial revolutions
Source: Own elaboration based on [1, 2]

In the Third Industrial Revolution, technology strongly replaced manual labour and further increased industrial production. A feature of the revolution is Robotic Process Automation (RPA) and Computer Business Processes (CBS). The technologies are taking over the execution of business process step by step. Robotic Process Automation (RPA) is mainly applied to the activity of frequently performed tasks, which can be described by rules of conduct (algorithms) [3]. These rules are programmed and executed by the IT system when specific triggers occur. RPA ensures the high quality of the work performed, mainly by avoiding process errors. Automation rules are repeatable and can be created by their users, without the need to involve central IT departments [4].

The automation of business processes is strongly linked with the development of IT tools. ICTs improve the performance of employees and ensure better quality of processes. The computerisation of business processes (CBP) was accompanied by orchestration, i.e. standardisation of the IT tools used in the organisation. Orchestration is needed because the number of IT tools in companies still increase and new links between them are created. Computer Integrated Manufacturing (CIM) is an important area of change in CBP. ICTs has been strongly linked to the processes of supply, production, management, etc. Companies have implemented the following systems to control the entire production process: ERP (Enterprise Resources Planning) – management support system, which includes modules such as finance; HR (Human Resources) – accounting, customer management, sales, production, logistics, maintenance, reports; APS (Advanced Planning and Scheduling) – responsible for production planning and scheduling, MES (Manufacturing Execution System) – used for production registration, PLM (Product Lifecycle Management) – supports product management, BI (*Business Intelligence*) – business analysis, decision support, and other systems [5].

Development of automation caused that new process management methods and techniques, e.g. Six Sigma, Lean Management (LM), Quality Management (QM) are introduced by companies. New management concepts were applied to improve process management on assembly lines in factories. Attention to quality and the elimination of waste became challenges for companies at the end of the last century. On the one hand, the determinant of the change was the development of the (ISO 9000) standard on quality, on the other the market success of Toyota, which initiated the TPS (Toyota Production System) based on Lean principles [6].

The Third Industrial Revolution is transforming into the Fourth Industrial Revolution called *Industrie 4.0* (in German). The features of the revolution are [7, 8]:

- strong digitisation of business processes both in enterprises and supply chains,
- development of decision-making techniques based on virtual simulations and real-time data processing,
- access to Big Data obtained from machines and manufacturing process technologies and stored in the cloud computing,
- development of industrial robots and application of artificial intelligence (AI) to machine learning (ML),
- development of the Internet of Things (IoT) and machine-to-machine (M2M) and machine-to-people (M2P) communication.

In the Fourth Industrial Revolution, more and more companies are adopting full automation and robotics, Internet of Things (IoT), Web3, blockchain, 3D printing, genetic engineering, quantum computing, and intelligent machines, integrated into modern communication systems based on the exchange of a lot of data, are creating machine learning (ML). Cognitive automation, intelligent automation, machine learning are technologies that, through advanced data analytics, by observing human work, technologies are able to search for activities themselves that can be automated. The technology detects patterns and repetitive problems, recognises the procedures to be performed when they occur, and then takes over their execution (often self-assessing its level of knowledge and accuracy) [9].

The Fourth Industrial Revolution is based on standards and components of process, interconnection and flexible systems, networks, rules of process optimisation and virtualisation, analysis of product life cycle (LCP), humans collaboration with robots, components of product and machines, communication of everything and everyone, horizontal and vertical integration of processes etc.

New industrial technologies will create smart factories in which production systems, and their components, are autonomous. Already in many factories, production is surrounded by digital technologies and mechatronics of products and processes. Computerised production systems equipped with network links, with established digital twin systems, communicate with other facilities and transmit data about machines, product components and processes. The networking of physical objects and digital technologies leads to the creation of 'cyber-physical production systems' (CPPS). According to Baheti and Gill, Cyber-Physical Systems (CPS) is defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities [10]. Cyber-physical production systems (CPPSs) are forms of integrating smart manufacturing into networked enterprise systems [11]. CPPS in the result of "marriage" the cyber word (space) and physical word (Figure 1.2).

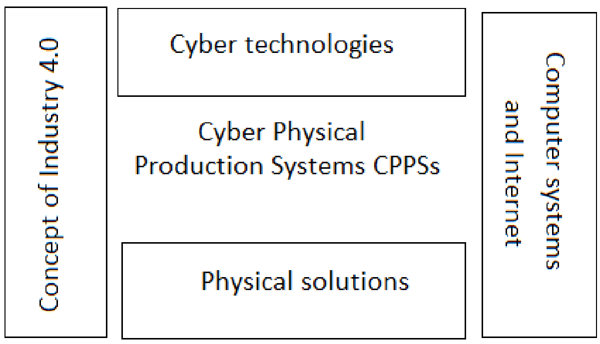


Fig. 1.2 Cyber-Physical Production Systems: components were used to definition
Source: Own elaboration, author B. Gajdzik.

Wang et al. (2015) presented the following definition: CPS are "embedded computers and networks which monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" [12]. The Cyber-Physical Production Systems (CPPSs) are the solutions for smart factories (more about the CPS in: [13, 14, 15]).

Lee et all. [15] proposed five levels of CPS, called by them "The 5 Architecture of CPS". The structure provides a step-by-step guideline for development of CPS in enterprises:

– Level I: "Smart Connected Leve" with plug &play, tether-free communication, and smart networks.
– Level II: "Data to Information Conversion Level" with smart analytics, maintenance, multi-dimensional data correlation, computer prediction.
– Level III: "Cyber Level" with twin models form components and machines, time machine for variation identification and memory, cluster for similarity in data mining.
– Level IV: "Cognition Level" with integrated simulation and synthesis, remote visualization for human, collaborative diagnostic and decision making.
– Level V: "Configuration Level" with self-configure for resilience, self-adjust for variation, self-optimize for disturbance.

The Cyber-Physical Production Systems (CPPSs) currently being developed are 'islands' of intelligent machines with storage systems, accessing data in cloud computing and collaborating with the Industrial Internet of Things (IIOT). The systems are capable of autonomously exchanging data and triggering actions to autonomously control each other. The Industrial Internet of Things (IIOT) enables the exchange of data provided by sensors mounted on machines that operate in real time and transmit the data to a local server or cloud server, where data analysis is performed and process prediction models are developed. In the future the systems will create the smart factories.

Production systems are increasingly autonomous hybrid structures with real world objects and computers, improving as the infrastructure for equipment and people to communicate evolves [16]. The physical components of supply, production and distribution processes are increasingly linked to the computer world, and these systems cannot (should not) be considered separately. These hybrid structures are used to control processes in companies and supply chains. Systems (CCPSs) enable real-time optimization of processes, management of product quality throughout the supply chain, early detection and prediction of process anomalies, prediction of the remaining life of critical components by means of tools using data (often Big Data) captured by sensors (according to predictive maintenance algorithms).The systems control process execution with a reduction in live labour (manual labour has been replaced by machine learning). Virtual solutions take over the monitoring of business processes [17, 18]. The functioning of the systems requires interoperability, which means that all systems are able to communicate with each other by creating modular configurations in network systems. Highly modular cyber-physical systems are able quickly to adapt to new requirements (replacing or exchanging individual modules) by building ever better process solutions [19].

Machine learning (ML) and Intelligent Artificial (AI) increase the autonomy of business processes. CPSs are more accurate in production planning, predicting downtime, resource management, etc. Developments in technology are resulting in continuous increases in productivity. Smart factories have state-of-the-art production lines, backed up by a carefully constructed process for the transport and distribution of final products, often able to match competences and resources to planned processes. To test (validate) processes, virtual (digital) copies of the real world (digital twin) are created. Computer process visualization in the CPS allows the monitoring of the physical processes carried out in the company. Sensors on the machines and sensor data together with a virtual model of the plant and processes, as well as simulation models, create copies of the real world. Process technologies make decentralised decisions about the flexibility of operations, in terms of reacting to events and anticipating changes. Production optimisation takes place in real time. RFID tags tell machines which work steps are necessary for an efficient process. A huge number of sensors and sensors provide data on machine operation, which is analysed in real time (Big Data Analytics). As a result, central planning and 'post' control are no longer necessary. Machines, through the Internet of Things, communicate and collaborate with each other and with humans in real time. Internet and cloud computing increase access to operational services (Internet of Services – IoS) [20]. Internet in the Fourth Industrial Revolution is so popular, that is the Internet of Everything (IoE). Intendent is needed for M2M (Machine – to – Machine), learning machines, blockchain, product tracking etc. [21]. CPSs are changing production modes, manufacturing engineering, material and energy supply, materials management, product life cycles, value chains. Network relationships are in collaborative manufacturing processes, in logistics chains (integrated networks), in resource sharing (resource networks, distributed networks), in project execution (project networks, pulsed networks) and during data exchange (virtual networks).

Although processes are constantly being improved there is still much of the potential of the technologies that are called 'smart' that have not been exploited. Collaborative robots can bridge the gap between traditional robots and workers and open up new areas for optimising processes in real time. Industrial robots in autonomous manufacturing systems can perform work in a very human-like way, with the added ability to monitor and transmit data in real time, as well as machine learning. The industry of the future will have smart factories, operating in global networks with cooperative machines, storage systems and manufacturing in the CPS [21].

Smart factories with CPPSs will produce more and more smart products with the characteristics of unique, original products, obtained from the latest materials, manufactured using additive technology (e.g. 3D printers). To have personalised products, the customer participates in the design of the product, its creation and even the final assembly of the product. The customer communicates his or her expectations, predispositions and even dreams to the manufacturer. The customer participates in the design of the product remotely (remote collaboration) using the latest technology for the transmission of messages, images, sounds, etc. Smart factories produce for the customer (mass production has given way to individual production). In smart factories there is a high (strong) interaction between customer and producer (customer and producer get to know each other in order to produce better and better products) [22, 23, 24]. In CPPS, a hybrid value is created. Hybrid value creation can be defined as "the process of generating additional value by innovatively combining products (tangible component) and services (intangible component)" [25].

Conclusion: the key features of the industrial megatrends in the Third Industrial Revolution and the Fourth Industrial Revolution are: automation of business processes, robots, additive manufacturing, artificial intelligence and machine learning, Big Data, IoE, M2M, interoperability and process visualisation, decentralisation, and cyber-physical systems. More and more self-optimize CPSs are able to cooperate with each component, machine and process in real-time and improve efficiency of business. The smart technologies are able to produce more and more personalized products.

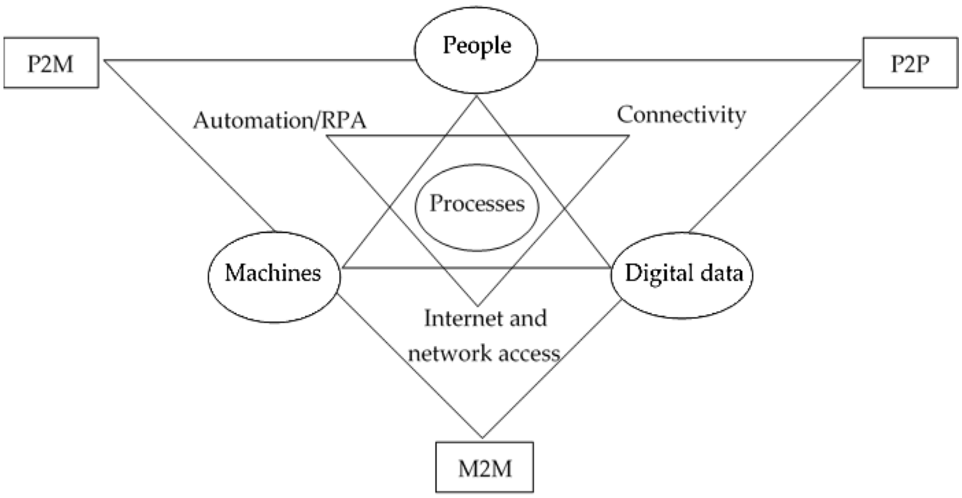
1.1.1 Business digitalisation in smart manufacturing (SM)

The term "digitisation" was coined in the 1950s. Digitisation is the processing of analogue material into digital form [26]. Synonyms for digitisation were (at the time) data processing, document scanning or digital photography. The development of computer technologies have made digitisation an agent of change in business processes by creating access to data on a global basis. At the end of the last century, digitalisation entered economies and societies, starting the transformation towards global digitality. Technological advances have resulted in analogue data being quickly converted into digital data, easily read and transmitted to users.

Digitalisation is an ever-improving process of convergence of the real and virtual worlds. Digitalisation is a major driver of innovation and change in economies around the world. In broad terms, the term 'digitisation' is being replaced by 'digital transformation'. Modern digitisation is based on a range of digital and computer technologies. Some of the most popular digital technologies are Artificial Intelligence, Machine Learning, Virtual Reality and Augmented Reality, Robotic Process Automation (RPA), Quantum Computing, Edge Computing, Blockchain, 5G, Internet of Things (IoT), etc.

At present, many companies are in the process of digitization. Business digitalisation means transforming any business into a digital business using digital technologies. The main purpose of digitalisation is to generate higher revenue and create new value-added opportunities. With people having better access to computers and the Internet, digitalisation has become widespread. In today's world, advanced digital technologies are increasingly penetrating almost all aspects of people's daily lives and business activities. Digital transformations are revolutionizing all aspects of manufacturing, touching processes and productivity but also people (virtual and online training). Digitalisation is opening up new fields of business activity and competition for companies. The key technologies driving the digitisation of industries globally are: Internet of Things (IoT) and Internet of Everything (IoE), ubiquitous connectivity (hyper connectivity), cloud-based applications and services, Big Data Analytics (BDA) and Big-Data-as-a-Service (BDaaS), full automation (full automation) and robotization, multi-channel and Omni-channel distribution structures for products and services. Modern digitalisation in combination with physical objects is intelligent, i.e. it takes over many of the functions previously performed by humans [27, 28].

Digital businesses rely on technology to operate and grow. Depending on the industry, this can look like: using paperless in the workflows, using productivity apps and task management systems to automate workflows, using artificial intelligence to improve the customer experience and capturing data to improve business intelligence. For online-only businesses, doing 100 per cent of work through digital platforms. R. Berger (2015) [29] identifies four components of digitalisation: digital data, automation, connectivity, digital customer access. In intelligent digitalisation, the process of creating, transferring, processing and storing large amounts of data has been embedded in people-to-people (P2P), people-to-machine (P2M), machine-to-machine (M2M) communication. Communication is not limited by time, space, but Internet and network (5G) access is needed. Key components of modern digital business are presented on Figure 1.3.



RPA: Robot Process Automation

Fig. 1.3 Triad of industrial digitalisation

Source: Own elaboration. Author: B. Gajdzik

Information and computer technologies collect and analyse data on customers, suppliers, contractors and other stakeholders. Technologies perform real-time data analysis, build models of current trends based on full data sets (Big Data), forecast 'stocking', etc. Ubiquitous connectivity means that an increasing number of businesses are in constant communication with customers, suppliers, contractors (24 hours a day, 7 days a week). Communication through online channels and social media is strongly personalised. Here are examples of areas of digitization in companies:

– digitalisation of information (digital storage and processing of data to obtain information and create knowledge about processes, machines, components, products, users etc.),
– digitalisation of communication (various forms of digital communication at all levels of the organisation and within supply chains, as well as between the company and its stakeholders),
– digitization of supply (computerised planning of material needs, control of stock levels, etc.)
– digitalisation of production on the principles of a pull system (customer-organised production),
– digitalisation of products and services (equipping products with data collection and transmission solutions, e.g. QR codes),
– digitalisation of distribution (e.g. online shopping),
– digitalisation of operational technology (installation of sensors for data transfer in machines, RFID in flow organisation, computer-aided process visualization, etc.),
– digitalisation of finances (accounting and financial management of the company with the support of IT systems, e-invoice accounting),
– digitization of other processes within the company and within the supply chain (strong emphasis on vertical and horizontal integration with the support of ICTs).

A requirement for good process digitization is the integration of information and computer systems. In many manufacturing companies, the beginning of process integration is the purchase of an integrated package of ERP system software modules to support management, above all the economic and financial activities of the companies and their contacts with the business environment. Other IT systems are attached to ERP systems in enterprises, supporting:

– production planning processes, production scheduling, manufacturing optimisation,
– online dispatching operations to: monitor, control and report the work of production departments,
– analysis of operating parameters of equipment, as well as reporting of irregularities and disturbances of these parameters of technology,
– monitoring of technological lines inside companies,
– control of internal transport and logistics,
– reactions of technologies to limit states, prediction of potential threats and emergency states,
– cataloguing, archiving and speed of controlled access to technical documentation of processes,
– diagnosis of technical states of control systems in basic machines,
– metering and billing systems for electricity and raw materials,

– heterogeneity and inter-modality of IT and automation communication networks,
– management of repair and production assets (systems intended mainly for maintenance services),
– management of real estate and property records,
– other systems for handling processes or systems and facilities.

Companies need to invest in tools to analyse data and correctly interpret its results to optimise processes and the efficiency of operations. IT systems work with cloud computing and IoT. A strong link between operational and digital technologies is a determinant of intelligent business (more in [30]). Table 1.1 presents used technologies in digital business.

Table 1.1 Examples of technologies using in digital business processes

Technologies	Applicability/results
Business Intelligence (BI) tools used for corporate decision-making.	– the ability to create automated and personalised processes, – flexible adaptation of production to the unique needs of the customer, – a wide range of proactive measures, – an analysis of the customer's behaviour, purchasing history and experience.
Integrated ERP system	– ERP package supports the resources management, – ERP analyses the economic and financial spheres of company, – ERP supports relations with the business environment.
Electronic payment systems	– solutions such as e-invoicing, online communication, company website, social media, etc. – business customers are most often interested in optimising invoice workflow processes in the first instance. This is the area in the office that is the fastest to undergo digital transformation and, with good experience, allows digitisation to be extended to further fields. Modern OCR (Invoice Optical Character Recognition) systems can immediately index individual elements such as invoice number, contract number, customer's VAT number, date or amount to be paid when scanning. They can even load dozens of invoices per minute. An advanced OCR system automatically enters the read invoice into the VAT register and triggers further accounting processes (e.g. debt recovery) in the FK system or logistics processes in the ERP system.
RPA: Robot Process Automation	– RPA of operations allows real-time to operate processes immediately and solve problems without delay, – RPA reduces production time and increases precision, – RPA in the company and supply chain reduces operating costs.
Internet and network (5G) access	Internet creates new opportunities to maximise the number of interactions of multiple participants with devices, and devices with each other.
Big Data - processing large, variable and diverse data sets	– Big Data correlation analysis of huge volumes of related and unrelated with different sources, – Big Data Analysis creates entirely new added value by combining data, finding data, establishing correlations, reusing data, extending data, increasing the scope of analysis, cleaning up heterogeneous source data structures, penetrating data sets, etc.

Cloud Computing - a group of services aimed at facilitating the process of data management through the use of computing power, storage, network access and various applications available on the servers of external providers.	– Cloud Computing provides the opportunity to collect and process data (internet communication) using the cloud provider's IT resources, – the company does not need to have an extensive IT architecture, and instead of purchasing systems and applications - companies pay a subscription for the use of ready-made or custom-built solutions available on the provider's servers.
IT platforms, servers, process virtualisation	– IT platforms are used to manage facilities and processes, using 2D imaging technology and Virtual Reality 3D modelling (employees equipped with special virtual goggles), – Platforms have an "open" configuration and can combine various types of specialised software into a single operating system, making it possible to build integrated simulation programmes on their basis, – IT platforms used in companies have interactive, interdisciplinary and intuitive operating menus that make it possible to learn how to work on the platforms without the use of a manual, based on intuitive selection of operational functions.
Mobile applications (computer software that runs on mobile devices such as mobile phones, smartphones, PDAs or tablets).	– People working with the company have access to the company's digital website and its mobile applications (images, maps, content, graphics, etc.), including: interactive upload tools data, navigation systems. – Authorised persons have access to non-public networks (e.g. extranet - a non-public telecommunications network which can be accessed from accessed from access points located in organization).
Sensors (tools that are most often a component of a larger system whose function is to capture signals from the surrounding environment, recognise and record them)	Sensors and transducers are used in the automation of production processes they detect changing measured quantities and then produce the corresponding output signals. Various types of sensors (optical, electromagnetic, inductive, ultrasonic, capacitive, etc.) are used in companies.

Source: Own elaboration. Author: B. Gajdzik

Digitization of business involves the introduction of technological solutions in various areas of activity within the company. With the right strategy and implementation of new solutions, the company becomes more efficient and competitive in the market. The implementation of the digitisation process in the company can consist of three stages.

- Stage 1: Preliminary identification. At this stage, it is important to have a mutual understanding of the company's processes and to identify areas that require technical improvements.
- Stage 2: Optimisation study. The result of this stage is a prepared functional specification and architecture for the new system.
- Stage 3: Implementation. Realisation of the set objectives and adaptation in the company.

Conclusion: digitization is dedicated to companies that want to organise their documentation and increase their capacities and the efficiency of their employees and operational technology. Through process digitisation, the number of repetitive and monotonous activities performed by employees is minimised. The role of RPA (Robotic Process Automation) software is growing in Digitisation. The widespread use of RPA depends mainly on the good identification of repetitive activities performed by employees in the company. Entrepreneurs are already aware that IT solutions are available on the market that allow tedious and repetitive work to be significantly automated, and they are reaching for them more and more. A very important element related to Robotic Process Automation is also the use of business process modelling (BPM), which defines the conditions for performing a given operation. The use of robotization additionally allows processes to be controlled in the event of unexpected external events. In addition to RPA, some of the most popular digital technologies are Artificial Intelligence, Machine Learning, Virtual Reality and Augmented Reality, Quantum Computing, Edge Computing, Blockchain, 5G, Internet of Things (IoT), etc.

1.2. PILLARS OF INDUSTRY 4.0 AND THEIR TRANSFORMATION TO INDUSTRY 5.0

The concept of "Industry 4.0" was founded on the technologies of the Fourth Industrial Revolution. The concept is a very general direction of industrial development based on the strong interactions of full automation and robotization of production, Big Data processing and exchange, smart manufacturing and smart factories. The detailed features of Industry 4.0 are described by Professor Klaus Schwab in his work entitled "The Fourth Industrial Revolution" [31].

The term "Industrie 4.0" was used, first time, in the project about high-tech strategy, by the German government. The project highlighted the need to accelerate the computerisation of manufacturing processes in order to proceed with the development of high technologies. The term "Industrie 4.0" was used at the Hanover Fair in 2011. In October 2012, Bosch GmbH presented a set of recommendations to the government for the implementation of high technology in industry. Based on these recommendations, the final report "Industrie 4.0" was developed and presented on 8 April 2013 [32].

"Industry 4.0 describes the organisation of production processes based on technology and devices autonomously communicating with each other along the value chain in virtual computer models" [33]. The concept takes account of the increased computerisation of the manufacturing industries where physical objects are seamlessly integrated into the information network. As a result, "manufacturing systems are vertically networked with business processes within factories and enterprises and horizontally connected to spatially dispersed value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics"[34].

The first platform called 'Plattform Industrie 4.0' was established in Germany in 2013. The platform was the result of an agreement between three business associations:

BITKOM, VDMA, ZVEI. The German platform was the first common knowledge platform for digital and smart technologies of the Fourth Industrial Revolution. The platform quickly became popular and more components were added. The architecture of Industry 4.0 was embodied in RAMI 4.0 (German: Referenz Architektur Modell Industrie 4.0). RAMI 4.0 [35]:

- is a three-dimensional map showing how to approach the issue of Industrie 4.0 in a structured manner,
- ensures that all participants involved in Industrie 4.0 discussions understand each other,
- is a service-oriented architecture,
- combines all elements and IT components in a layer and life cycle model,
- breaks down complex processes into easy-to-grasp packages, including data privacy and IT security.

The success of the German platform has inspired other European Union countries to develop their own Industry 4.0 platforms. Information about the platforms is available on the European Union website at: https://ati.ec.europa.eu. Participants in the platforms include representatives from business, science and politics. Participants are grouped into project teams with different thematic scopes in the areas of technology, business, legal, social, education and cyber security.

The principles of the Industry 4.0 concept has translated into the economic priorities of other European Union countries, which have been enshrined in action strategies for the coming years.

The application areas of the Fourth Industrial Revolution are: advanced manufacturing technologies, advanced materials, artificial intelligence, augmented and virtual reality, big data, blockchain, cloud computing, connectivity, industrial biotechnologies, Internet of Things, micro and nanoeletronics, remote devices, nanotechnologies and photonics, robotization (robots), and cybersecurity. From these areas, six technologies are called Key Enabling Technologies KETs), they are: micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies – increase industrial innovation to address societal challenges and creating advanced and sustainable economies [36]. Industry 4.0 is assumed to increase industrial productivity and competitiveness through the use of Advanced Information Technology (ATI). Industry 4.0 has enormous potential and creates a set of economic and social opportunities through changes in work organisation, production, products, services, design, distribution, etc.

Industry 4.0 is a number of projects with different paths towards 'smart' (there are no mandatory regulations in the EU). The programmes (strategies) of the different countries differ as to priorities, project scopes, beneficiaries, sources of funding, etc.

According to Hermann et al. [37] the characteristics of Industry 4.0 are: cyber-physicality, intra-operability, visualisation, decentralisation, modularity, virtual and augmented reality, servitisation, personalization, and the components are: CPSs

(cyber-physical systems), IoT, IoS, Big Data and Big Data Analytics, smart products, smart factories.
In addition to the nomenclature "Industry 4.0", adopted to describe the changes brought about by the Fourth Industrial Revolution, other terms are also used. One of them is "Industrial Internet" [38]. This name emphasises the role of the Ubiquitous Internet (IoE) in the development of industries. The Industrial Internet integrates (fuses) innovative physical machines and devices with sensors and software on a network, used to predict, control and plan business and social outcomes [39, 40]. The name "Industrial Internet" is particularly popular in the United States. According to General Electric the 'Industrial Internet' goes beyond manufacturing to cover the wider adoption of the web into other forms of economic activity [41]. Also synonymous with Industry 4.0 is the name: "Integrated Industry". The term is used for networked systems built by organisations working together in the supply chain [42]. Instead of the name Industry 4.0, the terms: "Smart Industry" and "Smart Manufacturing" are also used [43, 44, 45]. These terms are used when one wants to highlight (expose) the latest virtual reality solutions being introduced in companies.
Each concept, and this one has its pillars. The pillars of Industry 4.0 were extracted from the results of the Fourth Industrial Revolution. The list is open-ended and constantly expanding, demonstrating the development of the concept. G. Erboz [46] describes four pillars of Industry 4.0. These pillars are: CPS, IoT, cloud computing and cognitive computing. In contrast, D. Burrell [47] (three years later) and C. Senn [48] characterise the nine pillars. According to D. Burrell [47] the pillars are: IoT, Big Data, Cloud Computing, Advanced Simulation, Autonomous Systems, Universal Integration, Augmented Reality, Additive Manufacture and Cyber Security. C. Senn [48] expands the names of the pillars, to Augmented Reality author adds Safety Training by using AR and Maintenance by using AR, to Universal Integration author writes Streamlined Logistics with system integration and autonomous system, to Additive Manufacturing author adds Design 3D and Prototyping 3D, furthermore in Additive Manufacturing, C. Seen points to limited volume production (Low-Volume Production), in Big Data author exposes data analysis , therefore in his pillar Big Data is Big Data Analytics. The other pillars are unchanged (Simulation, Cloud computing, Cyber Security).
At that time, research companies have joined the scientists with the pillars of Industry 4.0. Deloitte [49], in its description of pillars, uses the name "Industrial Internet" to emphasise the place of the Internet in the development of industrial transformation. Furthermore, this organisation expands the scope of IoT to the level of Internet of Everything, and to the name IoT gives a definition of the scope and a name is created: Internet of Things for Manufacturing. At the level of building a smart industrial environment, enterprises must be connected hence the pillar: "Connected Enterprise". The implementation of Fourth Industrial Revolution technologies into enterprises is referred to by this company as "Manufacturing 4.0" or "Smart Manufacturing". The achievement by companies of the pillar: "Smart Manufacturing" should culminate in the pillar named: "Smart Factory". The Boston Consulting Group (BCG) [50] adds autonomous robots and cobots to the pillars of Industry 4.0, and

emphasises 3D printing in additive manufacturing. In turn, it combines data with analytics as one pillar called "Big Data and Big Data Analytics". A broad nomenclature is applied by BCG to simulation capabilities using computers, calling this pillar "Simulation Everything". In the pillar called "Universal Integration", BCG points in two key directions of integration, i.e. vertical and horizontal integration using system software and process visualisation. To emphasise the application of IoT, the abbreviation IIoT, or industrial, is used. The other pillars remain the same, which are augmented reality, cloud computing and cyber security.

The various pillars of Industry 4.0 interrelate and interact, with the common links being digitality, connectivity and intelligence. The Internet in Industry 4.0 has taken on a new meaning. Its role has been reinforced through interactions with intelligent manufacturing technology. In a network of vertical and horizontal relationships, collaboration using cyber technology in the global business space is being realised. Industry 4.0 is based on potential IT and OT (operational technology). Advanced technologies connect the physical world and the digital world. In Industry 4.0 there is a cycle: physical-to-digital-to-physical [51]. Industry 4.0 is the combination of key technologies, information and computer systems, processes with their visual presentation, intelligent products as well as the competences of people into a single network that oversees itself increasing the efficiency of work execution. Table 1.2 presents key pillars used to description of Industry 4.0.

Table 1.2 Pillars of Industry 4.0

Cloud computing	Could services
Internet	Internet of People (IoPeople)
	Internet of Everything (IoE) IoEverything
	Internet of Things (IoT)
	Internet of Data (IoData)
	System of Systems (SoS)
	Web-Based Organisation
Embedded Systems	Cyber-Physical (production) System CPPS
	Wireless Sensing (Nodes/Network)
	RFID
	Smart Sensing and Actuators
Smart Factory	Ecosystem of Smart Factories (factory ecosystem/manufacturing ecosystem)
	CCPS
Inter Connection	Networking;
	Interoperability
	Vertical Integration of Production Systems
	Horizontal Integration of Partners in Value Chain (Via Value Creation Networks)
	Simultaneous Planning of Products and Production Processors
	Cross-Functional Activities.
Servitisation	Product Service Eco Systems
VR/AR	Virtual and Augmented Reality
Value Chain	Added Value
	Supply Chain Flexibility and Visibility
	SCM and Logistics
Mass Customisation	Individualisation/customisation

	Personalised product
	Consumer experience
	Additive manufacturing/3D printing
	Smart Product
Digitalisation	Digitalisation of Physical Processes
	Virtually Reality
	Virtual Assistance
	Digital Transformation End-End Digital Integration
	Process/Product/ Simulation and Virtualization
Adaptability	Adaptive Manufacturing
Agent Theory	Multi-Agent Systems
Intelligent and Autonomous	Intelligent and Autonomous Shop-Floor/ Processes
	Personalised products/services
	Connected/smart products and machines self-organised
	Machine learning
Decentralisation and Distributed	Decentralised decisions
	Decision Support Systems (DSS)
	Networked and Distributed Data Diffusion
Data Analysis	Big Data
	Information Provision
	Information Transparency
	Real Time Data
	Promptly Analysing Data System
	Open Data
Security	Cyber security
	Protecting privacy
	Protecting knowledge
3D Printing	Prototyping 3D
	Design 3D
Collaboration	Collaboration Network
	Co-Innovation
	Human Machine System
	Communication and Collaboration
	Synchronous Operations
	Information Sharing
Miscellaneous	Standards
	Physical Assistance
	Production Time
	Improvement
	Resilience
	Scalability
	Complex Event Processing (CEP) Complexity Management
	Systemization of Knowledge
	Modularization
	Gamification
	Mechatronics
	Adaptability systems
	Multidisciplinary
	Holistic Management
	Resource Pooling
	Condition Based Monitoring
	Synchronous Operations
	Information Sharing

Source: Own elaboration (B. Gajdzik) based on [52]

The concept of Industry 4.0, after past decade, transforms towards Industry 5.0. The principles of the new concept was prepared by European Union ("Industry 5.0 Towards a sustainable, human centric and resilient European industry") [53]. A global challenge for Industry 4.0 was the COVID-19 pandemic. Social and economic restrictions, at the time, disrupted supply chains and shook the business stability of many industries. After the COVID-19 experience, new policy assumptions were introduced into industry development. These new assumptions were called "Industry 5.0". First time, the term was used by Esben H. Østergaard, CEO at REInvest Robotics in 2017. Two years later, Industry 5.0 was discussed by Aroop Zutshi, CEO of Frost & Sullivan. In 2021, the European Commission presented the report "Industry 5.0" [51]. The document states that Industry 5.0 will have three big pillars: human-centric, sustainable and resilient. This document was preceded by the European Commission study from September 2020, the document authored by Julian Müller entitled: "Enabling Technologies for Industry 5.0 (…)". The study describes the technologies relevant to this phase and identifies social, governmental, political and economic challenges. The key transformation levers are:

– synergy of integration of people, process, and technology, cyber and physical aspects of ecosystems,
– collaboration of internal and external stakeholders in the industrial transformation and horizontal and vertical integration,
– lifecycle integration where there is digital continuity between the various stages/phases/states of the product or service from the time it is conceptualized to its state in operation, and then when there is an end of life when it needs to be salvaged or recycled,
– sustainability and responsibility for smart technologies,
– business resilience in a labile environment (pandemic, war), intelligent technology and ubiquitous connectivity should protect businesses from lability ("black swan"),
– the centrality of the Human in the CPS (H-CPS).

After several years of technological change based on principles of Industry 4.0, sustainability and environmental responsibility have entered more strongly into the concept. The following trends have emerged: energy saving, clean technology (without CO_2 emissions), green energy, etc. "The common environmental goals can only be achieved by incorporating new technologies and rethinking the production processes in respect to the environmental impacts. Industry must lead by example in the Green transition. A transformed industry will also have a transformative impact on society. This is especially true for industry workers, who may see their role changed, requiring new skills. The transition to Industry 5.0 will require action in a whole range of areas" [53]. In a cyber-physical space, people operate and supervise technologies, teach machines to be intelligent, track processes through real-time data provided from machines and increasingly interact with machines. In the cyber-physical space being built, it should remember the basic principle that technologies that replace human labour must be combined with the capabilities of the people who introduced them. Humans will be realized the new operations in CPS. Operators guide robots by allowing them to handle repetitive and boring tasks while operators critical think and cooperate with them [54, 55, 56]. “Digital technologies such as artificial intelligence (AI) or robotics allow radical workplace innovation, optimising human-machine interactions will capitalise on the added value human workers bring to the factory floor.

Table 1.3 Key directions of Industry 5.0

Area	Direction	Examples
Ecology	• Sustainable: ▪ industry ▪ technologies ▪ production ▪ consumption	• development of production systems based on renewable energy sources, • reduction carbon emissions. • reduction of negative environmental impacts: ▪ reuse and recycling of natural resources, ▪ closed loop economy, ▪ waste reduction, ▪ substitution of natural resources by others, • improve processes: new materials, reduce material losses, new technologies • sharing economy: not wasting purchased products, using reusable products, purchasing remanufactured products, handing over (renting, sharing) products to other users • analysis of the product life cycle (from project through manufacture and use to recycling)
Human factor	▪ Human-centric	• people at the centre of the production process - the message: instead of asking what we can do with modern technology, we should consider what technology can do for us - machines and people can work together in harmony, complementing each other, • the use of technology must not infringe on workers' fundamental rights, such as the right to privacy, autonomy and human dignity, • better working conditions and higher safety at work (intelligent robots do dangerous work) • development of the skills needed to operate and cooperate with new technologies (digital competences: basic and advanced with soft skills (creativity, openness, flexibility), • H-CPS: human cyber-physical systems (human-technology cooperation).
Volatility environment	▪ Resilient	• industry should be resilient to a variety of geopolitical turbulence and natural disasters as well as other unforeseen events, using the latest technological developments (predictive analytics can forecast upcoming problems and strengthen industry resilience, e.g. weather predictive analytics, maintenance predictive), • supply chains should be resilient to a variety of geopolitical turbulence and natural disasters, the latest technology should be used for this, e.g. maintenance predictive, predictive analytics for demand fluctuations, digital twins.

Source: own elaboration (B. Gajdzik) based on the document [51]. The Table was published in [57]

By developing innovative technologies in a human-centric way, Industry 5.0 can support and empower, rather than replace, workers; we increase industries' resilience and make it more sustainable" [51]. Table 1.3 presents key approaches of the new concept, called "Industry 5.0".

Key transformational forces driving companies to prepare for the future and explore their impact on the industry are [58]:

- Sustainability: climate change, geopolitical shifts, the emergence of disruptive technologies, the move towards net zero operations and other trends are making Environmental, Social, and Governance (ESG) strategy even more important. Technology can reduce operational costs through better management of internal energy waste and reduction of carbon footprint.
- Lifecycle value: the pandemic has forced companies to rethink their value creation process due to changing demand patterns and a disrupted supply chain. Companies have responded by moving from a product-focused model to one based on the purpose of value generation.
- Products and ecosystems: Companies need the ability to innovate and get to market faster in order to offer a higher degree of personalisation and remain profitable. Above all, however, they also need to remain relevant in new market realities.
- New business models: with the help of newer technologies, companies not only achieve new levels of process and cost efficiency, but also create new revenue streams.

When comparing Industry 5.0 with the concept Industry 4.0, it is possible to find both common characteristics (similarities) and differentiating features (differences). Industry 5.0 complements and extends Industry 4.0. The range of common features relates primarily to the applied key technologies of the fourth industrial revolution. Unlike previous industrial revolutions, the current transition is no longer accompanied by revolutionary changes. The technologies or pillars of Industry 4.0, such as the Internet of Things, artificial intelligence, Big Data, cloud computing, additive manufacturing processes, augmented reality and virtual world, are also applied in Industry 5.0. Industry 4.0 technologies are available and will continue to play a major role in the development of industries, economies, societies. In addition to the Internet of Things, artificial intelligence or additive manufacturing processes, of decisive importance, for the development of societies and economies, is the 5G network, which has long been part of the ongoing development and the 6G [59]. Industry 5.0 will develop blockchain, e.g. in the energy, fuel, chemical steel and other sectors [60]. Blockchain is a preferred choice as a security enabler to Industry 5.0 ecosystems owing to its inherent property of immutability, chronology, and auditability in industrial systems [61]. In Industry 5.0 supply chains, smart contracts (SCs) also play a vital role in ensuring security enforcement, access control, authentication, etc. SC-assisted digital identities are used to manage assets, goods, items, and services [62]. Both Industry 4.0 and Industry 5.0 focus on sustainability and solutions to increase the resilience of supply chains, but in Industry 5.0 there is a

greater industry focus on people, social and environmental issues, while in Industry 4.0 there was a greater focus on the development of the Fourth Industrial Revolution technologies in symbiosis with the established, (Agenda) goals of industrial and supply chain sustainability with the 6R principles: Recognize, Reconsider, Realize, Reduce, Reuse and Recycle.
In mass-customization are needed fair information practices and user-defined norms to access the data, with authorization is a baseline strategy to address privacy issues. The process data must be protected against malicious attacks, and information must be preserved among communicating nodes [61].
An important difference between Industry 5.0 and Industry 4.0 is that Industry 4.0 exposes the achievements of the fourth industrial evolution, while Industry 5.0 points to the goals that technology development should provide. Industry 5.0 addresses socio-economic problems and tries to find possible solutions using the technologies of the fourth industrial revolution [63]. Industry 5.0 is neither a development nor, still less, an alternative to the concept of Industry 4.0. It can be seen as a kind of course correction of the sequence taken by Industry 4.0. Table 1.4 presents the key principles both concepts.

Table 1.4 Industry 4.0 vs. Industry 5.0

Directions	Industry 4.0	Industry 5.0
Technology	The technologies of the Fourth Industrial Revolution are the pillars of Industry 4.0: IoT, AI, additive manufacturing, Big Data, computer simulation, digital twin, ICT integration, VR, AR, visualisation.	Fourth technologies are still part of ongoing development but their usefulness for society, humans, ensuring sustainability and stability is emphasised.
Sustainability	Technological development in line with sustainable development of industry.	Highlighting the importance of technological development to achieve radical progress in sustainable development.
Supply chains	Improving supply chains through digitization and technologies of the Fourth Industrial Revolution.	Building the resilience of supply chains using advanced technologies and IoT to economic problems and global crises, as well as other events with global impact.
Human factor	Technology displaces humans, automation of production lines, robots activities.	People at the centricity of technological change, improving working and safety conditions. Technology supports people.
Society	Society 5.0 with smart cities.	Society 5.0 with smart cities and towns.

Source: own elaboration (B. Gajdzik) based on [64]. Additional information: this Table was published in [57]

1.3. TOWARDS SMART MANUFACTURING

Manufacturing 4.0 or smart manufacturing (SM) (two names are used) consists of intelligent manufacturing technologies and the IT and network systems that support them. The collection of technological solutions is a dynamic structure centred on a common object, interaction or process, which is constantly reconfigured according to changing objectives (production tasks) and production conditions [65]. „Smart manufacturing (SM) is a technology-driven approach that utilizes Internet-connected machinery to monitor the production process. The goal of SM is to identify opportunities for automating operations and use data analytics to improve manufacturing performance" [66].

In the Fourth Industrial Revolution, new technologies are based on the standardisation and modularisation of processes and create interconnectedness and flexible modular combinations. Smart manufacturing is characterised by the ubiquitous integration of machines and IT systems into cyber-physical systems. The identity of machines and their components with communication systems is identified in the systems. Machines integrated with computer systems need IoT and cloud in order to be able to develop interconnectedness and improve machine operation in real time. Modern technologies are widely used to virtualise processes and products at the design, analysis and process control stages. SM needs IoT so that machines can communicate and work better. Other technologies supporting SM are: Artificial Intelligence (AI)/machine learning, drones and driverless vehicles, blockchain, edge computing, predictive analytics, digital twins. The determinant of smart manufacturing is the combination of two perspectives:

- cyber space by integrating ICTs, equipping machines with smart sensors, mobile interfaces and analytical systems,
- physical objects with advanced manufacturing technologies with autonomous robots, new materials and smart products.

Companies, that plan new projects, must carry out a reliable diagnosis of development needs in order to select optimal technologies from the set of possibilities of the Fourth Industrial Revolution. Companies must realize the principle of integration of planned technological solutions in the common smart manufacturing system. Integrated devices are able to control processes or facilities and provide full control in a dynamic environment. Companies plan change according to their capabilities. Companies investing in new (high) technologies are highly oriented towards collaboration and information exchange on technological platforms, which are themselves the sources of information. In addition, benchmarking of the implementation of new technologies in competing companies is used at the planning stage. Factories interested in advanced manufacturing technologies collaborate with IT companies by purchasing their IT products and services. The access of companies to IT and computer technologies determines the opportunities for the development of smart manufacturing. Companies' decisions to improve smart require an analysis of the process handling methods and techniques used, as well as existing IT solutions. The in-depth analysis is in many process areas. In preliminary studies, project managers are assisted by consulting companies and public support institutions. IT companies are designing intelligent manufacturing system solutions for the process industry. The service applications on offer range from partial to full production automation, from the installation of intelligent sensors in individual machines to autonomous maintenance systems with the installation of performance monitoring for all machines, from the mapping and visualisation of a single production line to visualisation systems for all processes, from a single machine learning algorithm to lines or nests of intelligent robots. IT companies design full or sectional digital models for principals in many industries. The ordered technology solutions consist of universal (repeatable) modules, which, however, need to be tailored to the company's specific operations and the industry to which it belongs. Changes start with a few selected installations or machines. Investment projects are realized in key processes at a selected level of business activity. Experience gained from the first project, allows companies to implement others.

The industrial changes are different in industries. There are industries that build smart manufacturing more easily and quickly (e.g. automotive), as well as industries with small changes. The first group, apart from the automotive sector, includes: household appliances, food, clothing, footwear etc. The second group includes: heavy industry, e.g. metallurgy, mining, as well as process industries, e.g. fuel industry, energy industry, chemical industry. In sectors where the life cycle of technology is counted in decades (steel industry, mining industry, energy industry), change is slower than in consumer goods sectors such as clothing, shoes, cars, household appliances. Sectors such as automotive, clothing, household appliances are investing in SM to better customise their products. Customisation of products is a priority for these industries. First, the customer is encouraged to reveal his or her preferences, and then a product is designed to fit him or her well. There are also companies on the market that pursue strategies of multiple product variants so that the customer can choose the product that is most attractive to them. Product proliferation is observed in many sectors in consumer markets, such as books, electronics, toys [67]. The modern customer, is impatient and wants to receive a personalised product as quickly as possible. Therefore, another direction for implementing change is for manufacturers and suppliers to strive for shorter delivery times and door-to-door delivery [68]. Here are examples of innovative customer-facing activities [67]:

– company Uber provides passenger transportation services by drivers who are not part of traditional taxi groups;
– the Adidas-Salomon company produces smart footwear for the individual customer;
– the H&M chain, which relies on cloud-based information about its customers' tastes and behaviour, designs entire collections of products for well identified customer segments;
– the car conglomerate BMW, among others, produces cars with BMW Mini roofs designed by customers on the company's website;
– McDonald's offers consumers the possibility to compose their own burger line-up.

In technological changes in companies, a sequence of stages is generally sought. In the PwC report (2018) [69], six key stages in smart manufacturing are presented (Table 1.5).

Strategic changes in companies must be supported by targets in the company's development strategy. Investment in technologies that create Smart Manufacturing (SM) or smart factories must be approved by members of the top management. The company's management declares its support for the idea of SM. Strategies usually include the statement: our company transforms to SM. The information in the strategy, is subject to clarification as to the direction of the use of the latest technology in the enterprise. Companies/factories enter the investment planning stage.

Table 1.5 Key stages in smart manufacturing (SM)

Stage	Name	Description
1.	New strategy	– presentation the SM in the strategic document of the company, – development of small SM strategies/programmes, – presentation of SM at the level of business units.
2.	Launch of pilot projects	– checking the feasibility of new projects and preparing future activities, – project implemented on one installation or one workstation, – assessment of the measures taken and adjustments to the manner or content of the changes before the rest of the installations and workstations are transformed, – creation of intelligent peninsulas, – to communicate the essence of the change and its effects in order to build the employees' favourability to carry out the transformation in the remaining installations and workstations.
3.	Identification of needs and resources	– stage of change management for other projects.
4.	Data collection and analysis	– data collection and analysis from installations, workstations and production lines, – data transmission to the cloud, which provides analysis, remote diagnostics and work management capabilities via the Internet, – improving data collection and transformation systems, – improving decision-making systems.
5.	Construction of cyber culture	– from smart factory to cognitive cyber-physical production system and cloud manufacturing.
6.	Construction of factory ecosystem	– using ecosystems to accelerate smart manufacturing.

Source: from [65]

The planning process begins with a diagnosis of the conditions and opportunities for change, taking into account the phasing of project cycles and with particular emphasis on evaluating the results of planned investments. It is good company practice to perform a SWOT analysis for planned developments. SWOT analysis is a basic method of identifying the factors influencing the company's situation in the studied area of change, analysed in terms of strengths, weaknesses, opportunities and threats Individual external and internal factors are assessed in terms of possible (potential) interactions. For each group of factors, a list of possible positive or negative interactions is created [70].

A key element of change management is the technological audit, which is a form of answering the following questions: What technologies are important to development of the company? What are the company's opportunities to invest in Industry 4.0

technologies? What technologies are considered key to the company's development? What are the areas of possible technological innovation? What benefits can be expected from implementing the changes? The technological audit assesses the technological potential of the company together with the procedures in place and the investment needs [71]. Participants in the audit should seek to answer the question: Which technologies can bring the company closer to Industry 4.0? It can be helpful to brainstorm where participants identify key change initiatives. The directions set for change should relate to technologies and related processes. Directions are a form of relationship between planned technologies and individual spheres of the company's activity, taking into account the company's potential to implement new solutions. Directions are presented to the company's management and form the basis for determining projects. The analysis is summarised by comparing the following aspects: technological, economic and social. In each of the aspects (fields of analysis), there are factors with negative impact (Table 1.6) and positive impact (Table 1.7).

Table 1.6 Negative factors in SM

Field	Negative factors
Economic	– lack of financial security for firm production orders, – lack of a multi-annual investment plan, – lack of own resources for investment projects, – lack of competitions for aid funding, – lack of knowledge of the possibility of obtaining external funds, – fear of financial support from external funds, – fear of credit or leasing investments
Technology	– lack of knowledge about the real price of investments, – unreliable analysis of the internal rate of return (IRR) of the investment, – fear of investment risk, – lack of subsidy mechanisms from government institutions. – Lack of technical and technological knowledge, – lack of R&D support, – lack of human resources to carry out change, – lack of human resources to sustain change, – lack of knowledge of the feasibility of making changes to the existing (mostly manual) production system, – Lack of knowledge of the feasibility of process, product changes, – blocking from the IT department (resistance to change), – fear of data loss, – shortage of IT equipment to create an internal IT network and production management systems.
Social	– perception that robots are taking jobs away from people, – fear of shareholders and external stakeholders of losing dividends (especially in the early stages of the investment cycle), – fear of increased costs of maintaining a large number of IT staff, – fear of executives (resistance to change), – reluctance on the part of local communities, lack of acceptance of the local environment, – lack of willingness to upskill staff to operate automated, robotic workstations, – lack of knowledge of what the entrepreneur can actually achieve and how to support current human resources to improve the production process.

Source: Own elaboration (B. Gajdzik) based on [72].
Additional information: this table was published in [73]

Table 1.7 Positive factors in SM

Field	Positive factors
Economic	– an increase in production orders, – increased productivity, efficiency and asset utilisation, – remote monitoring of processes and assets within the company and business network structures, – integration and optimisation of process flows, – evidence of sustainable process improvement, – flexible cooperation structures in supply chains, – increase in supply chain efficiency, – increase in customer satisfaction (increase in number of buyers), – development of best business practices (best practices are identified on an ongoing
Technology	– basis and communicated throughout the company and replicated outside the company). – new technical and technological knowledge (knowledge build-up), – development of R&D and process and product innovation, – development of information and computer systems, – higher level of digitalisation of the company, – automation of processes, – rapid response to emerging problems - technology is able to anticipate problems and assess risks, – improvement of the internal IT-computer network and production management systems, – unified internal communication (transparent communication rules, availability of data and information), – wide access to data, machines and equipment communicate with each other via network services, – production systems are automatically planned and controlled, – continuous flow of materials, components and finished products, – quality assurance using CPS, – development of innovation networks (networked cooperation), – remote asset and process monitoring capabilities in a blockchain model.
Social	– humans are robot assistants (human and machine interaction, software such as assistants, augmented reality, etc. are used to exchange data and information), – staff development (ability to manage machine-human collaboration, ability to manage networked distributed devices, ability to manage change, comprehensive engineering knowledge, comprehensive IT knowledge), – improvement of working conditions and occupational safety, – technological objectives are aligned with local, regional, national and international development goals, – the organisation is at the forefront of developing and promoting new solutions across the industry, – the organisation has developed best practices, – information about the company is available to customers, contractors and other groups interested in the development of the company, – environmental loads are controlled in real time.

Source: own elaboration (B. Gajdzik) based on: [74].
Additional information: this table was published in [73]

The implementation of change in companies starts with pilot projects. Pilot projects are characterised by the fact that all project implementation work is subject to continuous review and adaptation to new challenges. This stage involves finding a good path to implement broader technology investments through small steps. The company checks whether the pilot project achieves its objectives, if not, it starts a change phase, if so, further projects are implemented on the experience gained. Once one smart stand has been built, one can move on to the next, and so on.

In order to determine the maturity level of smart manufacturing, Mitsubishi Electric has proposed the Smart Manufacturing Kaizen Level – SMKL. The SMKL matrix of the Mitsubishi Electric, is a 4x4. The rows of the matrix are the categories of change and the columns are the locations of the changes implemented. Mitsubishi adopts the following stages of change: "a"- collecting, "b"- visualising, "c"- analysing, "d"- optimising. These changes are implemented at: "1 " worker or installation, "2" workstation, "3" factory, "4" supply chain [75]. In project management, the current place (state diagnosis) is marked, as well as the place to which the company is moving, e.g. from 1A to 1B (IAF document, 2020, 4/1, p.6) [75] .The SKML matrix is a good and simple tool used at the maturity assessment stage. Changes start from individual machines (installations) and single workstations to entire production lines and supply chains.

On the road to Smart Manufacturing are realized many projects. Factories start on the road from small projects with low costs to increasingly complex ventures and investments [more in 76]. The projects are realized by several months or several years. Among the projects, technology investments are very cost-intensive with a stretched time rate of return (IRR). The investor of a long-term project (5 years and more) can apply for financial support from co-operators and co-financing institutions. The number of projects increases as the levels of development of the Industry 4.0 concept increase. Each pillar of Industry 4.0 can be a separate project for the factory, e.g. the installation of sensors on machines, the development of AI algorithms for object handling, the design of a visualisation system for a 3W assembly station.

According to [77], building a smart factory based on the following elements:

- exploration of the potential of the organisation,
- creation of agile skills,
- selection of an agile methodology in the pilot,
- selection of a framework to carry out the transformation,
- actual implementation of changes in the organisational structure,
- IT transformation,
- roll-out in other areas.

Factories, when working to implement new technologies, should consider the staging of machine learning (ML). Several phases (stages) can be distinguished in the ML [78]:

- shallow machine learning phase: machines learn with the help of a teacher (learning machines with the teacher), operating machines:
- a human 'prompts' the machine, gives and controls data, and participates in the machine's decisions,
- traditional computer and information systems are used in the machine learning process, using average statistics to predict and make corrections in the operation of the system or to carry out corrective or preventive actions,

- deep machine learning phase: machines learn on their own,
- autonomous working (learning machines without the teacher), machine operations are fully autonomous (without operators), machine learning algorithms operate on data sets without human assistance,
- machines automatically find patterns of action based on the collected data,
- patterns of action are used to remove existing faults, solve problems, identify and "bypass" anomalies, obstacles, disruptions,
- configuring equipment (machine adapting) is based on adding or reorganizing the modules that make up the machine.

The final result of machine learning is activities based on full openness and decentralized systems. Improved production systems with artificial intelligence use cognitive processing algorithms and complementary learning [79]. The varying levels of learning are due, among other things, to the fact that no one hardware vendor can provide an optimal solution for all its functions. Therefore, it is absolutely necessary to create a solid foundation for the compatibility of devices with existing systems and to strive to build systems created from open technologies that allow objects to work with external systems (more in: [80, 81 ,82 ,83]. Key questions are: How to produce? What to produce? Who to produce for? Technological changes are strongly linked to production engineering and management. The product life cycle co-exists with engineering design. The SM are oriented on value creation networks and global business.

Conclusion: it can be assumed that not all companies will become smart factories. A focus on full automation and robots, as well as artificial intelligence (AI with machine learning), will characterise organizations (capital groups) with a strong market position. Depending on the level of market development, companies will either maintain the current base technology recognised in the industry or reject current solutions and start their own path to the smart factory. The operation of solutions based on the combination of the physical and digital worlds within a company requires adherence to a number of strictures arising, for example, from technology usage protocols, communication protocols, security standards. Investment is characterised by gradualism, and in addition to the material objects that condition technological progress, organisational changes and the adoption of protocols to protect the interests of the enterprise are also important.

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2

BACKGROUND TO SMART MANAGEMENT PROJECT

2.1. SMART MANUFACTURING PROJECT IN IMPLEMENTATION ASSUMPTIONS

Changes in the activities of companies and organisations (related to the globalisation of commercial activities, the strong increase in data related to company activities and the rapid development of modern technologies as part of Industry 4.0) are forcing the implementation of more and more new projects. The environment for enterprises is becoming increasingly unstable and industrial technology use cycles are getting shorter. The rapid development of information and computer technology is changing the space of realised projects. Projects are moving beyond companies and are being realised in entire capital structures and supply chains. IT is still a fairly young field, with its widespread use beginning less than 30 years ago (even later in Poland). Human interaction with information technologies is constantly changing. Modern information technologies, for many users, are becoming a determinant of effective action. In such conditions, companies are forced to develop and implement technological investments in line with Industry 4.0. Technological projects are accompanied by: reorganisation of workstations, purchase of computer software, modification of computer systems, design of process visualisation systems, prototyping of products, etc.

In Industry 4.0, are needed the investments whose essence is founded on smart process technologies. Among the new projects, most are IT projects. Such projects are characterised by a high degree of digitalization of workplaces [1]. In Industry 4.0, the links between devices, programmes and processes are important. Physical objects (machines, equipment) and digital technologies should form cyber-physical production systems. The projects that are carried out under the strategic objective of constructing smart manufacturing are a collection of various sub-works, ranging from individual installations and workstations to production lines and even the entire factory. Each project is a collection of activities undertaken to realise this objective and to achieve the result, which will be a smart production system. When looking at IT projects in enterprises, there is a dimension of difference between these projects and those before Industry 4.0. The implementation of projects in the smart transformation brings with it changes in all areas of activity of industrial enterprises.

The importance of project management in enterprises has increased even more in enterprises than was previously the case. This situation is due to the increasing number of projects, their diversity and their wide spatial scope. There are more and more projects in the companies and the implemented installations are almost a common organism that can react to the environment.

Manufacturing systems are combinations of the digital and the physical solutions. Companies are investing in modern manufacturing systems, analytical systems, smart sensors, mobile interfaces, new materials, smart robots, automated vehicles, smart products. IT solutions are becoming increasingly important in new technology projects. The synchronisation of databases and the compatibility of IT systems is a start to building intelligent manufacturing technologies [2]. Project Management (PM) is a way to achieve the goal of smart manufacturing by investing in evolving smart technologies. All project resources, available inside and outside companies, have an impact on the success of projects. Resources must be integrated, with the aim of creating smart manufacturing systems with autonomous manufacturing systems [3]. According to Hirman et al. [4] such phases have be realized:

– definition of company vision and strategy for implementation of smart manufacturing,
– identification and description of company processes and system (audit of system and data),
– implementation of fully-fledged information system (e.g. ERP/ERP II) and manufacturing data collection,
– digitalization of collected data, creation of a digital twin and modification or purchase of machines (based on information from the digital twin),
– implementation of horizontal integration (i.e. definition of rules that control of production processes and automatic data collection),
– data analysis and vertical integration (data aggregation for top management and process optimization based on the data,
– self-managed production and logistics (Cyber Physical System: CPS).

Every project is a construct including quality, budget (cost) and time [5, 6, 7]. The outcome of a project is called the product of the project but the product itself is not the project. However, it is the product that defines the technical, time and financial dimensions of the project [8]. A poor definition of the purpose of a project, i.e. its product, can therefore be one important factor in project failure. Many authors use the word quality as a reflection other user's requirements for the project. Costs are the total capital expenditure: material – those things that are consumed during the life of the project, these are: building materials, stationery; financial – these are the costs of loans, leasing or insurance; administrative – these are the costs of the PMO office, HR, accounting, management. Project time is the project cycle. Quality, time and costs are widely recognised as the basis for defining project management, and their interaction constitutes the shape of the project [9, 10, 11]. Lewis [12] introduced the additional parameter, which is "scope", which is important when representing the relationships that exist between the basic (quality, time, costs) parameters of a project. The project scope and managing scope change is a very different process from developing an understanding of a client's expectations and managing those expectations. Meredith and Mantel [13] added another aspect of project management – customer expectations. One definition of customer-focused project management is the application of knowledge, skills, tools and techniques to meet or exceed customer expectations. This definition focuses on delivering a product or service to the client that meets expectations rather than project specifications. It is possible to meet all project specifications and fail to meet customer expectations or to fail to meet one or more specifications and still meet or exceed customer expectations [14].

According to Project Management Institute (PMI) [8] "projects are temporary efforts to create value through unique products, services, and processes". Some projects are engineered to quickly resolve problems [15]. Project management – is a set of different activities in order to produce a PRODUCT of appropriate quality within a specified

TIME and assumed COSTS; includes elements such as:

➢ PLANNING (Project Plan – Design Assumptions, DIP),

➢ DEVELOPMENT OF A SCHEDULE AND COST ESTIMATE (HRF – Material and Financial Schedule),

➢ PROJECT IMPLEMENTATION (production of products in individual stages of implementation),

➢ CONTROL OF PROJECT IMPLEMENTATION (monitoring and evaluation)

➢ CLEARING OF PROJECT TASKSA (project is a venture that has a marked beginning and end).

A project is unique because the product or service is distinctly different from all similar products or services. A project is the result of the needs and expectations of the project principal. The principal's requirements can be fully defined as well as undefined. The result of a project is the solution to a problem, after the problem has been initially and accurately defined and the change activities performed [8].

In popularised concept: Industry 4.0, projects aim to adapt the enterprise to the demands placed on it in the Fourth Industrial Revolution, i.e. to create a cyber-physical production system, enabling quality defined as adapting production to personalised needs (individual orders), while at the same time the enterprise must ensure process optimisation and reduce energy consumption. The projects implemented by Industry 4.0 companies are based on the key technologies or pillars of the Fourth Industrial Revolution, which are: autonomous robots, simulation, systems integration, Internet of Things (IoT), incremental manufacturing (3D printing), data processing, cloud computing, Big Data, augmented reality and cyber security [16]. The cyber-physical systems will be surrounded by a multitude of intelligent support systems inside and outside the factory. The scope of project SM are presented in Figure 2.1.

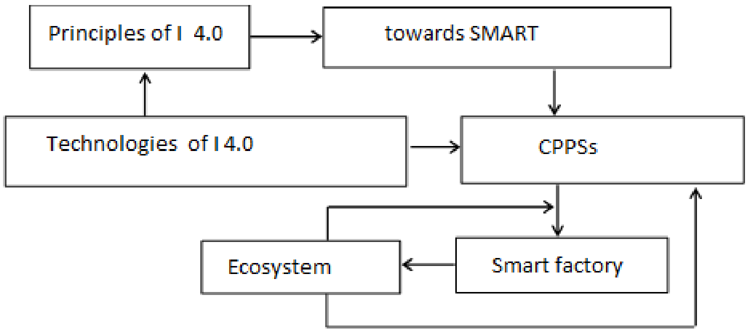

Fig. 2.1 Background of project management in Industry 4.0
Source: Prepared by B. Gajdzik

The solutions that a company can introduce are not as obvious in Industry 4.0 as one might think, because the road leading to the creation of a cyber-physical production system is long and complex and consists of a great many projects planned over several years. It is assumed that only after 2030 will it be possible to see a stronger impact of technological progress on our everyday life than before, enshrined in the word 'smart'.

New technological projects in factories are not simple projects, due to the diversity and range of applications of technological solutions. The complexity of the technology and the diversity of technological solutions in relation to other projects is such that new complex relationships are created between individual devices and information systems in terms of the flexibility of technological solutions and the building of collaborative technologies. Each project entails further projects that need to be implemented to create an intelligent solution. The new projects are so innovative that designers may feel that they are doing something beyond human capability and competence. Artificial Intelligence (AI) is supposed to control entire production lines, ensuring the right quality of products and improving the energy efficiency of processes. Algorithms can be used to anticipate many problems, but algorithms must first be prepared, taking into account the company's specific process conditions.

A lot of new projects start with the pilot, where data analysis is prepared and trends are simulated to assess the end result. From project to project, the time extends considerably, due to the complexity of the Industry 4.0 concept. In addition to the need to integrate IT systems, Industry 4.0 projects require a lot of automation of activities, or even full automation. Industry 4.0 technologies, together with integrated IT systems and full automation, only provide insights into cycle times and the entire process. Determining the number of devices and where they will be installed also requires the creation of visualisation systems, which have to take into account various disturbances, e.g. disturbances to the learning algorithms of the mobile robots carrying out the process. The implementation of Industry 4.0 projects takes place in small steps, from individual workstations to entire production lines, up to factories and supply chains (more in [17, 18]).

New Industry 4.0 projects have a high technical risk due to the complex environment of implementing new technological solutions (intelligent devices, machines, installations reacting to emerging problems and able to adapt to changes) and completely new manufacturing engineering assumptions (intelligent optimisation). The lack of communication and cooperation between devices can be a fundamental barrier to the success of projects. The basis for new technological projects of Industry 4.0 is the integration of IT systems in the enterprise, so that the new technologies do not perform many unnecessary activities, such as data re-entry. On the basis of integrated IT-computer systems, equipment operation measurement systems, machine communication systems, machine learning algorithms, etc. [19]. Table 2.1 shows the structure of an example project realized by a company on its way to smart manufacturing.

Table 2.1 Components of the project: *Development of a machine monitoring system*

Step	Scope	Results/quality
1.	Determination of the range and type of sensors monitoring the operating state of the machine "A"	Installation of temperature, pressure and level sensors on machine "A" and others/reporting of machine performance in real time.
2.	Generation of machine operation data "A"	Providing data, in real time, on the operation of machine 'A' to the decision-making system/optimising machine operation.
3.	Transformation/processing of machine performance monitoring data "A"	Visual version of data (tables, graphs, etc.) on machine operation "A"/machine operation control via mobile devices.
4.	Preventive maintenance system for machine "A" (system adaptation to the needs of end users)	Condition monitoring through systems with extensive analysis options and machine condition assessment software "A"/IoT/Predictive Maintenance
5.	Granting access and testing a system for so-called successful predictive and preventive maintenance of the "A" machine	Active 'A' machine prediction system with dynamically changing data presentation and analysis modules.

Source: own elaboration (B. Gajdzik) based on [20]. Additional information: this table was published in [21]

The creation of a virtual production line requires the company to obtain a high degree of automation of production work, and individual devices should be equipped with sensors and sensors to generate data on the parameters of devices and create a cloud. Cloud computing is coupled with the production infrastructure on the basis of data generated by the devices and can perform the correlation processing between various parameters, characteristic for the cyclic operation of industrial machines. Individual production parameters are provided to the manufacturer (tablet, computer, laptop, touch screens, cameras). At this stage of the work, the companies commission a specialized IT company to configure the data so that the information provided to the manufacturer is up-to-date and complete. Information and computer systems that are already in enterprises must be compatible so that there is no duplication of data and, what is worse, transmission of incoherent (contradictory) data [17, 22, 23, 24]. The decision maker receiving data can't be exposed to losses due to outdated data (data is provided in real time). Information systems (equipment services) (at this stage) are equipped with subsystems for early warning and prevention of unforeseen events.

The aim of this stage of works (project no. 1 named: AUDIT OF SYSTEMS and DATA) is to monitor the operation of the production line in real time and to eliminate unwanted events by early warning based on processed data and intensive monitoring of dependencies. At this stage, the producers are benefiting from, for example, the knowledge gained about processes, which directly translates into time savings and funds allocated for periodic (sectional) control [17, 25]. Manufacturers have insight into the data in the cloud and are accurately informed of how the production is going, and when and at what time the (potential) manufacturing error or an undesired event may occur. In order to be able to process data (project No. 2 named: ENVIRONMENT FOR DATA PROCESSING), this data should be somehow obtained (more in: [26]). For this purpose, devices are created whose task is to obtain process data from various types of PLCs from leading brands as well as from industrial robots. Since the devices used in the production line work are not equipped with data aggregation mechanisms and appropriate communication interfaces, a dedicated device will be created to supplement the production line with the necessary mechanisms for this purpose. In the era of ubiquitous Internet, it will use open communication protocols of the REST/SOAP type, transferring data to the cloud computing, while implementing available solutions, enabling the acquisition of data directly from the machines. This type of device extends the capabilities of production lines towards achieving the Fourth Industrial Revolution and introduces a layer of backend that enables subsequent business analysis of distributed data without affecting the use of device resources. As for the equipment and cloud system, available Microsoft AZURE computer environments and accompanying components, as well as traditional HMI interfaces, as well as tablets, laptops and touch screens, and at the quality control stage – cameras will be used for this purpose. The described stage of the construction of the production line consists of two sub-stages of the implementation of the Industry 4.0 project: a sub-step called DATA and a sub-step called COMMUNICATION [17]. The DATA sub-step consists in creating production lines - machines - which exchange data, hence the need for digitization od business. The information needs to be transformed into zeros and ones and stored in an orderly form in the database. Machines provide a large amount of data and records, which is why enterprises must have adequate large systems to store them. Most often enterprises create many databases, eg accounting (financial), CRM, MRP or ERP, on the website, etc. It all depends on the type of data and how to use them (so-called relational and non-relational databases). The number of owned databases does not matter. The interface is important. Sub-step COMMUNICATION is the way in which machines communicate with each other, how they exchange data. Enterprises create (program) a communication interface (Programming Interface) that can communicate with different types of databases, and devices/applications (regardless of how we name them), refer to this program (via GET or PUT functions) [17]. Such programs function as links between various databases and devices that generate data (they are in the middle and do not generate data themselves, meaning they do not have their own data). These are programs for searching data from databases or other connected devices [27].

The next stage is defining the scope of activities performed by machines and by people (machine operators of equipment owners). This stage (project no. 3) can be called: TASKS OF MACHINES AND PEOPLE. Enterprises determine what activities will be carried out by people, and by machines. According to Industry 4.0, you have to assign new tasks to the machines. Implementation projects – based on determining what machines are doing are very creative, because not only the number of transferred jobs increases, but also machines get new roles, e.g. data analyst, performance evaluation of other machines and people's work. Wizards (creators) of projects at this stage of the works propose new (innovative) machine operations. Industry 4.0 assumes replacing people's work with machines because the machines perform more precisely than the employees [27]. Proposals for innovativeness in the scope of work carried out by machines are implemented non-stop within project no. 4: MACHINE MAINTENANCE or MACHINE LEARNING. The machine learning project (carried out at the start-up phase) involves the start-up of machine learning elements and the use of current data processing algorithms to enable production machines to learn. The scope of machine learning concerns the area called: OPTIMIZATION OF PRODUCTION. Machines learn to perform their tasks optimally while simultaneously calibrating their adjustable parameters. Machine learning, cloud computing and feedback in the form of robot calibration based on experience (historical data also understood as Big Data) are the basic elements of implemented projects [17].

Conclusion: projects in Industry 4.0 are a mixture of the physical world and the digital world. Projects are amalgams of tasks, activities and outcomes that must be carefully organised and executed to achieve the desired result. The main vision of the concept is the transformation towards smart factor. The smart factory (sensors, machines and IT systems) will be connected to production facilities called cyber-physical production facilities called cyber-physical systems (CPS). This concept consists of autonomous robots, the Internet of things (IoT), big data, simulation (digital twin), horizontal and vertical systems integration, cloud cyber security, incremental manufacturing and augmented or virtual reality. The application of these nine technological fields will transform standard production into a fully integrated, automated and optimised production flow. In connection with smart manufacturing technology, it is possible to achieve a flexible and intelligent production process suitable for a dynamic market.

2.2. ASSUMPTIONS TO AGILE PROJECT MANAGEMENT

Project Management (PM) is based on many analyses, decisions, collaboration of people and resources. Large projects are so complex that they are broken down (are decomposed) into small tasks. Project management is the process by which a project manager carries out the deliberate planning and control of the tasks that make up a project and makes an appropriate allocation of the resources allocated to the project, using appropriate techniques and methods to achieve the set objective within the set time, at the set cost and with the right quality. “Project management is the application of knowledge, skills, tools, and techniques to meet project requirements" [28]. Project management is a way for a company to influence its future. Changes are the causes of projects based on taking preventive or adaptive measures resulting from internal and external imbalances of the company. According to PMI, "project management is the discipline of initiating, planning, executing, controlling, and closing the work of a team to achieve specific goals and meet specific success criteria" [29]. The functions of project management are: planning and selecting, organising and decomposing, launching and coordinating tasks, making decisions, controlling and measuring the results. Particular phases can overlap or stagger. The larger the projects, the more time the company needs to perform pre-project analyses. The result of these analyses can be a report or a feasibility study. In its modern version of PM, the functions are planning, organising, commanding, co-ordinating and controlling (PO3C). All functions are performed continuously as a cycle. Managers continuously plan successive activities, organise their implementation, motivate performers (and themselves), participate in and support the process of communication and coordination between performers, and control the course of tasks, accounting for results [30].

New technologies (computer modelling, machine learning, statistical analysis, big data analysis) have led to further changes in the way management functions are interpreted. As digitisation in the broad sense plays a key role in the development of Industry 4.0, it can therefore be assumed that there will be a strong proliferation of agile techniques in project management [31]. According to R. Marousek and P. Novotny (2016, pp. 80-85) [32], the importance of PM in companies increases in Industry 4.0. Projects need to use hybrid methods and agile techniques. In PM, on the one hand companies use traditional (waterfall model), on the other hand agile techniques in the overall process [31]. Table 2.2 presents the key characteristics of two models.

Table 2.2 Waterfall model vs. iterative (incremental) model

Waterfall	Iterative (incremental and evolutionary model)
Sequence of project implementation	Sequence of project implementation
Certainty-oriented model. The objectives and the solution are defined and therefore there are: clearly and precisely requirements are defined, minor changes to the scope of the project are made, established and proven templates are used.	Flexibility/adaptability-oriented model. Adaptability is equated with the ability simultaneously create value and respond to change in order to benefit in a turbulent business environment.
Detailed definition of the objectives projects based on the SMART. Breakdown of long-term and short-term objectives based on a thorough needs analysis.	Developing a vision of overall vision, i.e. the concept of what is to be the result of the project (emergence of effects).
Each project always has a precisely defined number of stages. Linear project management cycle based on precisely defined stages.	The iteration work list (backlog) should be fully linked to the programme's critical chain. A way of aligning the results and the time of producing results in the individual iterations with the critical chain would be to change the size of the individual buffers. Iterative (based on the delivery of

	elements of functionality) and incremental project management cycle project.
High level of formalisation of the project.	Low level of formalisation of the project.
The change is not part of the normal mode of operation for this model. Change is a necessity when the conditions of the project change.	There are permissible changes to the plan and specification during the implementation phase. Changing to a better solution is, as it were, part of the normal mode of operation in this model.
Planning based on a detailed schedule, which is the basis for project management.	Short process schedules value creation.
Each stage must end with a specific product. Should not go back to earlier stages and modify an already finished product.	Reversing to previous stages and modifications to the finished product are permitted. The product is improved.
Variation is at the planning stage, not after the selection of a project.	Variation is allowed until the best solution is found.
The next level takes place after completion of the previous level, following confirmation that the product complies with the specification.	Work progresses in iterations, achieving results in sequences, (e.g. several iterations of a sequence: specification, implementation, integration).
There is no feedback between stages. Each stage is separately accounted for.	Reversing to previous stages and modifications to the finished product are permitted. The product is improved.
Results comply with the specifications prepared at the start of the project.	Each iteration achieves a better product, more and more knowledge about the product and more and more compliance with the client's expectations.
Examples of the traditional (engineering) approach are the PRINCE2 methodology and PMI's lexicon of good practice - the PMBOK Guide.	The iterative model is based on agile techniques, e.g. Scrum, Kanban, Scrum board, Iterative Development.
The project is implemented in accordance with the documentation. A report is produced on completion of the project.	The final project documentation builds on the product developed in successive iterations.
An example: this approach is often used in IT and web projects, e.g. in a traditional approach, a manager would define the purpose of some complex software and then order the developers to work according to a predetermined plan.	An example: Agile developers will first write a small application with basic functions (MVP or prototype) and then hand it over to customers - not yet fully finished. They will then develop this application over a number of months, based not on a design plan, but on customer needs and feedback - which in a traditional approach would not have been foreseeable at the planning stage.

Source: own elaboration (B. Gajdzik) based on: [33, 34, 35]

In factory on its way to Smart Manufacturing, many projects are being implemented at the same time. Project management in Industry 4.0 makes use of the latest developments in ICT and the digital networking of industry [32]. The number of projects is increasing as the popularity of the Industry 4.0 concept grows. Each pillar of Industry 4.0 can be a separate project, e.g. mounting sensors on machines, developing AI algorithms for object handling, designing a visualisation system for a 3W assembly station. The process of managing change consciously should start at the strategy preparation stage. A strategy is an overall, long-term sequence of activities with the achievement of desired goals as its outcome. Before developing a strategy, companies perform SWOT and PERT analyses.

The form of preparing a strategy can be planning or incremental. The first form is characterised by a top-down approach and the second form by a bottom-up approach. In the first, that was called: centralised, the objective, deadlines, tasks "flow down" from above. It is a planning approach. In the second, that was called: decentralized, the strategy is created in the individual business units, after the management has first given an overall framework/vision (hybrid model) [36]. Projects are the product of all stakeholders, who are brought into it from the beginning, becoming co-authors. The projects in the strategy prepared, as well as the strategy itself, are cyclically reviewed and amended as better development options emerge. This is the approach of incremental strategy creation.

Multiple project management requires a division of labour. Companies are moving from centralised structures to decentralised structures in the process of project management. In large projects, a hybrid approach (centralised supervision and decentralised management) is used. The specifics of the management forms are shown in Table 2.3.

Table 2.3 Strategic project management models

Centralised	Decentralised	Hybrid
Strongly embedded at the strategic level of the company (strategy developed by members of top management).	Strongly embedded at business and operational levels companies.	Project framework developed at central level (Top Management) but details are agreed at business unit/functional team level
The selection of projects for implementation is a Top Management decision.	Project selection is a decision of operational services/direct proposals of business units/process managers.	Project selection by the Top Management, synthesis and development of the final project with strong involvement of business units or operational services.
Project coordination by a Top Management representative.	Project coordination by the project manager at business unit or process level.	Project coordination by a team comprising a management representative and bottom-up controllers.
Top management involvement in project implementation.	Supervising project implementation by Top Management.	Control structures at business units, departments, process levels.
Project strongly linked to corporate strategy.	Each strategic unit has strategies in line with the company's development vision.	The main objectives of the project derive from the strategic objectives (corporate strategy), but the objectives and tasks are strongly related to the specificity of the unit implementing the project (fits into the framework of the strategic, main project).
One (final) version of the ongoing project.	Each Business Unit carries out its own internal projects.	Strong diversification of projects, with projects strongly tailored to the needs and capabilities of each operational level.

Source: own elaboration (B. Gajdzik) on the based on [36]. Additional information: this table was published in [37]

The organisation of the projects that will lead the company to Industry 4.0 can be task-network or task-matrix. This is because such structures are used when new and complex technologies are implemented in companies [38]. These structures are characterised by a high degree of flexibility and extended supervision (double supervision principle). The network approach in the organisation of task force work is facilitated by access to the Internet, the use of mobile devices, the integration of information and computer systems used in process control. The process of exchanging information between SCADA, MES and ERP systems, for example. The early CIM (Computer Integrated Manufacturing) and later MES (Manufacturing Execution System) systems gave company managements an overview of the company's processes and their impact on the achievement of business goals. This enabled companies to coordinate activities on a large scale, resulting in real reductions in individual divisions and business units, significant lengthening of supply chains and co-operations. There has been an important shift in the understanding of planning in management. Employees have access to emails, the Internet, instant messaging, cameras, plans and reports. Employees can use tablets to write reports while inspecting workstations and then insert the information directly into the report with appropriate annotations (observer comments). Employees (inspectors) are able to send the report immediately to all project participants. Digitisation therefore saves time and people effort. Project management makes use of the latest developments in ICT and the digital networking of industry [32].

Digitisation also applies to project management platforms, which have become commonplace in many areas of project management. There are many different platform providers on the market and it is also possible to create personalised project management platforms. Platforms can be individually created or customised for each project and designed to include different functions based on the activity or project. Platforms can store information such as plans, meeting reports, photos, contracts, construction plans, invoices, data sheets, specifications, drawings and correspondence. In addition, each user can receive information when a new report is published within a specific category. Invitations to meetings can also be sent via project platforms, which can thus act as planning tools. Meeting reports and project plans can be uploaded, as well as annotated, authorised and modified in real time. The history of reports on the platforms helps staff to determine which version of the plan is the most up-to-date and to see how many changes have been made and by whom [39].

The development of artificial intelligence also facilitates project management, as devices can identify, react and adapt to changing conditions [40]. Intelligent technology learns by doing. Simulations and theoretical calculations are helpful in determining how technology works, but only real-life experience will allow the technology to learn and adapt. The evolution of project management will also have an impact on project, portfolio and programme management software [41]. In Intelligent Production Systems (IPS), algorithms optimise the flow of tasks, people, energy and resources to increase the efficiency of business goals. The key technology in the intelligent manufacturing includes CPS, big data analysis, Internet of Things, cloud computing, embedded sensor, artificial intelligence and so on. Tasks are carried out by systems that include mixed teams of people and machines (autonomous or semi-autonomous). Intelligent management systems reduce the need for direct human intervention, what is needed is rather to control and make adjustments to control programmes, to develop ever better operating algorithms.

Digital twin is also being used to manage projects. The digital twin is a technology based largely on simulations, mathematical models, artificial intelligence and the Internet of Things. A digital twin is a virtual model of a real machine, product, process or system based on data that comes from sensors, such as IoT. The concept consists of three elements: a physical product that is located in real space, a digital model located in virtual space, the connection between the two. “Twin” in this context implies that this digital information would be linked to the physical system throughout its entire lifecycle. Applying digital twin in project management allows manufactures to create fit-for-purpose digital representations of their production systems and processes using collected data and information to enable analysis, decision making, and control for a defined objective and scope (Fig. 2.2) [42].

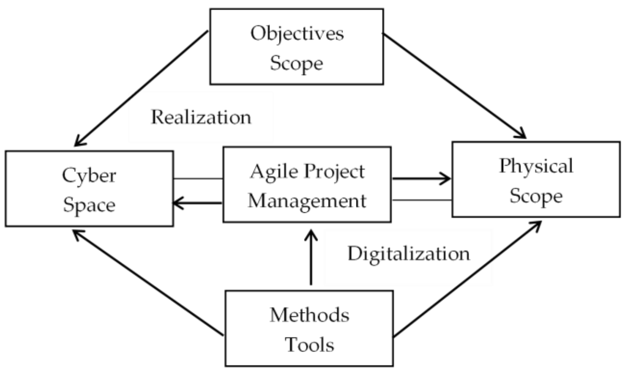

Fig. 2.2 An overview of the digital twin concept

Source: Adapted from [42, 43]

Standards, methodologies and risk management will also become crucial, as companies cannot afford to make mistakes. In project management, efficient organisation of work and effective synchronisation of resources, which are in fact limited, is essential. The question arises: is the working mode single or multi-tasking? It is therefore important to choose a way of working that guarantees their effective use. Single-tasking is used in the critical paths of the project, and multitasking in the sub-critical paths of the project.

One such approach is the Theory of Constrains (TOC). TOC in its basic version applies to production and distribution processes. TOC has also been successfully adapted to project management. The TOC algorithm is shown in Figure 2.3.

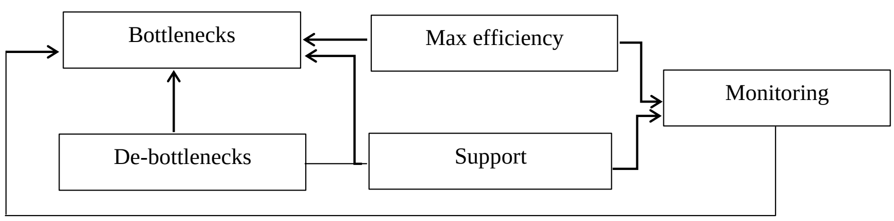

Fig. 2.3 Algorithm of TOC

Source: own elaboration

The TOC is described by a buffer (buffer), a snare (drum) and a rope (rope). The snare, or critical resources (bottlenecks) sets the rhythm of the work, the buffer is the stock of materials, while the rope is the most efficient way to deliver the buffered materials, determined by the rhythm of the 'snare' [33].

Description of the five points of the TOC [32, 33, 44]:

1. Identification of constraints: bottlenecks (e.g. staff competence gap, decrease in machine productivity by shutting down parts of machines due to overhaul).
2. De-bottlenecking, i.e. planning the work in the project and the project programme in such a way that the resource representing the constraint is working at maximum efficiency.
3. Subordinating the work and activities of other project participants and non-critical resources to the work rhythm of the resource constituting the constraint.
4. Reinforcing the constraint (support), i.e. through a series of management and organisational decisions and even in special situations, e.g. hiring a missing specialist, breaking the constraint and minimising its possible negative impact on the project, or on the project programme.
5. Return to the first point, i.e. continuous monitoring of constraints/bottlenecks, continuous improvement of the project implementation (focus on optimisation of work, removal of obstacles and best use of company resources).

In project management can be used such methodologies:

1 Cascading methodologies (PRINCE2, PM BOK);
2 Agile methodologies (AGILE – SCRUM;
3 Mixed methodologies (cascade-agile);
4 Methodologies recommended by the European Commission – e.g. Project
5 Cycle Management (PCM methodology);
6 Corporate methodologies – something has been selected from each methodology that benefits the company and makes it easier for people to work, and then adapted this approach into a single coherent project management approaches.

In the project management in Industry 4.0, the focus of assessing project results is changing. The aim is to create a smart environment in the factory. According to E Sońta-Drączkowska [32], in the management of projects aimed at smart production, a "throughput-oriented" working model should be used, which should replace the silo-cost structure model. In the silo-cost model, the goal of the project is cost effectiveness: efficiency improvement, or cost reduction. In the incremental model, the focus is on incremental results (value) (see SCRUM technique [45]) and the achievement of strategic goals shared by all participants in the transformation towards smart production. Thus, it is no longer the efficiency of a particular department or organisational unit that counts, but the result of the whole [33]. Scrum is used in IT projects, which offers a general framework for proceeding with a set of desired behaviours. Scrum method is transparency because all stakeholders in the project should receive needed information and interpret it in the same way using the same standards and codes. Moreover project inspection based on verification (audit) of the current level of progress. In the method is used the adaptation by continuous

improvement of the project to the current situation [46, 47]. Basic determinants of Scrum are [48]:
– the list of tasks,
– the list of operations,
– the analysis of results and increments.

Table 2.4 Scrum characteristics

Genesis	Scrum (from rugby mill) originated in the early 1990s. It originated from the world of computer programmers struggling with the volatility of customer needs and requirements, poor timeliness of completed projects, and discrepancies between project outcome and customer expectations.
Target	delivering (providing) value to customers
Deming cycle	plan-do-check-act
Organisation	The basis of working in Scrum is to work cyclically in so-called sprints. These have a fixed, fixed length (1-4 weeks) and are intended to result in tangible added value for the project customer.
Scrum team/structure: • The Product Owner • The Scrum Master • The Scrum Team	Teams working in the Scrum methodology are interdisciplinary and self-organised. The project team plans, implements, checks and improves only the current sprint. In Scrum, there is no project manager, but there is a Product Owner and a Scrum Master. In Scrum, there is no project manager role, but there is a project owner (Product Owner) and a Scrum master (Scrum Master). The former takes care of prioritising the tasks that determine the realisation of the customer requirements (stories), while the latter is responsible for the process of their realisation - its quality and rapid feedback. The Scrum Master is a strong support for the project team, as one of his main tasks is to remove all the problems standing in the team's way.
Planning or not planning	At the end of the sprint, a decision is made "What's next?" i.e. what should now be our priority from a whole list of tasks and ideas. The environment in which all companies currently operate is very dynamic both externally and internally. This has a direct bearing on the projects being implemented. Since we are uncertain about events in the distant future, why take the time to carefully plan tasks that will be possible (or completely unnecessary) in the future. Uncertainty is an indispensable part of the project process, so it is necessary to react quickly to changes in the project environment, and this is what working in sprints is supposed to enable us to do.
Visual Performance Management/Daily Management	VPM helps to monitor the achievement of targets, but above all it helps to visualise any deviations from set standards and to react to problems in a timely manner. The simplest solutions are the best, which is why, despite the availability of increasingly sophisticated technology, VPM uses simple white boards on which information is applied by hand. Not only is this a low-cost solution, but above all it allows the information on the board to be updated quickly. Scrum also relies on visualisation, which allows for easier monitoring of progress and more efficient project management. The basis of the Scrum board is information on the scope of the upcoming sprint and the status of tasks. The complete board also has a place to put the problems that the team encounters in completing the tasks and discusses them during regular (daily or weekly) meetings at the board. Visual Performance Management does not exist without meetings.

Source: Adapted from [50]

The key Scrum characteristics are: mutual respect, openness to any challenges in the project, commitment to the goal, focus and courage to overcome difficulties [45]. In turn, Scrum events are: sprint, sprint planning, daily sprint, sprint review and sprint retrospective. The key characteristics of Scrum are presented in Table 2.4.
The whole idea of Agile -CascadScrum is to give the end users (consumers) exactly want they want. This can be achieved through "Sprints" or continuous feedback and iteration. Sprints are meant to be short, but regular, cycles of no more than four weeks for which a significant product increment in expected to the presented (Figure 2.4).

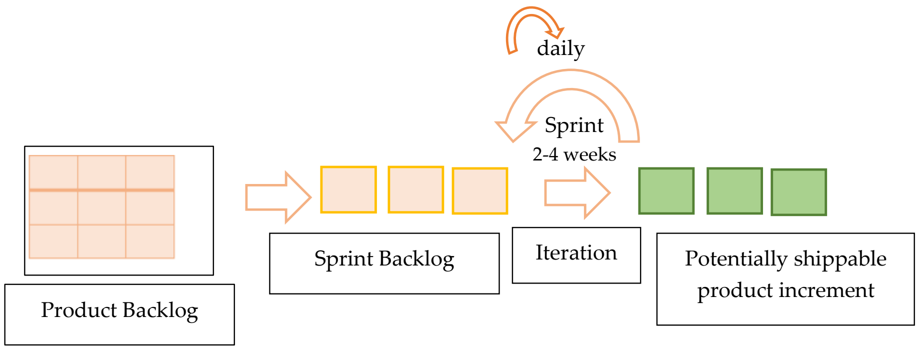

Fig. 2.4 Agile-Scrum

Source: Adapted from [49]

Figure 2.5 presents the Scrum board.

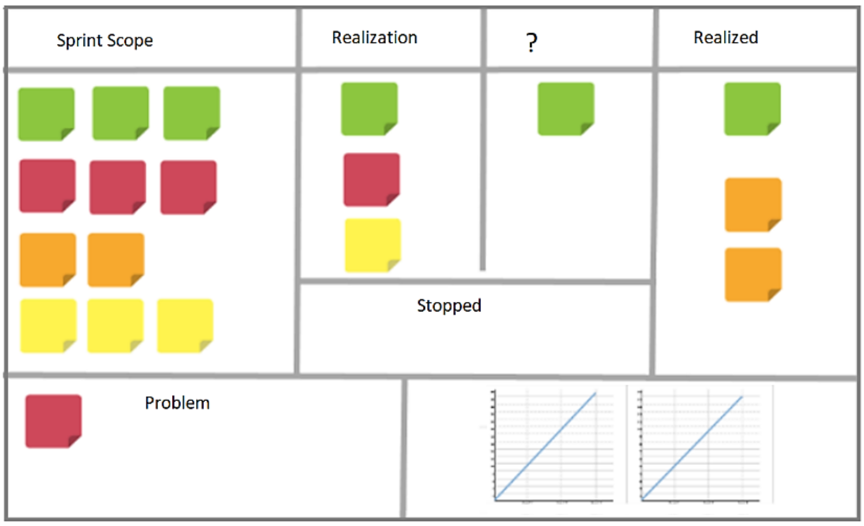

Fig. 2.5 Scrum board

Source: Adapted from [50]

In managing projects that aim to create a smart environment in the factory, a critical path has to be set for each project, or as in the case of the transformation to Industry 4.0 for the entire programme (package) of projects. The critical path is the longest list of tasks in a project, arranged in such a way that the next one can only start after the previous one has been completed. It is therefore the shortest duration of a project.
The project's critical chain must have time buffers and inventory buffers. Work in projects is done as quickly as possible and, according to the relay rule, its result is

immediately passed on to the next team and the next task is done [34]. In order to avoid multitasking, the ALAP (as late as possible) principle is applied in the critical path, unlike in classic project management where ASAP (as soon as possible) applies. Critical chains are used for programme optimisation and efficiency, as a 'bundle' of projects pursuing a common goal, described by the strategy of a company that has expressed its will to participate in Industry 4.0.

The above description is actually a description of operating in an Agile methodology that will bring to the enterprise the advanced adaptability, dynamism, flexibility and interdisciplinary necessary to cope with such a complex undertaking as any form of transformation to I4.0. Such techniques/frameworks are e.g. Scaled Agile Framework, Large Scale Scrum, Disciplined Agile Delivery, Leading Agile, Scrum Lean in Motion (more in [51]). However, this is about agile at an enterprise-wide level, not at 'island' levels which are the first implemented projects towards smart production in companies. Table 2.5 presents the short descriptions of agile methods/techniques.

Table 2.5 Agile techniques in PM

Agile techniques	Short description	Source
Scaled Agile Framework	SAFe is a set of organizational and workflow patterns for implementing agile practices at an enterprise scale. The framework is a body of knowledge that includes structured guidance on roles and responsibilities, how to plan and manage the work, and values to uphold.	https://www.google.com/search?q=Scaled+Agile+Framework&oq=Scaled+Agile+Framework&aqs=chrome..69i57j0i512l5j0i22i30l4.521j0j7&sourceid=chrome&ie=UTF-8
Large Scale Scrum	LeSS is a framework for scaling scrum to multiple teams who work together on a single product. It starts with a foundation of one scrum team, and applies to multiple teams who work together on one product.	https://www.atlassian.com/agile/agile-at-scale/less
Disciplined Agile Delivery	DAD is a people-first, learning-oriented hybrid agile approach to IT solution delivery. DAD addresses all aspects of the full delivery life cycle, supporting multiple ways of working (WoW) that can be tailored for the context that you face. DAD encompasses all aspects of agile software development in a robust, pragmatic, and governable manner.	https://www.pmi.org/disciplined-agile/process/introduction-to-dad
Leading Agile	Leading Agile Teams is a practical and engaging guide to help your organization embrace a more agile mindset.	D. Rose (book), *Leading Agile* Teams, 2015. PROJECT MGMT INST; Edycja Illustrated ((1 Oct. 2015))
Scrum Lean in Motion	Scrum in Lean Concept.	https://leancenter.pl/bazawiedzy/scrum-a-lean
Agile Manifesto	A declaration of common principles for all Agile methodologies that say: - people and interactions over processes and tools - working solutions over documentation - customer collaboration over formal agreements - responding to change over following a plan	https://leancenter.pl/bazawiedzy/scrum-a-lean

In agile PM there are 4 levels of agile value:
(1) individuals and interactions over process and tools,
(2) working solutions over comprehensive documentation,
(3) customer collaboration over contract,
(4) negotiation responding to change over following a plan.
In Table 2.6 are presented the 12 principles of Agile Manifesto.

Table 2.6 12 principles of agile in Agile Manifesto

satisfy the customer	In Agile Project Management, the highest priority is to satisfy the customer through early and continuous delivery of valuable solutions. Customer is participant of realized project.
work together	Business people and developers must work together daily throughout the project.
working solutions	Working solutions is primary measure of progress during realization of project (sprint).
simplicity	Simplicity - the art of maximising the amount of work not done - is essential
welcome change	Agile processes harness change for the customer's competitive advantage
motivated individuals	Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.
sustainable development	Agile process promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely
self-organising teams	The best architectures, requirements, and designs emerge from self-organising teams.
deliver solutions frequently	Deliver working solutions frequently from a couple of weeks to a couple of months, with a preference to the shorter timescale
face-to-face conversation	The most effective and efficient method of conveying information to and within a development team is face-to-face conversation and scrum board.
continuous attention	Continuous attention to technical excellence and good design enhances agility.
reflect and adjust	At regular intervals the team reflects on how to become more effective, then tunes and adjusts its behaviour accordingly.

Source: Adapted from [52]

Conclusion: project management at Industry 4.0 level firstly uses a number of IT techniques to facilitate project management and the project management model is agile; secondly, the projects themselves are geared towards building a smart environment in the factories and their implementation from single installations grows to include more and more installations/machinery. An iterative rather than cascading project management model is proposed, with single-tasking in the critical project paths and multi-tasking in the remaining paths.

2.3. KAIZEN IN SMART MANUFACTURING

In the Fourth Industrial Revolution, Kaizen acquired a new frame of reference, which is cyber-physical solutions, as coherent reference structures of the combined virtual and physical world of manufacturing, computer-aided manufacturing, no limited communication and autonomous control systems of productivity. The centre of the structure is formed by intelligent, networked machines independently performing repetitive tasks and exchanging information, and through learning algorithms, able to adapt to change (more about M2M platform in [53]).

Kaizen is based on small steps without great financial investments. Kaizen can be used at the stage of implementing intelligent technologies at individual workstations and individual installations/machines. By applying Kaizen, the operational team of employees outlines the development paths of digitisation projects at work. With Kaizen proposals, many digital improvements in production can be implemented immediately, even at no or low cost. Large projects – huge investments (e.g. construction of a new hall fully equipped with intelligent machines) require many financial and economic analyses, as well as many very detailed analyses of: optimisation of processes, productivity of equipment, energy savings, flexibility of supplies, availability of staff, staff reorganisation, levels of equipment cooperation, process innovations, quality of processes and products, customer expectations, as well as social and environmental analyses. In small projects, the quality of the work is assessed above all, which is continuously improved in accordance with the Kaizen concept. The bottom-up initiative of changes allows factory owners and production engineers to analyse the validity of implemented solutions at a specific work place in the context of cost efficiency and directions of improvement. Employee projects take into account the ideas and suggestions of contractors (machine operators, process plant managers, facility managers) to improve work areas [54].

Increased access to digital information at the level of Industry 4.0 shortens the execution of activities, provided the ability to use data (search for relevant data) in order to improve production. Having the right data is not a guarantee of production improvement, data must be able to be analysed and, above all, understood. Data from multiple sensors must be filtered and processed in order to be useful for the content process optimisation task. In smart factories, the management of machines and, in particular, the prevention of equipment failures is facilitated by the use of advanced analytical algorithms and machine learning techniques on the basis of the vast amounts of data collected by individual sensors. Machine operators gain greater accessibility via the network to all relevant information from all processes in real time. Computer process visualisation and mobile devices enable optimal data to emerge from the information flow at any time and according to different evaluation criteria: cost, resources, quantity, quality, availability, time, productivity, etc. [55]. Additive technologies, 3D printing and others, make it possible to produce even complex shaped products at the workstation (single workstation) without finishing operations. A similar effect is obtained by using multi-tasking machine tools, e.g. machining centres. Multi-tasking technologies contribute to the reduction of transport, storage, inter-station operations, etc. [56]. As learning machines evolve, machine operators will require support during process improvement from IT teams or gain digital skills that will enable them to act as machine teachers [57]. Lee et al. (2015) [58] identified five levels of CPS architecture within the collaboration of physical processes and digital space. The different levels of CPS correspond to the functions of technology in smart factories. The first, lowest level includes data collection and interpretation – the level: Connection. The second level is the application of modern technology for analysing process performance – analytics capability – the level: Conversion. The next level includes monitoring of work (processes) in real time – real-time acquisition, and comparing monitoring – the level: Cyber. The fourth level is called cognition, annoyance or presentation – the Cognition level. At this level, technologies strongly support humans in optimising processes. The fifth (highest) level is services, processes, and network configurations – the level: Configuration. At this level, machines have cooperative learning and adaptive and executing algorithms. At each of these stages, a different scope of Smart Kaizen is implemented. The participants in Smart Kaizen are the operators of machines and process technology [59].

Employees in Industry 4.0 are operators of intelligent technologies. The name "Operator 4.0" has been applied to describe the role of humans in cyber-physical systems [60] The established new arrangement of cyber-physical systems with human factors, abbreviated H-CPS, is a new concept of human-machine collaboration in increasingly intelligent production [61]. The team Rupper et al. (2018) [62] classified operators according to the extent of their collaboration with machines and the type of activities performed, starting from the lowest level or Operator 1.0, where manual activities dominate, to the highest level of Operator 4.0, which represents a new philosophy of collaboration between the operator and increasingly intelligent machines, at the level of their adaptation to each new situation in a dynamic production process. As part of cooperation with new solutions (machines) in cyber-physical production systems, the operator can take on various roles, such as: VR/AR (virtual operator), smarter operator, being a personal assistant of this technology, operator cooperating with robots (collaborative operator), analytical operator and many others. In addition to these functions, operators can also perform the functions of social operator and even personal data operator in the context of the impact of technology on humans and the efficiency of using technology (healthy operator) [62].

The usefulness of Lean in the development of Industry 4.0 is confirmed by the just-in-sequence method. Production cycles are getting shorter and shorter, and the modern technology of Industry 4.0 (big data, data analytics, artificial intelligent (AI), CPS, sensors, machine sensors, RFID, etc.) are used in lean production [56]. Lean production is also supported by computer models and simulations that provide new techniques, e.g. in predictive maintenance. Plant operators and managers are using a wider range of mathematical and statistical techniques in product design and process improvement. Widespread employee access to wireless technologies supports suction systems, e.g. e-channeling. Employees equipped with mobile devices collect and transmit data faster, e.g. within SPC, SQC, TPM systems, etc. [63]. By using computer technologies, mapping processes and evaluating their progress is easier. Furthermore, information technology facilitates the synchronisation of process maps with information and computer systems, e.g. ERP. Value stream maps (VSMs) with extended MRP (Material Requirements Planning) system components are called SyVSM (synchro-MRP VSM) [more in 64]. Enhanced process visualisation systems make it easier for employees to make adjustments in the context of value creation and muda elimination. In Industry 4.0, the product takes on smart characteristics hence and a new framing of quality as: smart quality (SmartQ). SmartQ is produced in the cyber-physical production systems. The SmartQ is strongly personalized. This quality is in smart products, as well as many other characteristics associated with the form of sale and services [54].

According to Logu (2021) "Lean is one of the promising alternative strategies for achieving continuous improvement in business performance through identifying a company's value stream and then systematically removing all waste" [65]. According to Mrugalska and Wyrwicka (2017) [66], the determinants for defining the Lean 4.0 concept are the following smart levels, i.e. smart product, smart machine, smart operator and smart planner. The Lean tools are used on such levels [66]:

– smart product with process mapping and value stream mapping of particular operations;
– smart machine with Kanban cards, SMED, RFID, Andon, TPM,
– smart operator: operator has a contact with virtual and augmented reality,
– smart planner with traditional and virtual Kanban.

Wagner et al. (2017) [67] propose three data accesses:

– data acquisition and data processing,
– machine to machine communication – M2M),
– human machine integration – HMI).

The highest level of usefulness, as far as the application of Lean tools in smart production is concerned, is standardisation, the second position belongs to Kaizen, the third to Just-in-time, followed by: Jidoka, Heijunka, followed among others by teamwork, pull flow analysis, time settings, and the last place belongs to 5S (due to the development of technology and replacing manual activities with it, many workstations will disappear hence the lesser importance of the 5S method). Lean Manufacturing is a base for Smart Manufacturing. In the process of evolution of production systems the following features are exposed: importance, priority, key, flexibility, continuity, validity, agility, personalization. „Lean is one of the prevalent approaches in the present scenario because it uses several strategies to focus on the elimination of non-value-added activities along with resource utilization" [68].

The background to Kaizen is the digitalisation of workstations, so the company checks whether it electronically collects workstation data (data from machines, installations), if not then it starts this step, if so then the data collected from machines must be visualised and the results from specific equipment must be provided for analysis to managers and/or designers who make decisions on process optimisation directions. The basis for new projects is the integration of IT systems so that the technologies introduced do not perform a lot of unnecessary work, such as re-entering data. Through Kaizen at this stage, employees look for problems related to the lack of data at particular stages of the process and the inability to improve activities on an ongoing basis. Projects to address the data gap are linked to projects to equip machines and technology with smart sensors. Projects for the purchase of sensors and their installation on machines, together with the gradual modernisation of existing machinery, are implemented in small steps on used machines. In order to assimilate Smart Kaizen principles, an employee needs to interact with computer modelling and with computing simulations. Simulations support the design and evaluation of Lean Manufacturing systems. Once one station is optimised, you can move on to the next one until you reach the entire production line. The phasing of the changes implemented as part of the project to modernise the means of production allows for the reorganisation and preparation of employees to handle the new functions of the machines [54].

The end result of many Smart Manufacturing projects is significant operational improvements and measurable process optimisation. A common mistake made during process digitalization projects is to assume that the implementation must be fast and complete – as a result of extensive activities and large investments. Management would like to achieve full compliance with the new paradigms of Industry 4.0 within a few months. This cannot be done for several reasons. Large projects are difficult to justify economically, and the period of return on investment (ROI) may be longer than planned due to difficulties in estimating particular risk categories (natural, technological, market, etc.). Example of a large-scale investment: construction of a new facility equipped with machines that meet all the criteria of the requirements of intelligent production in terms of data collection and transmission. Example of a small project: installation of sensors on machines and data collection and/or modernisation of machines – replacement with intelligent ones [54]. Large investments requires more time and many analyses. The path of digital transformation of companies through Kaizen starts with small changes in workstations, where the costs are small or the changes are almost completely costless. In small projects, measuring the effects and learning lessons is done almost on an ongoing basis. After one project the next step is taken, from one machine to another, from one workstation to another, from one line to another, until a smart factory is created. Recently, the method of small steps in Smart Manufacturing projects is proposed by the Japanese company Mitsubishi Electric. On the corporation's website in the news section you can find a lot of information about the project activities undertaken using the SMKL methodology – Smart Manufacturing Kaizen Level (IAF, 2020 [69]).

Examples of SM projects implemented in small steps:

Project 1: Automation of places and processes. Initial condition: activities were so far handled by people, without the participation of industrial automation systems or machines at all. Activities: introduction of a cobot to cooperate with people, requiring relatively small expenditures, but enabling contact with software for work control and optimization, purchase and installation of equipment for automatic sorting, palletizing of manufactured parts. If these activities have so far been performed by people, automation may bring measurable benefits and at the same time initiate the process of transformation towards Smart Manufacturing (iautomatics.pl).

Project 2: Implementation of the poka-yoke system at the assembly station. Initial condition: the company relies on the knowledge and predisposition of its employees. Actions: equip the assembly stand with electronic documentation of the process, preferably supplemented with 3D computer models, divide the production process into elementary activities, during which the worker uses individual assembly elements, subassemblies and tools, place the parts in lockable containers, sometimes additionally equipped with light signals. Course of operations: once the assembly of a new device has started, the worker is guided step by step through the system opening the containers with the elements to be used at a given moment. Similarly, manual or pneumatic (electric) tools are only unlocked at precise stages of the assembly cycle. The end result: a lower risk of mistakes, an increase in the employee's efficiency, the plant receives objective information about the time of performing particular activities and the efficiency of the workplace (iautomatics.pl).

Project 3: Embedding sensors in machine:

Start: check if the machine is collecting data. If not, plan an action: how to collect information from the machines, how to visualise and provide the results from a specific device for analysis to the managers making the decision:

Stage 1: production data is stored in an electrical database (production data and machine status), machine status is collected and stored in an electrical method, either automatically or by simple actions (example: scanner, code reader), status: electrical copy, daily report of machine operation.

Stage 2: data used to manage the production facility is indicated by an HMI device such as a monitor or PC display, but is not analysed (graphs and lists are automatically generated in real time based on the collected data from the machine), status: generation of graphs and lists using computer programs (graphs and lists contain real-time analytical data).

Stage 3: the system can analyze data, the system automatically warns operators when action variance correction is necessary, state: notification is automatically given to decision makers (operators).

Stage 4: automatic processing and application of algorithms using AI to recognise and perform improvement based on results – systems automatically perform feedback checks, state: use predictive maintenance based on digitised data to optimise production and maintenance plan.

End state: Predictive Maintenance (PM) [70].

Conclusion: Kaizen is needed at the stage of the first small projects as well as during the improvement of already implemented solutions. Production automation improves the implementation of changes quickly (more in [71]). Each project is geared towards a specific goal of digitising operations and improving the quality of work. In line with Kaizen, it is worthwhile to involve employees at the stage of planning and developing projects for changes at workstations, and even to hand over the initiative for implementing changes to them, especially at the stage of improving the project at the control workstations.

2.4. PROJECT TEAM IN SMART MANUFACTURING

The automation of production has reduced the need for unskilled workers and led to an increased demand for people capable of solving problems themselves in the best way available. Such workers are able to bring change to their jobs. In the Fourth Industrial Revolution, there is a growing demand for creative workers with analytical skills and critical thinking. The "Z" generation entering the labour market wants to independently implement sentences without constraints. Z" employees are looking forward to intervening challenges. Among the human skills are: creativity, originality, own initiative, critical thinking, persuasion, negotiation/communication, attention to detail, resilience, flexibility, problem solving, emotional intelligence, leadership, and other interpersonal skills [72, 73]. The Fourth Industrial Revolution opens up new opportunities for employees. Skills such as technological design, computer programming, database architecture, data analysis, production automation, robotics, etc. are very important in companies [74]. In smart factories are needed teams with knowledge presented in the STEM model (Science, Technology, Engineering and Mathematics) [75]. Moreover, factories need employees with skills written in the letter "T" These three categories of qualifications and skills are represented by the letter 'T': technical skills, digital skills and soft skills. The 'T' model was presented in the document of the European Commission (blueprint) entitled: European vision on steel-related skills (...), May 2020 [76]. According to EC document [77], digital skills are needed to make informed use of the Internet and service applications and to operate digital devices in or out of the workplace, and, for higher level skills, programming, i.e. creating code for IT programmes. Digital skills of operators are strongly linked to the technologies used in companies. Digital skills include technical competences, ranging from basic to advanced skills to enable the use of digital technologies, and the cognitive, emotional and social competences necessary to use technical competences in the workplace [78].

Two levels of digital competences are:

1) basic digital competences include the user's ability to operate basic digital solutions,
2) advanced digital competences include working with technologies using artificial intelligence, cloud computing and the Internet of Things.

The period up to 2030 is expected to be a period of rapid development for machine learning and artificial intelligence. Experts estimate that by 2030, more than 80% of process handling tasks will be performed by artificial intelligence systems. Tasks in the area of quantitative reasoning will be carried out by humans and machines combined, with humans still responsible for completing 80% of tasks in the area of multifunctional reasoning. The use of cloud computing is also expected to grow exponentially. 5G develop smart city, business and services. Tools based on VR (Virtual Reality) and AR (Augmented Reality) enter more and more organizations.

Smart factories will use the Internet of Things (IoT) more widely than traditional factories [79].

The current level of knowledge and education of employees is higher than in the past (which is necessary to operate complex machinery and work in an automated industrial environment). The success of an organisation in the Fourth Industrial Revolution largely depends on the initiative and commitment of employees. Planning in an organisation consists of the company's management setting an overall strategy for action, giving its units specific objectives to be achieved at specific stages of completion, unit managers assigning tasks to teams and motivating them, holding them accountable for performance. In place of strict plans and schedules, the concept of Management by Objectives (MBO) has emerged, i.e. managers defining general tasks to be accomplished while allowing subordinates more or less freedom in choosing how to implement them. Each project is a complex venture, requiring the creation of teams made up of specialists from different fields. Project management requires a high degree of flexibility in the actions taken by the project team, which should be diverse in terms of the competences of the team members. In companies, in many industries, there are more and more teams and project management offices (PMOs) with experienced project managers. However, there may be a shortage of staff for the project team. Staff shortages have an inhibiting effect on the ability to execute projects. At the project development and implementation stage, companies very often use the services of specialised external IT companies. In Industry 4.0 projects implemented in specific companies, the importance of in-house IT and R&D departments that participate in project development and implementation is also growing. The members of the Industry 4.0 project team are strongly differentiated and selected according to the competences that are necessary at each stage (phase) of project development and implementation. The members of the project team include numerous computer scientists and programmers, as well as technologists, mechanics, material scientists, energy scientists, laboratory technicians, electro-mechanics, electronics engineers, planners, economists, etc. The team is open-ended, i.e. it is constantly being expanded to include more people or companies, contractors or stakeholders (consumers). The entire project team must be characterised by a high degree of flexibility in the actions taken, due to the fact that the developed and implemented project should be fully system-integrated and the technological solutions used should have the functions of: identifying, reacting and adapting to change [80, 81]. In addition, project team members and their managers need to use digital technologies and communication systems [82]. In new projects, as a rule, there is not one project controller but several due to the complexity of the technological solutions implemented. The decision-making centre of large projects is at the strategic level of production companies and the executive level is operational. In large projects (investment from scratch), managers manage and make decisions centrally. In small projects, project development and improvement is decentralised. Both project managers and engineering managers are heavily involved in project implementation. Both the project manager and the engineering manager have

supervisory roles. However, one of the key differences between them is their responsibilities, which means, differences in the scope and span of project management. A project manager oversees the progress of a specific company project. Projects can be very short or long, lasting several months or even years. The scale of the project can be small or large, but once the project is completed, the project manager moves on to the next project. An engineering manager is usually an engineer who oversees a group of other engineers, acting as the head of a team, department or programme. Because the engineering manager is responsible for his or her staff, he or she has the authority to coordinate directly with the human resources department on projects. An engineering manager may also oversee research and development or a specific project, but unlike a project manager, their position is permanent. While the project manager may come from a non-technical background the engineering manager must be an engineer and have technical knowledge and IT (industrial information technology) expertise. Engineers are heavily involved in project development at the operational level of the company. On specific jobs, they are supported by machine operators. It is a good idea to create a cross-functional team, as team members will then exchange knowledge, which will bring further benefits during the implementation phase, when tasks will involve the various departments of the company. Then the team members will become ambassadors for the project and will communicate and explain the transformation issues in a convincing manner.
Project teams should have leader, who is an authority for the other team members. Strategic thinking, change management, teamwork and networking are key characteristics of leaders (more in [83]). Team leaders of smart manufacturing operators should be authentic, i.e. have advanced knowledge of working with new technologies of Industry 4.0. In projects to modernise entire production lines and build intelligent manufacturing (CPS), teams and specialists are needed. According to AFITEP distinguish between two levels of responsibility in project management. These are:

- the decision-making level, carried out directly by the project manager,
- the decision-support level, carried out by a unit selected in the organisational structure of the company, dealing only with project management.

Implementation practice and project teams are, on the one hand, to ensure that very advanced quality and technological standards are maintained and, on the other hand, to ensure flexibility in working to solve complex project situations. The teams are firstly interdisciplinary and during the course of the projects, when there is an iterative process, more people are added to the project team. Interdisciplinary teams have, in addition to specialists, people with universal competences, including business competences. Projects should have a well-defined specification of the product that will result from the project. Due to the complexity and the need to adapt the product as the project work progresses, the specification and at the same time the resulting product should be adapted to the current implementation conditions and problems that the implementation creates. New factors trigger the matching process. The adjustment should take place in an iterative way [84]. In successive iterations, successive functionalities and stages of the finished product are incrementally delivered. Each iteration should end with a test, as well as an assessment of the fulfilment of quality standards and the compliance of the result with the assumed specification. On the basis of the tested results of the iteration, documentation for a given project iteration would be created. The work in a given iteration would be carried out in accordance with the priorities contained in the document describing the list of work/functionality/products of a given iteration, which would adaptively change in accordance with increasing knowledge of how to achieve the final product and the achievement of the final result/product itself [85].

Project teams should also be able to self-organise. This is because implementation difficulties are overcome adaptively and their solution is based on the advanced know-how of the project participants, so they should be able to adapt their work to the current needs in the project. The organisation of teamwork, in recent decades, has changed a lot. From hierarchical structures, in which the project manager gives the employees sequential orders, to task structures, in which the project manager communicates the vision of change to the employees, to self-organised teams.

Modern organisations use a cognitive approach to managing people. The manager does not tell employees what to do, but influences their beliefs and thinking in such a way that they themselves know what is best for the project in a given situation. Every person develops certain 'cognitive schemas' – ways of processing information that lead to certain ways of doing things and decisions.

Project team members work with specialists (a group of people who are most competent in the company in a given field and know best how to achieve a goal) A specialist becomes a team member at the self-organisation stage. By self-organisation is meant responsibility for the outcome, with freedom in how to achieve it. Teams should be small in number in order to work efficiently. The practice of the Scrum methodology indicates that teams of ten people or less are best. In very large teams there is a communication problem. In small teams, key information is exchanged quickly, both in terms of daily synchronicities monitoring current issues and progress, and during retrospectives and summaries. If the need arose for teams larger than ten people working on a single issue, the work would be split into several sections [85].

In companies that implement SM projects, task managers are appointed. The project (task) managers are coordinated by main investor/coordinator. A main coordinator is an employee from the management. Interdepartmental teams also participate in the implementation of office projects. At the strategic level, the position of management representative for PM is created. At senior or middle management level, directors or managers take charge of key projects. Executives, together with project coordinators, are involved in directing and supervising individual activities and managing the processes associated with ongoing investment projects. The initiator of major projects (smart factory) is top management.

With agile ways of working, organisations adopt: small, focussed, self-directed, dedicated teams; visual management; the ability to adapt to change; learning explicitly incorporated in the delivery cycle; prototyping; failing fast; drumbeat-paced incremental delivery of business value; and more goodies [86]. From the employee's perspective, some universal stages of adaptation to new projects can be distinguished (Manual 4.0 [87]):

– Precontemplation attitude – the employee is not interested in participating in the project. In his/her opinion, in his/her job, the change is not needed. He or she does not see any benefit from working with smart technologies.
– Contemplation attitude – the employee considers action and declares readiness to cooperate in the project, but does not actively participate in the implementation of changes (postpones them).
– Preparation attitude – the employee shows a real willingness to participate in the project and takes action to support the project teams.
– Action attitude – the employee actively undertakes change activities, learns about new systems, technologies, installations, programs, applications, algorithms, etc. and collaborates with project teams.
– The consolidation attitude – the employee is strongly involved in the project.

Working with project teams provides him with satisfaction. His participation in subsequent projects is evident (his attitude is active).

Conclusion: An important person who controls and supervises all activities during the project is the project manager. In addition to the project manager, the project team obviously plays a major role. Without it, the success of a project is completely impossible. Thus, the shaping of the main processes in projects depends to a large extent on the knowledge and skills of the employees. When forming a team, it is therefore worth reaching out to team members from different areas and levels of the organisation. In this way, the company will benefit during project work from the different experience of team members, different skills and knowledge, which will be useful in solving problems arising during digital transformation. Creating a diverse team – a 'cross-functional team' – will bring further benefits during the implementation phase, when the tasks will involve the company's various departments. Then the team members will become ambassadors for the project and will communicate and explain the transformation issues in a convincing manner.

2.5. PROTECTING INTELLECTUAL PROPERTY

Globalization and the fourth industrial revolution (Industry 4.0) created a knowledge-based economy. Generating and selling intellectual property is more profitable than selling tangible goods. The Constitution of the United States (Art. 1, Sec. 8) states“ [98] to promote the progress of science and useful arts by securing for a limited time to authors of the inventions the exclusive rights to their respective writings and discoveries” as one of the roles of the government [99, 100]. Intellectual property is the legal exclusive right to an invention, copyright or trademark. Intellectual property can be protected by using four different methods.

1. Maintaining the company secret

Only a small number of employees have access to the company secret. Those employees sign an agreement to guard and protect the company's secret even after their termination of employment. The ingredients in the production of Coca-Cola are protected for over fifty years by a company secret. If the company would apply for patent protection, the protection would have expired after twenty years.

2. Patent protection

A patent is a certificate of ownership to the invention. A patent in United States is granted by the United States Patent and Trademark Office (USPTO). A patent is a form of intellectual property which can be bought, sold or inherited. Patent protection is issued for twenty years from the date of filing the application. Patent protection is valid only in the country issuing the patent. The owner of the patent is usually the inventor or the employers of the inventor. Most employers including universities require their employees to sign an agreement that all the inventions developed during their employment become the property of the employer. The patent is an effective method to safeguard new inventions and prevent others from manufacturing, using or selling the patent without the permission of the owner. There are three different forms of patents [91, 96, 101].

2.a. Utility patent

A utility patent is often referred to as *patent for invention.* It can be issued for the invention of a new and useful process, material, machine, technology, chemical ingredients for medicine or drugs, etc. Most patents (90%) issued by the (USPTO) are utility patents. A utility patent is subject to an annual maintenance fee for the duration of the patent.

2.b. Design patent

A design patent is issued for a new or original ornamental design embedded or applied to an article to be manufactured. It is granted for fifteen years from the date of application. A design patent does not require a maintenance fee.

2.c. Plant patent

A plant patent is protected intellectual property for a new variety of asexually reproducing plants, mutants, hybrids or newly found seedlings. It is valid for twenty years and does not require an annual maintenance fee.

3. Trademark Protection

A trademark can be a design, word or phrase as well as a combination of those which identifies the company and distinguishes the product from many others on the market. The trademark identifies the source of goods or services. The trademark protects the company logo from being used by other companies when selling a similar product. The federal trademark registration provides legal protection for the brand associated with a product or service. Branding is a prominently used marketing concept. Customers usually associate a brand with their image, quality and reputation. Companies protecting their brand need to develop a trademark associated with the brand. Before applying for trademark protection, the company is advised to search USPTO (trademark electronic) search system. This needs to be done to determine if a similar trademark has already been registered or applied for. There are some trademark attorneys who can handle the trademark registration process.

4. Copyright Protection

Copyright protection applies to artistic, literary or intellectually-created works (music, movies, novels, photography, paintings, etc.) which are original and exist in a tangible medias (paper, canvas, digital form, etc.). Copyright protection grants the holder exclusive right to distribute and sell copyrighted materials.

2.6. PROVISIONAL PATENT AS A VALUABLE LOW-COST ALTERNATIVE

Since 1995 the United States Patent and Trademark Office offered a new low-cost option of filing for a provisional patent. A provisional patent is a valuable alternative to new inventors and small companies in the incubation stage. This type of patent provides one year of protection under the *patent-pending status.* During that one year, an application for a non-provisional patent needs to be submitted. The one-year period under the "patent pending" umbrella allows the inventor or small start-up company to market the invention before applying for a costly patent. A provisional patent allows the patent office to establish an early effective date for issuing the non-provisional patent. The effective date for issuing a non-provisional will be the application date for the provisional patent. *Claims-and-oath* is not required when applying for a provisional patent. The inventor needs to write a description of the invention including drawing(s) and sketches. These need to be sent to the patent office with a $260 filing fee. The filing fee can be paid by credit card. The provisional patent application can be written in any language and is not being checked for merit by the patent office. The application needs to be sent to the following address.

Commissioner for Patents:
P.O. Box 1450
Alexandria, VA 22313-1450

Applicants are strongly encouraged to file the application online by going to the following site. http://www.uspto.gov/web/forms/2038.pdf [106].

Applicants are encouraged to conduct a patent search to make sure that their invention (or very similar invention) has not been previously patented. The patent search can be done by going to the following website. http://patft.uspto.gov

If the non-provisional application for a patent is not filed within twelve months, the provisional patent-pending status will expire. The provisional patent is a valuable option to new entrepreneurs who are beginning their business. They can check the market value of the patent and decide if they want to apply for a non-provisional patent. A non-provisional patent is a more expensive alternative with an investment between $5000 and $15000. When the inventor has applied for a provisional patent, entrepreneurs can already start production and sale of the product and use the profit generated by the invention to cover the cost of the patent. If the invention does not generate a sufficient profit to justify the expenses associated with the patent, the inventor can abandon the idea without investing more money in the process [108].

2.7. PROCEDURE FOR APPLYING FOR A UNITED STATES PATENT

Preparation of the patent application is time consuming and requires the knowledge of patent law as well as technical expertise. Many inventors hire a patent attorney or patent agent to prepare the patent application. This increases the cost significantly. If a patent attorney is involved, the patent office communicates directly with the patent attorney or patent agent. The fees charged by a patent attorney or patent agent are not regulated by the patent office. Because of the high-cost factor, some inventors prepare their own patent applications. In the United States, there is website that independent inventors can use as a guide for preparing their own patent application. Every application for a non-provisional patent needs to include the following [96]:

- Patent application form available online
- Summary of the description of the invention
- Detailed description of the invention

Technical expertise is needed to correctly prepare the description of the invention. The most important part of the description of the invention is the claim (s) which define the scope of the protection of the patent. The scope of the claim (s) is often the decisive factor if the patent is granted or not. A non-provisional patent must have at least one claim. The description of the claim (s) must begin on a separate sheet of paper, so that the claim (s) can be easily distinguished from the rest of the patent description. If there are a number of claims, they need to be numbered. Each claim needs to be a single sentence. Most inventors seek help from an attorney when writing the claims.

- Drawings and sketches describing the invention
- An application requires a *claim-and-oath* signed in front of the government official or notary public.
- Appropriate fees

These fees include the application fee, patent search fee and patent examination fee. Citizens of other countries can apply for a patent in the United States following the same procedure as United States citizens. The most frequently followed procedure for applying for a patent in the United States is the two-step procedure.

1. Applying for a provisional patent to receive low-cost protection for the invention for twelve months.
2. Applying for a non-provisional patent before the twelve-month protection expires.

The patent office publishes a description of the invention within eighteen months of submitting the application. A patent is being granted approximately two-and-a-half years after the submission of the application. After the patent application in the United States has been submitted, the inventor has twelve months to apply for a patent in other countries. The fees associated with the patent application are listed in Table 2.6 [105].

Table 2.6 Fees charged by the patent office in the United States

Filing fee for a patent application	$680
Electronic filing of a patent application	$280
Filing fee for a provisional application	$260
Patent search fee	$600
Patent examination fee	$720
Patent issuing fee	$960
Processing fee (except for a provisional patent)	$140
Processing fee for a provisional patent	$ 50

Source: [105]

In addition to the fees charged by the patent office, there can also be a fee charged by the patent attorney or patent agent. The total cost of a non-provisional patent varies from $5000 to $15000. There is also a fee associated with maintaining the patent protection in the United States [105]. Fees associated with the maintenance of the patent protection are listed in Table 2.7.

Table 2.7 Fees associated with yearly maintenance of patent protection in the United States

Payable at 3.5 years for patent protection	$1,600
Payable at 7.5 years for patent protection	$3,600
Payable at 11.5 years for patent protection	$7,400

Source: [105]

2.8. PROCEDURE FOR APPLYING FOR A PATENT IN OTHER COUNTRIES FROM THE UNITED STATE

Residents of the United States need to apply for a United States patent before they can apply for a foreign patent. If they do not intend to apply for a United States patent, they will need written permission from the United States Patent and Trademark Office allowing them to apply for a foreign patent without applying for a United States patent. The procedure to apply for a foreign patent is shown in Fig. 2.5.

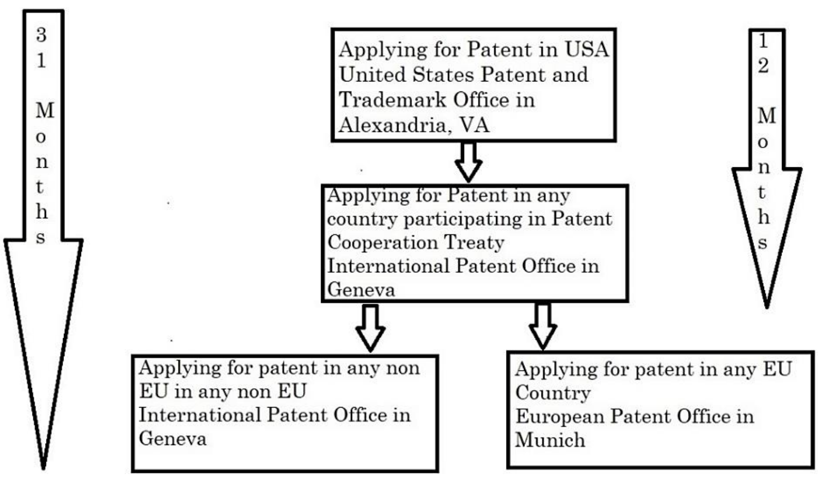

Fig. 2.5 Applying for patents in multiple countries from the United States

If the inventor desires to apply for patent protection in other countries outside the United States, there are three alternatives:

1. Apply for patent protection in a selected country by following the patent procedure in that country.
2. Apply for patent protection in more than one country under the umbrella of the Patent Cooperation Treaty (PCT),
   The location of the International Patent Office under the umbrella of the Patent Cooperation Treaty is in Geneva, Switzerland. One application submitted to the International Patent Office can be used to apply for a patent in most countries. (members of Patent Cooperation Treaty),
3. Apply for patent protection in the European Patent Office in Munich, Germany.
   One application submitted to the European Patent Office can be used to secure patent protection in all European Union (EU) countries.

Alternative #1 is being used if the inventor desires to apply for patent protection only in one country outside the United States. If the inventor intends to apply for patent protection in more than one country outside the United States, alternative #2 or alternative #3 are better options.

Table 2.7 International patent fees
(International Patent Office in Geneva, Switzerland)

Transmittal fee	$240
Non-electronic filing fee (Filed by paper)	$400
Patent search fee (Required even if conducted previously)	$2,080
Transmitting application to International Patent Office	$240
Examination fee	$600
Handling fee	$206

Source: www.wipo.int/hague/en/fees/sched.htm. [DOA: 11/30/2020]

Table 2.8 Patent fees charged by the European Patent Office in Munich, Germany

Filing fee	210 Euro
Patent search to check originality of the invention	1,635 Euro
Fee for protection in one or more European countries	585 Euro

Source: https://www.epo.org/applying/forms-fees/fees.html. [DOA: 11/30/2020]

Table 2.7 and Table 2.8 contain the patent fees charged by the International Patent Office in Geneva and the European Union patent office in Munich.

2.9. PROCEDURE FOR APPLYING FOR A PATENT IN POLAND

The procedure for applying for a patent in Poland is as follows [89, 90, 92, 93]:

- Applying for a patent by submitting the required documentation to the patent office in Poland.
- Patent office publishes the description of the invention twelve to eighteen months after the patent application was submitted.
- For eight months from the time the description was published anyone can file an objection.

- The patented invention is legally protected from the date that the description of the patent was published.
- The patent office issues the patent for four to five years from the date of submitting the patent application.
- After the application for the patent is filed at the patent office in Poland, the inventor has twelve months priority period to apply for a patent in other countries.

2.10. PROCEDURE FOR APPLYING FOR PATENTS IN VARIOUS COUNTRIES FROM POLAND

Polish citizens living in Poland are required to apply for a Polish patent before they can apply for a patent in another country. The procedure for applying for a foreign patent from Poland is shown in Fig. 2.6.

After the application for a patent in Poland has been submitted, the inventor has twelve months to apply for a patent in other countries [94, 95]. Some countries have the requirement that a patented product must be manufactured in the country (usually for three years) where the product is being patented.

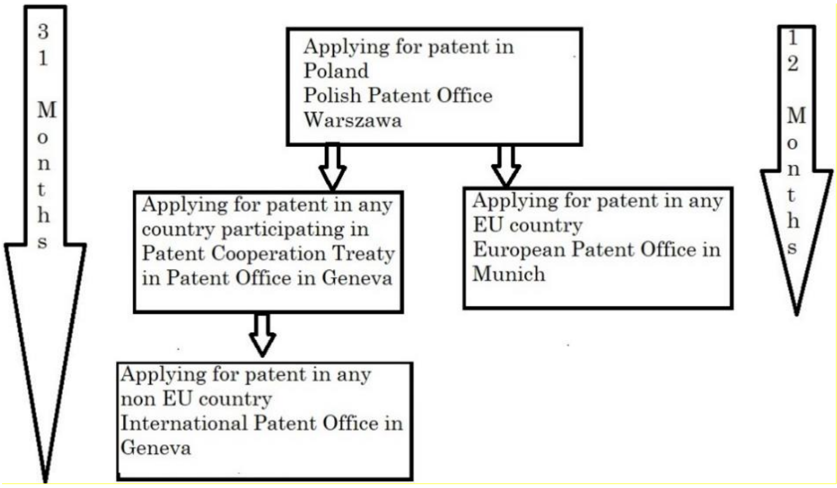

Fig. 2.6 Applying for a patent in multiple countries from Poland

If the inventor desires to apply for patent protection in European countries, the application needs to be submitted to the European patent office in Munich, Germany. One application to the European patent office can provide protection in any or even all European Union countries. If the inventor intends to apply for patent protection in non-European Union countries, the application needs to be submitted to the International Patent Office in Geneva, Switzerland. The International Patent Office in Geneva operates under the umbrella of the Patent Treaty Organization.

One application for patent protection to the International Patent Office can provide protection in any or even all countries belonging to the International Treaty Organization.

Patent protection of the invention is a very costly initiative. Table 2.9 lists a comparison of the costs of patent protection in different countries. The cost varies significantly based on the cost of a patent attorney or patent agent.

Table 2.9 Cost and timeframe of applying for patent protection

Country	Cost	Time (Before patent is granted)
United States (Patent pending "Provisional")	$260	Immediately (Up to 12 months)
United States (Non-provisional)	$5,000-$15,000	2.5 years
Poland	$2,000-$5,000	4-5 years
United Kingdom	$8,000-$9,400	2.5 years
Patent Protection in Europe (7 countries)	$16,000	2.5 years
Additional Non-European Countries	$4,000-$13,500	2.5 years

Source: [97]

Provisional-patent protection is the only low-cost alternative, but it exists only in the United States. This is a low alternative for many new entrepreneurs.

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3

HUMAN FACTOR IN SMART MANUFACTURING

3.1. CHANGES IN THE HUMAN FACTOR MANAGEMENT IN THE LAST INDUSTRIAL REVOLUTIONS

The first three industrial revolutions significantly changed the requirements of the workforce as well as the management style and methodology for motivating the workforce. Prior to the first Industrial Revolution (Industry 1.0), the agricultural industry was relying on slavery or forced labour. The *command-and-control management style* combined with physical punishment was the commonly used methodology to increase productivity.

3.1.1 First Industrial Revolution (Industry 1.0)

The first industrial revolution (Industry 1.0) which happened in the early 1800's abruptly changed the status quo. Water and steam became the commonly used source of power for manufacturing fabrics as well as for the agricultural industry. Slavery or forced labour could not be used anymore in manufacturing fabrics. In the United States (USA) this created conflict between the industrial North and the agricultural South. The northern states wanted to abolish slavery to gain workers for the growing new industries. The southern states were determined to maintain slavery as an inexpensive source of labour. After the Civil War (War between the States) slavery was abolished and replaced by a paid workforce. However, the management style did not change significantly. Physical intimidation was replaced by mental intimidation. Workers were under pressure to increase productivity and were threatened to be fired if they did not meet the quota. Workers were under constant mental pressure to increase productivity. At that time social programs were limited. Work was needed for survival. Child labour became a common practice.

Industrialization spread quickly, especially in the western countries. The development of the steam engine as well as the iron and textile industries were changing the life of many people. The new steam-powered machines were expensive, and many owners of small factories were struggling to raise capital. The option for them was a bank loan, partnership or joint stock companies [1]. Additional investment was needed to sustain the growth of production [2]. Industrialization increased the volume and variety of products on the market. At the same time, working and living conditions of the working class were poor. Working hours were very long and job security was non-existent [3]. Some regions with more industries were more prosperous than regions without manufacturing industries.

3.1.2 Second Industrial Revolution (Industry 2.0)

The second industrial revolution (Industry 2.0) took place in the early 1900's approximately one hundred years after the first industrial revolution. Industry 2.0 is associated with the introduction of electric power to manufacturing factories as well as residential homes. During the second industrial revolution, Henry Ford introduced assembly line production of the Ford Model T automobiles. The second industrial revolution was the golden era of Thomas Edison and Nikolai Tesla. Many new inventions were introduced and patented during this golden era for patenting and manufacturing of new products. Many Engineering programs in the United States and Europe were established during that time. Engineering programs were very practical, focusing on inventing new products as well as finding new methods for manufacturing existing products. In the United States the first Engineering society (American Society of Mechanical Engineers/ASME) was established. At that time Engineering programs were focusing on Chemical Engineering, Civil Engineering, Electrical Engineering and Mechanical Engineering. Chemical Engineering was focusing on the development of rubber as well as fuel for the automotive industry. The management style was still based on the *command-and-control methodology* with a great emphasis on innovations.

The period of the second industrial revolution was the period of the formation of large corporations [4]. This was a result of capital-intensive production. The technology was based on more expensive equipment which allowed for increased productivity. Productivity and living standards were increasing. However, the majority of the workforce was living in poverty. The location of factories during the second industrial revolution was determined based on the availability of transport (usually rail or water). Transport was needed to distribute manufacturing goods. The technology and technological change increased the size of some companies to thousands of employees. Many small companies could not compete on the market and closed [5]. This was the beginning of the era when the *rich were getting richer, and the poor were getting poorer.* There was economic uncertainty. Unskilled workers were working long hours with small pay and no pension [6]. The second industrial revolution already required people with technical and managerial skills. Those individuals were the beginning of the white-collar working class. They were paid much higher salaries than the working class. Sixty years later (in the 1960's) computer technology was developed. Machine automation and computer programming led to the next industrial revolution (Industry 3.0).

3.1.3 Third Industrial Revolution (Industry 3.0)

The third industrial revolution (Industry 3.0) resulted from the introduction of computer numerical controlled (CNC) machine tools in the manufacturing industry. Manufacturing was taking place without human intervention. The third industrial

revolution changed the requirements of the workforce significantly. There was a need for computer programmers as well as computer engineers and technicians. Engineering academic programs were becoming more theoretical and analytical. New Engineering majors (Computer Science and Computer Engineering) were being introduced at most schools. Engineering schools were also placing an emphasis on soft skills. The criteria for accrediting Engineering programs included soft skills as a priority in Engineering education. The psychological safety concept was gaining popularity in combination with a new method of management. The command-and-control method of management was becoming less effective. Empowering employees, transparency and a modern management style became more popular and effective.
This revolution created thousands of businesses and millions of high paying jobs. The third industrial revolution became the foundation for the globalization of the economy. Manufacturing companies needed to invest in new computer numerical control (CNC) equipment to remain competitive. Massive retraining of the workforce was needed. For that purpose, community colleges were established in the United States. Community colleges offer a two-year associate degree focusing on the technical and practical applications required by industry. The funding to establish many community colleges was provided by either the federal or state government. There was also a need to retrain entrepreneurs and managers. The third industrial revolution changed the business model as well as business strategies. Logistics and supply chain also needed to be revised and modernized [7, 8].

3.1.4 Organizational Change in Human Factor Management

Many changes were taking place during the first, second, and third industrial revolutions. The economy shifted from agricultural to industrial and later to service. At the same time industry was changing. The types of human resources were changing as well. During the first industrial revolution some management positions were created. The first managerial positions were created at the railroad and telegraph industries. During the second industrial revolution, the number of white-collar managerial workers increased. Industry was growing and becoming more complex. There was a need for engineers as well as managers at different levels within the company. structure. There was also a need for workers in administration and sales [9]. In the 1950's A Human Resources Information System was established at the General Electric Corporation. This system was established to manage human resources within the corporation [10]. Already in 1900, the idea of nurturing three educational skills was being discussed. Those educational skills [11] were as follows:

1. Fostering aspiration
2. Developing reflective conversation
3. Understanding complexity

All four industrial revolutions were started by new technology developments. Every technological change triggered organizational change(s) as well as changes in the human resources factor [12, 13, 14]. Before the first industrial revolution, the economy relied on agriculture. In 1850 approximately 60% of the population was employed in agriculture [15]. The number of people employed in agriculture kept decreasing until it was only 1% in 2010. Technology was the main factor in eliminating the need for workers in the agricultural sector. The demand for factory workers (machine operators, manual labour, construction jobs) kept increasing from 3% in 1850 to 11% in 1960. The technology introduced by the third industrial revolution (introduction of CNC machines) lowered the demand for factory workers to 4.3% by 2013. There, however, was an increase in the need for blue collar and white-collar workers (engineers, technicians, managers, sales executives, and clerical jobs). The demand for engineers increased from 0.15% in 1900 to 1.4% in 2013. At the same time the number of service jobs (food, hospitality services, healthcare, personal service jobs) was also increasing. The job openings were shifting from the manufacturing industry to the service industry [16]. During the first and second industrial revolutions, the number of engineers in the United States increased from 7,000 in 1880 to 136,000 in 1920. During the third industrial revolution, the number of engineers increased to 1.2 million [17, 18]. Table 3.1 describes the tendency of the increase or decrease of demand for jobs in different fields.

Table 3.1 Employment tendency in the United States (1850-2015)

Field of Employment	Employment Share of Change in the United States (%) (1850-2015)
Sales (Retail and Wholesale)	+12.8%
Education	+9.9%
Health Professionals	+9.3%
Machine Repair Services	+6.1%
Finance and Banking	+5.9%
Professional Services	+5.0%
Government and Administration	+4.9%
Household and Personal Services	+2.7%
Entertainment	+2.2%
Utilities	+0.8%
Telecommunications	+0.7%
Construction	+0.3%
Transportation	+0.2%
Mining	-1.3%
Manufacturing	-3.6%
Agriculture	-56.0%

Source: Author's compilation based on [14]

Advanced technology was responsible for a significant decrease in some jobs, especially agricultural, mining and manufacturing. There was a significant increase in jobs in the service industry as well as computer technology. Advancement in computer technology from 1970-1990 created 15.8 million new jobs.

3.1.5 Development of the Skilled Workforce as a Result of Technological Changes

Already during the first industrial revolution the operation of the small steam engines required low-to-middle skilled employees. The emerging factories powered by water or steam also needed to find a low-to-middle skilled workforce. During that time agricultural workers were upskilled [19]. During the second industrial revolution, the demand for skilled workers increased. The introduction of electric power in manufacturing as well as homes required highly skilled engineers. Engineering education at that time was very practical. Upskilling the existing workforce to a high-enough level was difficult.

A third industrial revolution substantially increased the demand for highly skilled engineers. Digital and computer technology was rapidly developing. Engineering programs at that time became more theoretical. The practical approach used previously was not enough. New engineering majors (Engineering Science, Computer Science, Computer Engineering) were developed. In the late 1970's and early 1980's many companies were investing in research and development as well as computer technology. The demand for highly skilled workers increased. High-skilled engineers were being paid high salaries. At that time the demand for unskilled and low-skilled workers was decreasing. This was the beginning of the knowledge-based economy. Selling intellectual property rather than tangible products became very profitable. By the year 2000 approximately 15%-30% of the job openings required high qualifications. This tendency continues until the present. By 2020, 35% of the jobs required high qualifications. Service jobs also required high levels of education. Teachers as well as medical professionals are listed under the service job category. The demand for medical professionals as well as teachers and university professor keep increasing. The *Skills Gap Survey* (2005) indicated that 90% of the manufacturing companies in the United State reported a shortage of skilled scientists, engineers and technicians. Presently we have entered the fourth industrial revolution. The demand for a highly qualitied workforce is still increasing. There is also a need for upskilled present employees. In the United States community colleges have the role of retraining the existing workers. The world has become a global society, so the fourth industrial revolution is already taking place globally. (It took over one hundred years for the first industrial revolution to spread across Europe) [20].

3.2. EMPLOYEES IN INDUSTRY 4.0

The fourth industrial revolution (Industry 4.0) has been taking place since 2015. The fourth industrial revolution created the potential to use data and machine learning to automate decision-making as well as reduce human involvement. Industry 4.0 built on the accomplishments of Industry 3.0 where computerization was introduced and refined. Industry 4.0 was created by adding smart systems, wireless connectivity, virtual reality and augmented reality. Machines are connected together with wireless connectivity and adapt to the workflow better and more responsibly. Industry 4.0 is revolutionizing modern production in the same way the Henry Ford assembly line revolutionized production during the second industrial revolution. One of the trends in Industry 4.0 is *increasing localization.* Industry 4.0 factories are moving closer to the people that they serve. This localization simplifies the logistic processes. Industry 4.0 increases competition by eliminating physical boundaries for getting resources and selling the product. Artificial intelligence (AI) and machine-learning can perform tasks that only humans would normally perform. AI can already assist a company with the following:

- Assist human resources in screening candidates for jobs.
- Detection and protection of cybercrime
- Interaction with customers
- Collecting mobile payments and paying the bills
- Enforce security compliance by using biometric technology.
- Traffic central control system (City traffic, airport traffic control)
- Overseeing manufacturing operations
- Overseeing and managing logistics in smart cities
- Supply chain management
- Allow for telecommunication of workers in a virtual environment.

Most companies are either participating in Industry 4.0 or assessing the needs and identifying how Industry 4.0 technology could meet those needs [21]. The next step is to develop a detailed plan to transform the physical plant, processes, tools as well as the workforce into Industry 4.0 technology. Transformation of the workforce is normally the hardest one. It was determined that the most efficient method is retraining the existing workforce, rather than hiring new people [22]. The existing workforce is often a company's greatest asset. Upskilling existing employees has several distinct advantages over hiring new workers. Those advantages are as follows:

- Existing employees know the company structure.
- Existing employees have a good understanding of the company's products and services.
- Existing employees are committed to the company.

Retraining and upskilling existing employees will reduce the digital skill gap and make the employee comfortable with digital technology [23]. The training methodology needs to be practical and resemble the system in which workers will be working. The most appropriate methods to retrain existing employees are the following:

- Augmented reality
- Digital performance support
- Virtual reality training

Retraining the workforce also needs to include soft skills such as [24]:

- Creativity
- Persuasion
- Collaboration
- Adaptability
- Emotional intelligence

Soft skills are extremely important and allow the employees to successfully change their career path as required by Industry 4.0. Industry 4.0 training is a complex iteration of training. The development of machine learning and artificial intelligence created new opportunities for new employment. The World Economic Forum [25, 26] reported the prediction that there would be 93 million new jobs related to Industry 4.0. At the same time millions of people are losing their jobs because of robotics and automation. Retraining the workforce is the highest priority. This is not a new phenomenon. This has happened previously during the first, second and third industrial revolutions. The scale of changes, however, is larger than before.

Transferring to Industry 4.0 creates great opportunities for educational institutions and many individuals working in education [27]:

- Primary and secondary educators
- Higher Educational Institutions
- Community Colleges (Retraining of the existing workforce usually happens at community colleges)

Many new jobs created during the transition to Industry 4.0 are high-paying jobs. Many of those jobs can be done in a remote-working environment. Currently academia views Industry 4.0 technologies as a separate silo. Academia is still aligned with traditional Engineering disciplines [28]. There is a need for partnership between educational institutions, industry and government agencies to address the needs of Industry 4.0. New education modules embrace flexible online courses and rapidly adapt immersive training using augmented and virtual reality. The expression was adopted that Industry 4.0 requires Education 4.0 [33]. There is no formal definition of Education 4.0. In 2015 the World Economic Forum published a report (*New Vision of Education: Unlocking the Potential of Technology)* [26] on the 21st century skill gap. The missing skills were divided into three categories:

1. Fundamental literacies
2. Competencies
3. Character qualities

In 2018 the World Economic Forum published *Future of Job* [25] which lists the ten top skills needed by the future workforce.

Those ten top skills are as follows:

1. Complex problem-solving
2. Critical thinking
3. Creativity
4. People management
5. Coordinating with others
6. Emotional intelligence
7. Judgment and decision-making
8. Service orientation
9. Negotiation
10. Cognitive flexibility

American Society of Engineering Education (ASEE) with funding received from the National Science Foundation (NSF) also attempted to identify the knowledge, skills and abilities of the future engineering workforce. Their report was issued under the name *Transforming Undergraduate Education* [28] The most important traits and competencies listed in the report are as follows:

- Good communication skills
- Engineering science fundamentals
- Ability to identify, formulate and solve engineering problems
- Systems integration
- Curiosity and persistence desire for continuous learning
- Self-drive and motivation
- Cultural awareness in the broad sense
  (Nationality, ethnicity, linguistics, gender, sexual orientation)
- Economics and business acumen
- High ethical standards, integrity as well as global, social, intellectual and technological responsibilities
- Critical thinking
- Willingness to take calculated risks
- Ability to prioritize efficiently
- Ability to do project management
  (Supervising, planning, scheduling, budgeting, etc.)
- Teamwork skills
- Ability to function on multidisciplinary teams.
- Entrepreneurship skills

In the European Union (EU) a similar project was undertaken to identify the educational needs for Industry 4.0. The name of the project was *Universities of the Future.* This project funded by the EU identified the following competencies [22].

Engineering Competencies:

- Science for collecting data and advanced data analysis.
- Novel human and machine interfaces
- Digital to physical transfer technologies (3-D printing)
- Advanced simulation and virtual plant modeling
- Data communication and network/system automation
- Artificial intelligence
- Robotics
- Programming skills
- Close loop integrated product and process/quality control management system
- Real-time inventory and logistic-optimization systems
- Understanding the impact of technology
- Human-to-robot integration and user interfaces
- Technology-enabled product and service designs.
- Technology-enabled ergonomic solutions and user experience

Business Competencies:

- Technology awareness
- Management strategy change
- Novel talent management strategy

- Organizational structure and knowledge
- Role of managers as facilitators
- Technology-enabled processes
- Forecasting and planning matrix/scheduling

Based on these skills required by Industry 4.0, Peter Fisk [27] identified the following characteristics of Education 4.0.

Fisk's Characteristics of Education 4.0

1. Diverse place and time/Flexible individualized learning (Incorporating the flip classroom where students are learning theory on their own and then use their time in the classroom for hands-on applied work and discussion. Incorporating e-learning as part of the educational experience)
2. Student-driven personalized learning.
   (Students need to learn at their own pace and receive positive reinforcement as well as feedback to move forward with confidence)
3. Students need to have a free choice of learning tools and methodologies. (Students select learning tools based on individual preference. Students select the most effective methodology of learning)
4. Project-based interdisciplinary learning [29, 30].
   (Project-based learning is an active learning method which can make students self-motivated and active learners through the process, results and analysis of the problem. Students can naturally be exposed to a teamwork environment and fully exercise their classroom knowledge into real-world applications. Very often in the Engineering curriculum, students are taking individual courses without the ability to cross-reference the knowledge from one course to the other. Students are viewing those individual courses as disjointed pieces of the puzzle. Most students do not see the *big picture* of the body of knowledge until they gain some industrial experience and get the opportunity to apply the knowledge that they had learned in their academic courses. The *project-driven curriculum* allows the students to see the *big picture* rather than individual pieces of the puzzle. Our work challenges are becoming increasingly interdisciplinary and transdisciplinary. Students need to be trained in an interdisciplinary mode (cross-disciplinary education).
5. Field experience.
   (Real world industrial projects are very important in engineering education. Internship and co-operative education are also very effective forms of learning.)
6. Examinations and modes of assessment.
   (In modern Education 4.0 mastering of skills is tested as learning happens. Student assessment should be based on their individual reflection of their own learning process. Standardized tests and general exams are useless and obsolete)
7. Student ownership/Source of knowledge and information.
   (The learning process is more effective if the students select the sources of knowledge and information (e.g., books, articles, search engines, blogs, etc).
8. Mentoring.

(The role of the teacher in Education 4.0 is mentoring the students and helping them to navigate through the large amount of information which is available to them)

9. Setting for learning.
   (Active learning is more effective than the traditional lecture format. Providing *enabling spaces* for students to meet with mentors is very helpful)
10. Collecting, analyzing and interpretation of data.
   (The interpretation of data to discover trends and logic is increasingly important in the future).

Engineering and Business academic programs are changing. Those changes, however, are not fast enough. Education is not very agile. Industry is more agile than academia. In 2018 MIT (Massachusetts Institute of Technology) published a report (*The Global State of the Art of Engineering Education)* [31]. The report lists the following challenges in Education 4.0:

- Alignment between governments and universities in their priorities and vision for Engineering education
- Challenges for delivering high quality and student-centered education to large student cohorts.
- The silo-nature of many Engineering schools and universities which inhibits education and cross-disciplinary learning.
- Faculty appointed promotion and tenure systems that reinforce an academic culture which does not appropriately prioritize and reward teaching excellence.

There are many challenges in implementing Education 4.0. The main challenge is the rapid changes in technology. The former United States Secretary of Education, Richard Riley, made the following four key points [32]:

1. 63% of children entering elementary school this year will work in a job that has not been invented yet.
2. 49% of current jobs have the potential for machine replacement, with 60% having at least 1/3 of their activities automated.
3. 80% of the skills trained for in the last fifty years can now be outperformed by machines.
4. At a global level, technically automatable activities touch the equivalent of 1.1 billion employees and $15.8 trillion in wages.

Every industrial revolution requires some changes in retraining and upskilling the workforce. This was the case during the first, second and even to a greater extent the third industrial revolution. In the United States the community colleges were established for the purpose of retraining and upskilling existing workers. The programs at community colleges are very flexible and can be customized to industries' requirements. In the United States community college already offered associate degree programs (two-year programs) based on the needs of Industry 4.0.

3.2.1 Leaders in Project Management

The main objective of project management is to obtain the maximum output with a minimum of resources. Presently during the era of Industry 4.0 additional criteria are being included. Those additional criteria include environmental friendliness as well as the social aspect. During Industry 4.0 many jobs will be replaced by robotics and artificial intelligence (AI). There is a digital transformation across industry. This transformation affects project management as well. Project managers will be using more technology and less manpower. There are four ways for project managers to adapt to digital transformation. To fully utilize technology the project manager will need to do the following:

1. Promote agility.
   (Agile and adaptable project managers will be more effective in recognizing value, promoting creativity and innovativeness as well as unleashing the flexibility of multidisciplinary teams)
2. Upskill intellectual capability.
   (Project managers need to possess a cognitive compacity and flexibility as well as emotional intelligence)
3. Adapt to the dynamics of technological resources.
   (A project manager needs to create multidisciplinary teams with a balance of traditional knowledge and new experiences. All members of the team need to have an open mindset)
4. Improve emotional intelligence.
   (Modern project managers are participating in a collaborative process. Project managers need to facilitate engagement, motivation and enthusiasm within the company)

The classical theory of project management has three constraints. Those constraints are time, cost, and scope. The project needs to be completed within the time and budget frame as well as meeting the scope and expectations of the stockholders (Fig. 3.1).

Fig. 3.1 Classical project management

The development of a sustainable project is increasingly more important to the organization. ISO 26000 defines sustainability as "integrating the goals of high quality of life, health and prosperity with social justice and maintaining the earth's capacity to support life in all diversity". Green project management is a model in compliance with ISO 26000 taking into consideration the social and environmental impact of the project [34, 35]. Fig. 3.2 illustrates *green project management.* The environmental factors in green project management should include five “Ps” (people, planet, prosperity, processes and products).

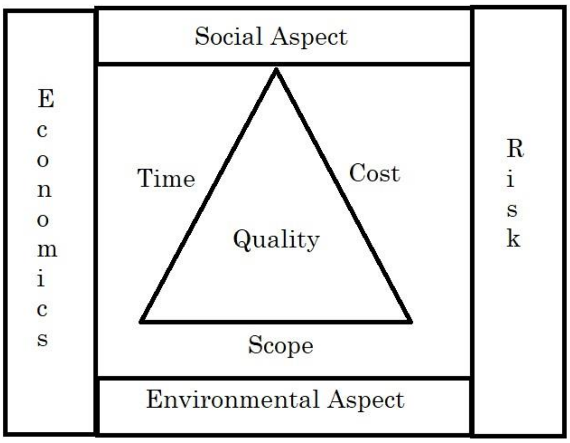

Fig. 3.2 Green project management

Methods used in project management are evolving into new technology and artificial intelligence.
According to Simion’s, [36] project management in Industry 4.0 has the following four characteristics:

1. Digitization
2. Virtualization
3. Trans nationalization
4. Professionalization

Project management also switches from the *waterfall approach* to the *agile mode*. There are significant changes in project management within individual task areas:

- Time management
  (Technology allows for real-time monitoring of the project’s progress and execution)
- Cost management
  (Technology allows for real time cost reporting. The foresight of total cost is more accurate)
- Quality management
  (Technology allows digitalization of the quality control of the deliverables)
- Project team management
  (Use of virtual teams and collective intelligence)
- Communication management
  (Use human-to-machine and machine-to-machine communication. This allows for auto-generation of a progress report)
- Project risk management
  (Technology allows us to analyze and assess the risk from the collected data)
- Resource management

(Technology allows for sharing knowledge about purchases where automatic ongoing reporting is available)

The use of technology in project management has an influence on project planning as well as project execution. The conditions of Industry 4.0 have changed significantly the soft and hard skills as well as the attributes needed by a project manager. Soft skills for Industry 4.0 project managers are as follows [37]:

- Communication skills to share information and knowledge about the project with the stockholders.
- The authority to have the right to create project agreements, define the resource management and appoint the team members.
- Skills needed for team management.
  (A project manager needs to allow the team to adopt different creative initiatives without losing the focus on the strategic objectives of the project)
- Skills to manage unforeseen events.
  (The project manager needs to have the ability to make a quick decision related to the project)
- Negotiation skills needed to manage the project effectively.

There are also hard skills for Industry 4.0 project managers [37]. The most important hard skills are knowledge and experience with innovative technologies, big data analysis and an algorithm which will help to focus on the objectives of the project. Pessl in his study [38] identified the competencies of the project manager and divided them into four categories.

1. Technical competencies
   (State of the art knowledge of technology and processes)
2. Methodological competencies
   (Creativity, entrepreneurial thinking, problem-solving, decision-making, research skills, conflict solving)
3. Social competencies
   (Language skills, ability to transfer knowledge, ability to work on teams, intercultural skills)
4. Personal competencies
   (Flexibility, tolerance, motivation, sustainable mindset, ability to work under pressure)

Research indicates that an agile methodology of project management is more effective than the waterfall method (especially in IT projects) [39]. Literature indicates that two enablers need to be implemented prior to using the agile method [40]:

1. Conducive culture [41]
   (High trust, ability to learn from mistakes, accountability, collaboration, continuous improvement, focus on customers)
2. Servant leadership [42, 43]
   (The responsibility of the leader is to remove obstacles from the team's path. The responsibility of the team is to deliver the work)

Servant leadership style is the most effective one in Industry 4.0. A servant leader as a project manager needs to focus and facilitate the development of each individual team member. The servant leader nurtures the autonomy of every individual team member. The first industrial revolution created a disruption which needed to be viewed by the project manager as an opportunity and not a threat [44]. There are eight attributes of a servant leader which are being listed from highest to lowest:

1. Forgiveness
2. Courage
3. Authenticity
4. Humility
5. Standing back
6. Stewardship
7. Accountability
8. Empowerment

Dierendonck and Nuijten [45] also listed five attributes of the servant project leader. Those attributes are listed from highest to lowest:

1. Courage
2. Accountability
3. Empowerment
4. Humility
5. Miscellaneous

There is a substantial overlap on both lists. The servant leader always challenges the conventional model of working. Industry 4.0 requires novel ways of managing a project team. Project managers often need to be retrained and upskilled to meet the expectations of Industry 4.0. There are still project managers using the outdated command-and-control leadership style.

3.3. WORKERS AND OPERATORS IN PROJECT MANAGEMENT

The fourth industrial revolution and digital transformation has changed the structure of companies and procedures of operation [46, 47, 48]. Prior to Industry 4.0 every department within an organization was a separate silo with low cross-functional collaboration. Industry 4.0 requires extensive cross-functional collaboration. Personnel with knowledge and expertise in different fields are brought together to work on multidisciplinary cross-functional teams. These teams can be very effective in addressing complex problems. Cross-functionality is a way of life in smart manufacturing companies. The global smart-manufacturing market is expected to grow to 658 billion by 2029 [49, 50]. Cross-disciplinary collaboration and communication as well as support for creativity and innovativeness is essential. *Internet-of-Things* (IoT) in a smart factory setting is very complex [51, 52]. To oversee the end-to-end process cross-functional teams are needed. The members of the cross-functional teams usually represent the following areas [53]:

- Executive committee
- Technology

- Recruiting
- Training
- Resources
- Sales
- Marketing
- Corporate strategy
- Operations
- Engineering

Internet of Things (IoT) makes it easier to foresee any malfunctions in the manufacturing sequences of the process. IoT can also optimize the logistics of the supply chain as well as the efficient distribution of the manufactured products. IoT can also optimize the process of transporting goods from manufacturers to customers. According to smart-manufacturing experts, the involvement of cross-functional teams enhances the growth of revenue and shortens the time of return on investment. Cross-functional teams were used successfully during the COVID-19 pandemic. During that time, there was decreased moral and inconsistent productivity. Cross-disciplinary teams are being credited for boosting morale and performance of employees. These teams bring together individuals having different functions within the organization. The organizational culture is being changed to be more inclusive [54, 55].

The typical company or organization is normally divided into a number of departments handling different functions of the organization. The traditional structure was working efficiently assuming the organization was static. The efficiency was focusing on the efficiency of the individual functions instead of the efficiency of the project, product or process. Smart manufacturing focuses on the efficiency of the process of manufacturing the product. Andy Grove in his book *High Outcome Management* outlined the role of cross-functional teams. This type of team is in a better position.to understand the consumers' needs and make the right decision related to the project or product [56]. The position of a functional manager is changing from a position of authority (resource allocation and line management) to a position of influence (setting a strategic direction). Google has conducted a study on the effectiveness of cross-functional teams. Psychological safety was determined as the main contributor to the success of cross-functional teams. Psychological safety makes people comfortable to try new things as well as to admit to previous mistakes and failures. There are some conditions which need to be met for the cross-functional team to be effective [57]:

- Mutual trust
  (Employees from different departments may not know each other and may not fully understand the function of their teammates)
- Lack of fear of conflict
  (The team members need to feel safe to discuss different ideas and have decision-making autonomy)

- Commitment
  (All team members need to feel ownership and responsibility towards the task of the team)
- Accountability
  (The team members need to prioritize the common interest and not the interest of their department)
- Attention to results
  (Team members need to focus on the bigger picture rather than the interest of a particular department)
- After the cross-functional team members are appointed, the first meeting should be a social meeting, so that the team members can meet in person and some mutual trust can be established. For the team to be effective the following conditions need to be satisfied [58].
- The team leader needs to be competent, trustworthy as well as having some experience as a team member and team leader. The team leader needs to communicate the vision and goals of the project.
- All the appointed team members are qualified and have the right skills. Team members participate in the decision-making process. The individual members of the team represent expertise in different fields.
- All the team members understand their role on the team. They also understand the decision-making model.
- All the ground rules are clear, and the team has everything that it needs to be successful.
- The lines of communication need to be clear and transparent.

Cross-functional teams foster innovation. Creativity and innovativeness are triggered by a multidisciplinary approach where cross-pollination takes place. Cross-functional teams increase employees' engagement, improve efficiency and reduce the time to market of any product. Cross-functional teams are usually agile teams. These teams need to be supported by all the departments within the organization. Cross-functional teams normally have five-to-seven members. The team members share the responsibility of delivering the project and meet face-to-face at least once-a-week. Cross-functional teams have a high level of authority. Team leaders are involved in coaching and mentoring as well as building a culture of trust and collaboration [59].
There are many benefits of cross-functional collaboration.
Those benefits are as follows:

- Allowing leadership and managerial skills to grow.
- Allowing for better communication and transparency.
- Building a team spirit and culture.
- Encouraging and promoting diversity.
- Creating an all-inclusive team culture.
- Generating creative and innovative ideas.
- Boosting productivity.

- Improving employee engagement.
- Meeting consumer expectations.
- Maintaining an alignment with organizational goals.

Some researchers have proposed nine steps to build a cross-functional team [60]:

1. Set clear goals related to budget, deadline and desired outcomes.
2. Assign a team leader.
   (The leader needs to collaborate with the team members allowing and respecting individual autonomy)
3. Define the roles and responsibilities.
   (Define who is responsible for which action and decisions. Define how the members of the team will relate to each other)
4. Assemble a diverse team.
   (A cross-functional team needs to include individuals from different demographics as well as different educational and professional backgrounds)
5. Involve the customers.
   (At least one member of the team needs to represent the customers for the company product)
6. Create a workflow.
   (A workflow plan helps the organization stay on time and within budget)
7. Promote team accountability. (Every action and decision of the team needs to support what is best for the project and the clients)
8. Establish a team matrix.
   (A matrix can assist in identifying areas where skills are lacking. It can also help with time management)
9. Invest in collaborate technology.
   (Technology can help with communication. It can also report on instant progress of the project)

There is no one way for creating cross-functional teams. As a result of globalization and the implementation of Industry 4.0, competition has become stronger than ever. Most businesses are scrambling to outperform their competition [61, 62].

3.4. PROJECT TEAMS IN SMART MANUFACTURING

Industry 4.0 at the operational level needs project teams, a team of IT specialists (programmers) and teams of operators. Teams are important not only from the perspective of the continuous development of technologies, but the possibility of applying them to company processes. The design team, together with the other teams, can effectively deal with the different types of challenges of Industry 4.0. Before automation and robotics can benefit the company, the design and operator teams need to implement many process changes. Firstly, they must change their companies' existing production systems and models. The technological innovations implemented need to be integrated into the entire company, i.e. not only operate on the production belts, but also throughout the production building. Additionally, a better approach is to use production systems, production cells, lines and factories that can be easily modified and adapted. Programming, use, maintenance and product support are very important in smart manufacturing. Another change is the adaptation of technology to the requirements of automated processes. This will include the reconfiguration of computer programmes and the combination of technologies (M2M).

Existing processes and systems are being replaced by those that are more suitable to support newer technologies. Project teams should keep an eye on emerging innovations and research findings that will help implement the automation and robots (cobots) in the company. In many companies, the first priority is to complete the automation and robotisation infrastructure that will form the foundation for future investments in intelligent technology. In companies where automation and robotisation have already been implemented, there may be a lack of linkage between the production workstation and the IT systems of cooperating companies. Design teams and operators are responsible for improving the functionality of automated machines, including industrial robots in the workplace [63]. Multi-arm robots and robots that work directly with humans (so-called cobots) are currently some of the most flexible production equipment available on the market. Their proper use and configuration, perhaps according to the one piece flow formula, i.e. creating not a series of products, but individual pieces, without the need for line retooling, is a challenge for project teams. Teams assigned to implement smart technology very often have to redefine or at least refine operations [64].

A project team is a group of people who work together to complete a project [65]. Typically, project teams are cross-functional - meaning that they are made up of people from different groups or departments in the organisation working towards a common goal [64]. The organisational structure of project teams is aligned with the scope of the objectives and tasks (an example Fig. 3.3).

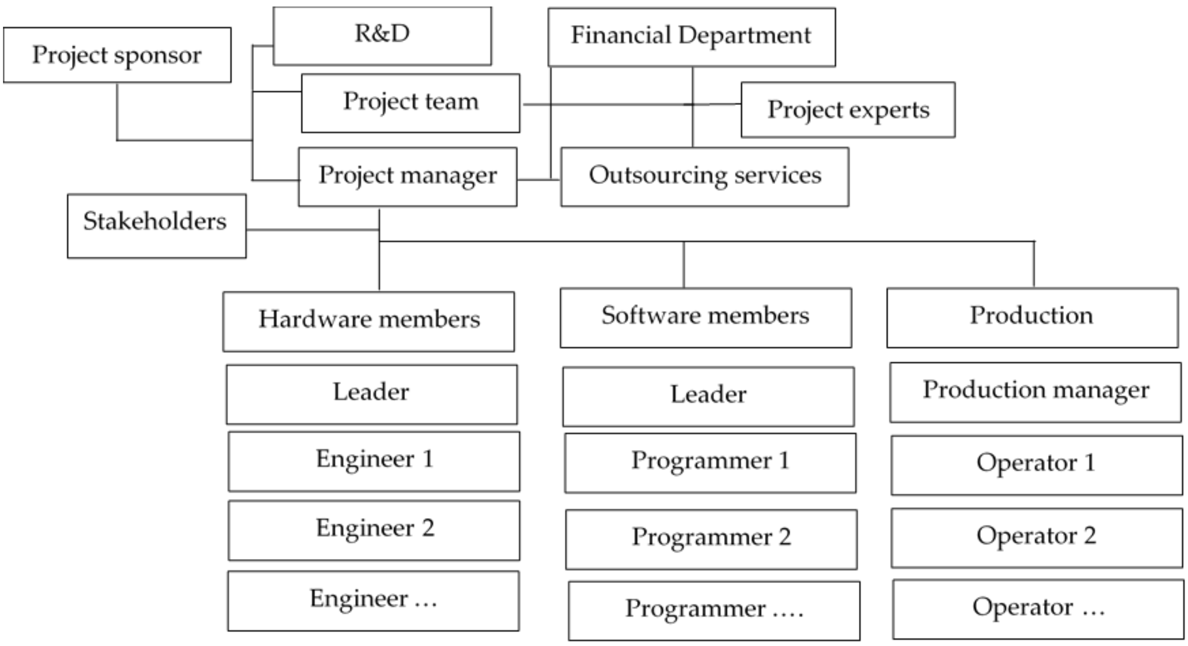

Fig. 3.3 Example diagram of a project team structure

Source. Own elaboration.

The quality of the project team's work and effectiveness is determined by individual predispositions, competences, skills, talents. At the beginning of project development, it is necessary to identify what human resources will be needed to make the project a success. The Project Director oversees the Project Management Team (PMT), which is responsible for the implementation of the project. Each project team has a manager (leader). Every project manager should bear in mind that even the best-planned tasks will not be completed if the team is not made up of the right people. The starting point for determining the required human resources is the work breakdown structure document. Based on this, the project manager determines what resources will be needed for the project. The next step is to create a matrix of roles and responsibilities, which is necessary to define the list of duties for which team members with specific roles will be responsible. Examples of roles of team members in Smart Manufacturing Projects (SMPs) are summarised in Table 3.2.

Table 3.2 Roles of team members in SMPs

A project manager/leader	Collaborates with high-level management in the goal setting and project plan development stages. Allocates project resources and manages resources. Defines the scope of the project (scope management plan). Communicates with project team members and manages the team. Assigns project tasks and project work. Administers the project schedule. Analyses (tracks) KPIs in projects. Intervenes on disruptions (problems). Coordinates communication between team members. Contacts stakeholders and informs them about the project and areas of collaboration.
Team members	They carry out a project (work that contributes to the overall goals and success of the project). They communicate with each other and support each other in the work. They collaborate with other team members on project work. They are results-, quality- and time-oriented.
Project sponsor	Responsible for the overall success of the project. Helps allocate project resources (securing funding). Supports the project and ensures its acceptance. Promotes strategic objectives within the company and demonstrates to stakeholders how the success of the project will provide value to the company. Provides guidance or approves higher level decisions. Acts as an intermediary between the project manager and members of the senior management team. Keeps senior management informed of project progress and necessary status or performance updates. Closes the project, including evaluating project performance.
Business analyst	Oversees (controls) business operations. Helps define project objectives. Ensures that the project provides value to the company. The analyst is oriented towards process optimisation.
Subject matter experts	They work with project managers, team members and stakeholders to provide expertise or advice on questions or processes related to their area of expertise.

	They help develop procedures, map processes, assist in gaining approvals and provide project recommendations.
Additional stakeholders	A project stakeholder is anyone who has a stake in or can influence the project. While this usually includes senior management, it can also include colleagues or cross-functional teams who do not work directly with the project team. Stakeholders can also be external, such as clients, investors or even shareholders.

Source: own elaboration based on [66]

According to the PM BOK [67], a project team is a group of people who work together on a project with common goals and objectives. Each member of the project team is responsible for performing his or her tasks and contributing to the success of the project. As there are usually several people on a project team, you will find a mix of experts with different skills, abilities and experiences, and the project team is often cross-functional or made up of people from different teams in the organisation. The project team aims to support the project office, the R&D office, the finance department, the team of operators (engineers), lawyers, IT specialists. The structure of project teams includes leaders (project managers) and team members. The project team may include: project manager, project team members, project sponsor, project stakeholders, business analyst, executive sponsor, project committee, functional manager, IT specialist, programme manager, team leader, quality assurance specialists, subject matter expert, etc. The project manager is appointed by the project sponsor [65].

The Scrum Team consists of the development team, the Scrum Master and the Product Owner. The team is led by the Scrum Master (Fig. 3.4).

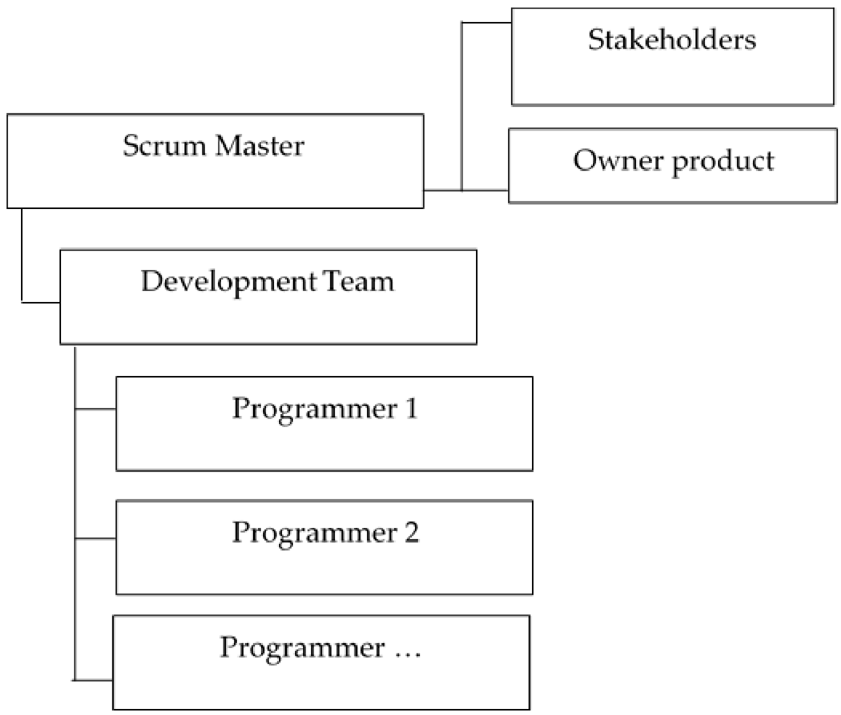

Fig. 3.4 Example diagram of Scrum team structure

Source. Own elaboration based on [68]

The Scrum Master should have experience in working in the Agile-Scrum methodology, he describes the objects (products) and processes, removes obstacles, makes sure that the development team is comfortable with the work. The Scrum Master does not manage the team, but the process. The traditional project team manager manages the team. Table 3.3 summarises the roles of the Scrum Team members.

Table 3.3 Roles of Scrum team members

Scrum Master	Describes objects (products) and processes. Removes obstacles to the work of the Scrum team. Takes care of the working conditions for the development team. Does not manage the team, but the process.
Stakeholders	They define the needs and expectations of the product.
Product owner	Creates a vision for the product. Manages the budget. Makes decisions about the product. The product owner is not a programmer.
Development team (from 3 to 8 persons)	They do the project /product. They communicate with each other. They build professional relationships. They exchange knowledge about the project (product). The team should self-organise and have all the skills needed to build the product.

Source: [66]

An optimal team is when each team member has one dominant role and two or three supporting roles; there are no good or bad roles in the team; the value of individual roles is determined by the type of task to be performed in the project; the need for specific roles changes over the course of the project. The project team should consist of staff with a variety of roles so that all staff as a whole can complement each other . The task is influenced by the content knowledge of the team members, the skills of their personalities [69]. In the literature there are many different types of team members described on the basis of their personalities, e.g. resource investigator, team worker and co-ordinator (the Social roles); plant, monitor evaluator and specialist (the thinking roles), and shaper, implementer and completer finisher (the action or task roles) (Belbin) [70], while in the skills category a distinction is made between hard and soft skills (Table 3.4).

Table 3.4 Skills of team members based on technical education

Soft skills	Hard skills
Experience-based	Rule-based
People-related	Technological/scientific
Attitudinal Behavioural	Industrial/mechanical Tools/techniques
Non-domain-specific	Specialised
General	Procedural/methodological
Trans-situational	Replicable
Non-technological	Predictable
Intangible	Tangible

Source: [71]

In the knowledge category, the model of combining mathematical, technological engineering and digital knowledge is popularised.
'Hard' skills, i.e. experience and specialist knowledge, are important factors in ensuring that these teams work effectively. Soft skills help the work. Through soft skills, people communicate better, learn to relate to each other, are more open, etc.
Project management is a complex process and requires soft and hard skills on the part of the person(s) responsible for its implementation. The success of this process depends on the fulfilment of many elements that need to be taken care of, which will greatly facilitate the work during project implementation and ensure the success of the entire project.
Good project management practices/principles are:
1. Define the project objective clearly and comprehensibly
2. Set a realistic time for the project and a budget for its implementation
3. Develop a schedule for the activity
4) Identify the strengths and weaknesses of the project and develop a plan for situations that may hinder the proper implementation of the project
5) Ensure good communication within the team (between workers and between supervisor and subordinate)
6) Provide appropriate tools to all project implementers
7) Monitor and give constructive feedback
8) Ensure high motivation of the project team
9. Report on the completion of the various stages of the work
10. Be effective

Conclusion: the basic element of any project is the people who are tasked with carrying it out. They are the ones who determine whether a project succeeds or fails. This is why it is so important right from the stage of defining the resources of the project to select the right personnel for the project team. The people who make up the project team are referred to as a key element of the project management concept. When forming a project team, the principle of maximum usefulness of its individual members in the context of a given project should be followed.

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4

LEAN INDUSTRY 4.0

4.1. INTRODUCTION

Currently, new innovative technologies and concepts are being introduced in the business environment. Their emerging widespread adoption and implementation across various types of businesses are referred to as the Fourth Industrial Revolution or Industry 4.0. Industry 4.0 represents the fusion of industrial production and information and communication technologies [1].

LEAN 4.0 is a methodology that combines the principles of lean manufacturing with modern Industry 4.0 technologies. The effectiveness of Lean 4.0 can be understood based on the assumption that Lean is a system in which processes are improved through data-driven visibility, and the higher the quality of available data sources, the more advanced the processes can become through continuous improvement.

LEAN was born out of manufacturing practices but in recent time has transformed the world of knowledge work and management. It encourages the practice of continuous improvement and is based on the fundamental idea of respect for people.

Womack and Jones defined the five principles of Lean manufacturing in their book "The Machine That Changed the World". The five principles are considered a recipe for improving workplace efficiency and include:

1) defining value,
2) mapping the value stream,
3) creating flow,
4) using a pull system,
5) pursuing perfection.

The next sections provides a detailed overview of each principle.

We present five fundamental principles of lean manufacturing that have been the essence of Toyota's success and can help businesses create customer-focused products.

1. Value: Identify and understand the value as perceived by the customer. Focus on delivering products or services that meet customer needs and provide value.
2. Value Stream: Map the value stream, which includes all the activities and processes required to deliver the product or service. Identify and eliminate any non-value-adding steps or waste in the process.
3. Flow: Create a smooth and uninterrupted flow of work by eliminating bottlenecks, reducing batch sizes, and optimizing the sequence of activities.

Ensure that work flows seamlessly from one step to the next without delays or interruptions.

4. Pull: Establish a pull system where work is initiated based on customer demand. Instead of pushing products into the market, respond to customer orders or requests, minimizing inventory and overproduction.
5. Continuous Improvement: Foster a culture of continuous improvement. Encourage employees at all levels to identify problems, seek solutions, and make incremental improvements to processes, products, and systems on an ongoing basis.

These principles focus on delivering value, eliminating waste, optimizing flow, responding to customer demand, and constantly improving processes, all of which contribute to creating products that meet customer expectations. Subsequently, we provide a more detailed explanation of the mentioned principles:

1. Define Value

To better understand the first principle of defining customer value, it is important to understand what value is. Value is what the customer is willing to pay for. It is paramount to discover the actual or latent needs of the customer. Sometimes customers may not know what they want or are unable to articulate it. This is especially common when it comes to novel products or technologies. There are many techniques such as interviews, surveys, demographic information, and web analytics that can help you decipher and discover what customers find valuable. By using these qualitative and quantitative techniques you can uncover what customers want, how they want the product or service to be delivered, and the price that they afford.

2. Map the Value Stream

The second Lean principle is identifying and mapping the value stream. In this step, the goal is to use the customer's value as a reference point and identify all the activities that contribute to these values. Activities that do not add value to the end customer are considered waste. The waste can be broken into two categories: non-valued added but necessary and non-value & unnecessary. The later is pure waste and should be eliminated while the former should be reduced as much as possible. By reducing and eliminating unnecessary processes or steps, you can ensure that customers are getting exactly what they want while at the same time reducing the cost of producing that product or service.

3. Create Flow

After removing the wastes from the value stream, the following action is to ensure that the flow of the remaining steps run smoothly without interruptions or delays. Some strategies for ensuring that value-adding activities flow smoothly include breaking down steps, reconfiguring the production steps, leveling out the workload, creating cross-functional departments, and training employees to be multi-skilled and adaptive.

4. Establish Pull

Inventory is considered one of the biggest wastes in any production system. The goal of a pull-based system is to limit inventory and work in process (WIP) items while ensuring that the requisite materials and information are available for a smooth flow of work. In other words, a pull-based system allows for Just-in-time delivery and manufacturing where products are created at the time that they are needed and in just the quantities needed. Pull-based systems are always created from the needs of the end customers. By following the value stream and working backwards through the production system, you can ensure that the products produced will be able to satisfy the needs of customers.

5. Pursue Perfection

Wastes are prevented through the achievement of the first four steps:
1) identifying value,
2) mapping value stream,
3) creating flow,
4) adopting a pull system.

However, the fifth step of pursuing perfection is the most important among them all. It makes Lean thinking and continuous process improvement a part of the organizational culture. Every employee should strive towards perfection while delivering products based on the customer needs. The company should be a learning organization and always find ways to get a little better each and every day.

The five Lean principles provide a framework for creating an efficient and effective organization. Lean allows managers to discover inefficiencies in their organization and deliver better value to customers.

The principles encourage creating better flow in work processes and developing a continuous improvement culture. By practicing all 5 principles, an organization can remain competitive, increase the value delivered to the customers, decrease the cost of doing business, and increase their profitability [2], Fig. 4.1.

Lean and Industry 4.0 philosophies are often complementary and can give manufacturing or operations managers insight into achieving a higher level of production efficiency. Many are calling it 'Lean Industry 4.0'. Given the increasing complexity of operations, many companies find Lean techniques are not enough to address competitive pressure. By deploying the right combination of industry 4.0 technologies, manufacturers can boost speed, efficiency, and coordination and even facilitate self-managing factory operations.

For example:

„Factories are no longer a series of siloed production lines; industry 4.0 enablers like integration allow production managers to oversee interconnected networks of moving

parts, akin to a living organism, that can highlight opportunities to improve, or even be trained to optimise performance. "

Fig. 4.1 The Five Lean Principles

Source: [2]

Boston Consulting Group [3] says manufacturers who have successfully deployed both ideas have reduced conversion costs by as much as 40% in five to 10 years; a better result than deploying either of the philosophies individually. But the concept is new, with fewer than five % of manufacturers reaching a high level of maturity in Lean Industry 4.0. BCG [3] also was quantifying the improvement potential. The improvement potential of an integrated approach is significant. We have found that when either approach – lean initiatives or Industry 4.0 – is applied alone, it can reduce conversion costs by approximately 15%. However, in our experience, companies that use the integrated Lean Industry 4.0 approach can reduce conversion costs by as much as 40% (Figure 4.2).

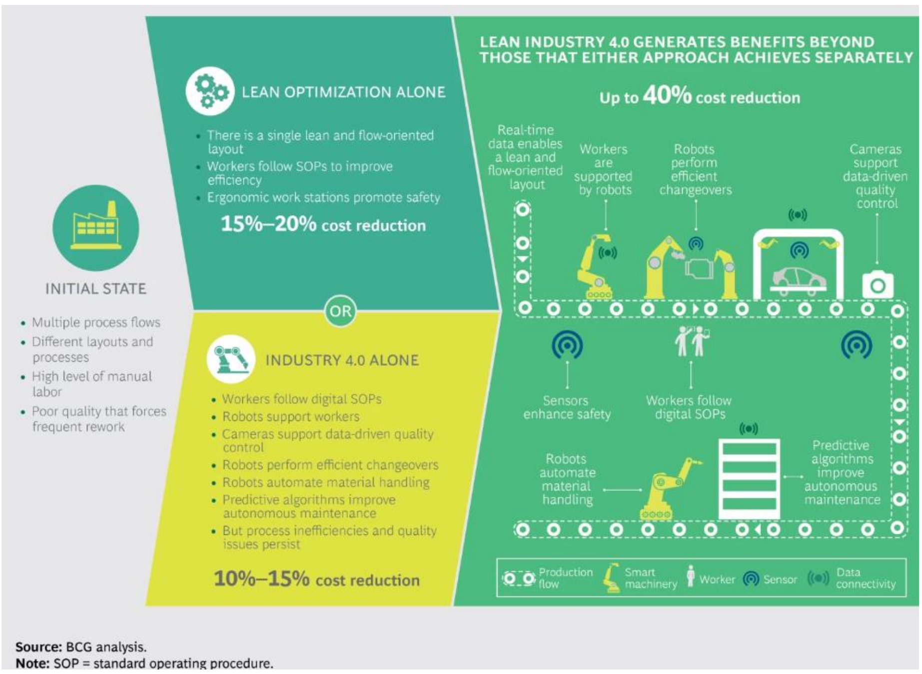

Fig. 4.2 Integrated approach – LEAN and Industry 4.0

Source: [3]

Companies have also used the integrated approach to reduce costs associated with poor quality by 20% and work-in-process inventory by 30%.

4.2. LEAN 4.0: HOW TO ELIMINATE WASTE IN SMART PRODUCTION

What is Lean 4.0? Can lean manufacturing and Industry 4.0 truly be combined? Both Lean Manufacturing and Industry 4.0 are industrial paradigms that aim to improve and enhance the manufacturing process across the entire value chain. While Lean focuses more on the people and the processes, Industry 4.0 focuses on modern technologies. At the first glance, it might seem like there's little connection between the two. However, the Lean 4.0 concept combines lean manufacturing principles and Industry 4.0 tools and technologies to help companies achieve superior productivity. Around 98% of manufacturing companies are expecting an increase in overall efficiency with the use of modern digital technologies and lean principles. Lean 4.0 can help companies as diverse as Automotive companies to a European food production plant. Let's look at Lean 4.0 in more detail Lean 4.0 is a methodology that combines the principles of lean manufacturing with the modern technologies of Industry 4.0.

The effectiveness of Lean 4.0 can be understood by the assumption that lean is a system where processes are improved by data driven visibility and that the higher quality the available data source the more refined processes can become through continuous improvement. Industry 4.0 technology offers advanced analytics algorithms to analyse data and discover inefficiencies in processes. Lean 4.0 looks to reduce waste with state-of-the-art modern technology so that there is no time wasted on performing non-value-adding procedures in lean production.

Last mile technologies such as Connected Worker platforms improve operational visibility and transparency and make it easier to implement lean manufacturing principles by optimizing the human element of job execution.

An example of Lean 4.0 in action could be additive manufacturing. In this kind of manufacturing, Industry 4.0 technology is used to prevent wastes. Instead of making a big structure and cutting it away to give the final shape, additive manufacturing focuses on adding only the materials that are needed. This opens up new possibilities for efficient manufacturing where products are made by following the lean principle of adding only necessary components instead of removing unnecessary ones to reduce overall waste.

4.2.1 Characteristics of Lean Production philosophy

One of the unquestionable progressive trends in 21st-century business development is lean manufacturing technology. This technology has its roots in the enterprise production management system that began to be referred to as "lean" in the United States during the 1980s. Its foundation lies in Toyota's production system (TPS – Toyota Production System). TPS gained attention during the oil crisis of the 1970s when Toyota, as practically the only Japanese company, managed to produce automobiles with higher quality, lower costs, and in a shorter time than its competitors, successfully navigating the oil crisis without financial difficulties. Although various global automakers adopted the Toyota production system to some extent and in various forms by the early 1990s, Toyota's excellent implementation of lean manufacturing is still considered the most advanced in the world, serving as the global benchmark.

We have described The Five Lean Principles earlier. The LEAN strategy, as understood by Toyota, can be characterized as a business paradigm that:

- Is based on the perception and systematic elimination of all business activities (processes) that do not add value to the customer (i.e., waste) at all levels of the work process.
- Strives for a fast and smooth flow of both material (production) and non-material (information, financial) processes within the company. Ideally, this should involve a seamless continuity of value-adding activities for the customer.
- Relies on the principle of balancing production flows, which means evenly distributing materials and products across all production corridors, ensuring an even distribution of work to individual workstations within the entire production process.
- Involves engaging the customer in the company's processes and being prepared to align the company's operations as much as possible with their needs, making the entire value stream driven by the requirements of external and internal customers (i.e., the demands of the next non-binding production stage or workstation).
- Aims for maximum flexibility in company processes and flow, enabling agile responses to changing market conditions.
- Enhances the knowledge level of the entire organization as the primary source of the company's competitiveness and long-term survival (knowledge management), which includes built-in mechanisms for continuous education, sharing knowledge, and problem-solving to continuously improve productivity, quality, and address issues.

Lean manufacturing is generally considered a business philosophy that aims to reduce the time between the customer and the supplier, as well as eliminate waste throughout the entire supply chain. It is not just about cost reduction but primarily about maximizing the value of the product for the customer. Streamlining is the path to producing more, having lower overhead costs, and efficiently utilizing production areas and resources. Lean manufacturing cannot function without close integration with product development, production preparation, logistics, and administrative functions within the company (Figure 4.3).

A lean enterprise is one that performs only necessary activities, does them right the first time, does them faster than other companies, and consumes fewer resources in the process. Lean is about increasing the company's performance based on customer requirements, with a minimal number of activities that do not add value to the product or service for the customer [4].

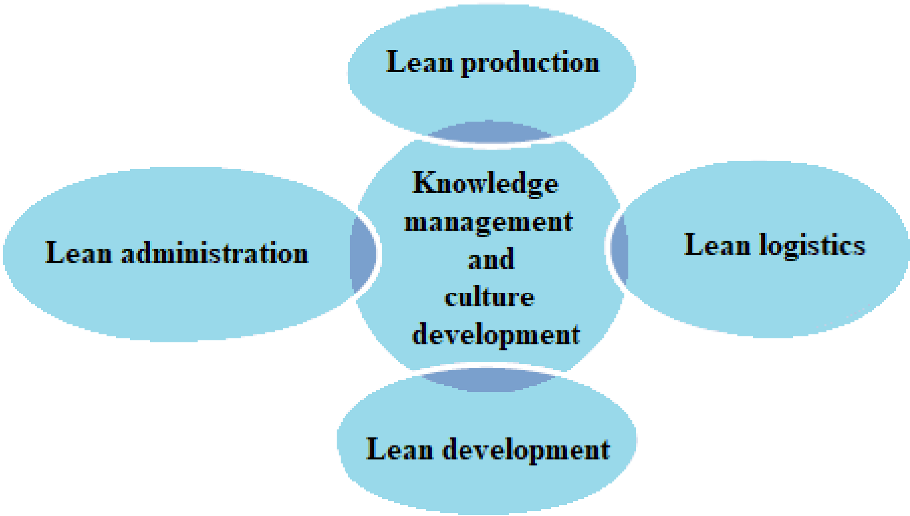

Fig. 4.3 Lean production philosophy

James P. Womack [5], and his colleagues argue that through proper implementation of lean manufacturing methods, the following parameters can be achieved:

- Half the hours of human effort in production
- Half the defects in the output
- Half the investment in machinery, equipment, and tools
- One-third of the hours of work by engineers
- Half the space for the same output
- Inventory reduction to one-tenth

The degree to which these goals are achieved depends on the extent of changes that need to be implemented within the company [5].

4.2.2 Seven waste of MUDA

In the context of waste, known as MUDA, it refers to everything that does not directly add value to the product or unreasonably increases the costs of its production [6]. Taiichi Ohno, the father of the most advanced production system (Toyota Production System), expressed his perspective on waste as follows: "Stand in the centre of the workshop with a clear mind and without prejudice, and observe the production process. With every problem, ask 'why?' five times." "The only thing we do is track the time from when the customer places an order to the point when we collect the money. And we reduce this time by eliminating waste" [7]. Hitoshi Takeda identifies three levels of waste, along with their respective detection and resolution methods, as shown in Table 4.1:

- Katakana-muda: This represents everything that is not necessary for the work process and can be immediately eliminated without major interventions. Examples include waiting, searching, postponing, thinking, double work, aligning parts, removing packaging material, fetching components, removing chips, and more. This is the most easily identifiable form of waste.
- Kanji-muda: This type of waste pertains to machines and other equipment. It includes long supply routes, empty return trips, unused capacities and tools, and

more. It manifests as different operations being performed at different rates, causing workers or machines to wait. Responsible managers or analytical methods can help identify these deficiencies.

- Hiragana-muda: This type of waste is influenced by the existing conditions in which the work process takes place. It relates to the physical movements of workers. Examples include improper placement of controls, surface cleaning, returning to starting positions, manual work, product retrieval methods, and more. These activities require laborious analysis but are crucial. Various motion analysis methods are used to address them, and their elimination requires training and skill development for workers [8].

Table 4.1 MUDA according to Hitoshi Takeda

How to identify?	Value creation	How to solve?
Performance standards, Coefficient of synchronization	Overtime	Standardized performance, Flexible job rotation
Human/machine work Material supply	Waiting	Production pace and rhythm, Standardization of waiting times
Distances, unnecessary transfers, accessibility	Transportation	Product layout, logistics change
Utilization, need or manual work	Equipment utilization	Reduction of underutilization, improvement of clamping and securing
Inventory management, item labeling	Inventory storage	Inventory monitoring, warehouse organization
Distances, reach, operability	Worker motion	Inspection process, selection of appropriate system Layout, standardization of movements, changing controllers and placer
Control process	Defect creation	Choosing a suitable system

Source: Adapted from [8]

Bauer et al. [9] state that in the "production process, there is an infinite amount of MUDA waste." However, there are 7 fundamental defined types of MUDA that are encountered most frequently in the production process and will be described in the following chapters:

- Waiting – for materials, missing parts, etc.
- Material Inventory.
- Transportation of products and materials, etc.
- Defective products.
- Production errors.
- Overproduction.
- Unnecessary motion.

Sometimes additional types are mentioned, such as unused employee creativity or poor communication.

The elimination of MUDA from the production process always results in a reduction of production costs. It should be noted that we are referring to current or potential costs. When we engage in useful activities, we inevitably create some non-value-added activities as well. As we add value to the product, there are often activities that do not contribute value. This is how we must view production. It is the reality of any process. This is what Ohno, Toyoda, Ishikawa, Shingo, Nakajima, and Masaaki Imai have presented.

A tremendous wealth is hidden in the utilization of time consumed by activities other than those that add value. The more closely we observe and document the process, the more we realize how much shorter the productive time is and how much longer the non-productive time is. Guru of KAIZEN, Masaaki Imai, said, "MUDA is eternal, it never disappears from the process." The results of value-adding analysis in companies can be astonishing. For example, Toyota states that only about 5% of the total time of all employees is spent on value-adding activities, and even the best companies in the world have more than 90% of their time as potential for transforming it into value-adding time [9].

4.3. LEAN TOOLS IN INDUSTRY 4.0

The Industry 4.0 technology offers advanced analytical algorithms for data analysis and identification of process inefficiencies. Lean 4.0 aims to reduce waste using the latest modern technologies to eliminate time spent on non-value-adding procedures in lean production [10].

In the previous chapter, the basic principles and characteristics of lean manufacturing were presented, which are followed by selected tools and methods to achieve it, as outlined in the following text.

Standardization (creation of norms) is a systematic process of selecting, unifying, and stabilizing individual variants of inputs, transformation processes, and outputs, both in terms of physical elements of processes and necessary information. Its goal is to reduce the number of variants and uncertainties in process management, enabling repeatability, easier control, and cost-effectiveness.

Quick Changeover (also known as SMED – Single Minute Exchange of Dies) aims to reduce the transition time of production equipment from one batch to another. The changeover time refers to the duration between the last flawless product of type A and the first flawless product of type B. The changeover time can be divided into the time when production is still ongoing (external changeover time) and the time when the production equipment is idle (internal changeover time). Optimization focuses on reducing both changeover times and transferring activities from internal to external changeover time, thus reducing the downtime of the equipment.

Andon – a visualization tool, display boards showing the current and planned state of production (thus monitoring the production rhythm), also used to indicate problems occurring on the line and as a signaling system for initiating a quick response (emergency stop system).

Kaizen – is the principle of continuous improvement of any process through incremental steps involving all employees.

TPM (Total Productive Maintenance) – a method of maintaining production equipment that focuses primarily on prevention, while also addressing the causes of failures and downtime. It is based on the assumption that the best person to perform simple repairs and regular maintenance on machines is the one who knows the machine best, i.e., the person who works with it every day.

Visualization – every important item has its precisely defined place and size. Easy orientation in the process also allows for quick onboarding of workers and easier detection of deviations. This includes tools such as Andon, various labeling techniques, and the 5S method. The use of visualization tools increases the clarity of individual processes, helps maintain established standards, and supports their continuous improvement by identifying bottlenecks.

VSM/VSD (Value Stream Mapping/Design) – is a method for mapping and designing the value stream. This tool is used to depict the material and information flow in a manufacturing system. The mapping is done in the direction of the material flow, from customer product receipt to supplier material purchase, enabling a better understanding of the functions of the manufacturing system and identifying the causes of waste. After mapping the selected value stream and uncovering deficiencies, a design is created for the desired state of this value stream.

Emergency brake – a tool for quick response that allows to summon assistance in case of any deviation from the standard in the production process, supply chain, malfunctions, and other issues. An employee can activate the emergency brake by pulling the signaling cord above the respective workstation where the deviation occurred. This signal is transmitted to the Andon signaling system, triggering an alert and calling for assistance. At the same time, the entire production line is stopped to prevent the recurrence of the error and enable the correction of the situation. This ensures that deviations from the standard are quickly detected and resolved, contributing to the overall improvement of the production process.

5S – a method to prevent losses through better workplace organization and gain greater insight into the process flow. The method is based on maintaining order in the workplace and is defined by five Japanese terms, which also represent the individual steps and tools of implementation (Seiri - Sort, Seiton - Set in Order, Seiketsu - Shine, Seisou - Standardize, and Shitsuke - Sustain). Using this method, we can create and maintain a clean and organized workplace, both in manufacturing and office environments. Achieving this goal requires the involvement of all participants in the production unit.

Leveling (Japanese "**heijunka**" – "smooth plan") – This tool enables the creation of a daily production plan that aims to evenly distribute the workload and production on the line (or workload division). Since customer demand fluctuates and order intervals vary in length and irregularity, the goal is to produce the main types as frequently as possible (e.g., every day) and in small batches. This also promotes a smooth flow of material supply from both external and internal suppliers. A leveled

production plan prevents excessive order fluctuations from being transferred to the supply processes and simulates an ideal customer who orders consistently and in small quantities. In reality, it may result in smaller finished goods inventory. Leveled production supports the process of continuous improvement due to increased requirements for smaller batch sizes and process stability.
One-Piece-Flow – represents the ideal case of flow-oriented production, where the batch size is limited to one piece moving between individual operations in the production cycle without any intermediate storage. Some advantages of this production method include the quick detection of faulty parts in the production process, which prevents the occurrence of extensive errors, a short production lead time (eliminating the need for batch storage before entering the line), reduced storage costs, and the ability to design production equipment in minimal sizes.
Poka-yoke – a Japanese term – represents a tool that helps prevent errors, ensures quality, and enhances safety in manufacturing processes. Common types of errors that occur in production include incorrect insertion of a part into a fixture, errors in clamping, or errors in completion and packaging. The product and fixture are designed in such a way that they allow assembly only in one correct position. This tool can be likened to a lock that can only be fitted with a specific key. This saves time in operating stations (human labor) during assembly and reduces setup time.
Bottleneck – a method for identifying constraints or limitations in the processes of a company (in production, sales, or administration). Bottlenecks represent the limiting factor in process throughput and are the focus of optimization and streamlining efforts. This concept aligns with the Theory of Constraints (TOC), which aims to identify and manage the most significant constraints in a system to improve overall performance and efficiency [11].

4.3.1 Areas of penetration of LEAN and Industry 4.0

In the beginning of Chapter 4, we stated the five principles of lean production. By knowing the aspects and characteristics of the Industry 4.0 philosophy, we can subsequently identify areas where the mentioned industry management strategies have intersections, where they can synergistically support each other. We identified three areas in our research where Industry 4.0 technologies and LEAN principles meet:

Customer Centricity

Lean has always put emphasis on a customer centric production approach first, and now digital technologies are enabling manufacturers to gain a clearer picture of their customers' needs. For example, **advanced data** analysis and even artificial intelligence can be applied to customer data to better determine customer needs. The simplest example is in analysing app use behaviour, or in understanding when, where and how many people access a product's origin information via the label. **Mass customisation**, where customers can heavily customise their orders, is also enabled through integrating automated and semi-automated robots into production lines, as they can cope with higher degrees of variety. This is how the customer centric 'just-in-time' philosophies of lean, are enhanced by industry 4.0 technology levers.

Continuous Improvement

A continuous improvement program on a production line might selectively alter a variable, test it in real time, and review the results accordingly. New technologies like powerful simulation tools and the digital twin allow manufacturers to test their assumptions in the virtual world first, prior to implementing them or testing them in the physical world. In this way, LEAN continuous improvement is enhanced by new Industry 4.0 technologies.

Integrated Value Chain

Lean aims to eliminate waste in the value chain – from customer order through to delivery – and industry 4.0 enablers like horizontal and vertical system integration and data analysis are invaluable to this pursuit. Integration and connection of your enterprise, IT, operational systems, machines and devices creates a holistic view of the entire value chain. This enables managers to identify patterns or weak spots in the process and prioritise them for improvement opportunities.

4.3.2 How does Lean 4.0 can improve LEAN manufacturing practices

The chapter offers suggestions on how LEAN 4.0 procedures can improve classic LEAN methods by applying five elements from Industry 4.0:

Just-in-Time Inventory

Just-in-Time or JIT is a major pillar of lean manufacturing that focuses on keeping inventory levels at an adequate level to meet customer demand but avoiding overstock waste. Through the digitization of supply chains and modern technology, keeping an accurate track of inventory levels becomes easier. This Lean 4.0 technology provides higher transparency about inventory movement and helps incorporate Just-in-Time or JIT manufacturing. The created platforms can improve standardization of work execution by digitizing processes, using highly visual training materials, capturing a wealth of actionable, high quality data and allowing management to find and eliminate inefficiencies. This increase in standardization can also improve essential practices like preventive maintenance and predictive maintenance. This greater emphasis on standardization creates predictability for manufacturers as they know how long it takes to complete a process and thus how long it takes to make a product. This means they can meet the customer demands of JIT.

Autonomation

Autonomation is another important pillar of lean manufacturing. Autonomation is the ability of a machine to recognize and detect any deviations from the normal functioning of the system or any other abnormal conditions. With the help of Industry 4.0 tools application, autonomation has been radically improved. Machines now have enhanced intelligence and can detect any anomalies, determine the root cause of the problem, and analyze and help initiate corrective measures. Equipments are now able to spot abnormal conditions related to the maintenance of the machines and rapidly escalate them. Deviations in processes are also easier to discover due to improved standardization which aids in waste reduction.

Overall Equipment Effectiveness

Overall Equipment Effectiveness is an important lean metric for measuring the Availability, Performance and Quality of the production line to determine productivity. Lean 4.0 offers technology to give big data and machine insights to determine the health of the machines with greater accuracy than ever before. Since OEE was instituted in the 1960s machines have become 20 times more reliable. The source of the majority of errors is no longer the machines but instead human error. Due to the increasing complexity of manufacturing and the wide variety of products each front line worker is now responsible for making it has become necessary to augment workers with digital technologies to help them keep pace with the changing landscape.

Manufacturers refer to Overall Equipment Effectiveness (OEE) as the gold standard of productivity for a reason. It's putting it mildly to say your equipment's availability to perform at the highest level and output high-quality products are essential to your company's success. Tracking your equipment's efficiency is the first step to improving it. Most manufacturers operate at between 60 and 65% OEE. World-class OEE is 85% or better.

Lean 4.0 Value Stream Mapping

Identifying and eliminating unnecessary or wasteful steps in the manufacturing process helps businesses cut down the overall production time and aids in value stream mapping as well. Value stream mapping is another important part of the lean methodology that analyzes the current state of a product and how it is made from its conception to reaching the customer. Every single step in the process is observed to discover inefficiencies and eliminate nonvalue adding steps. However, value mapping only focuses on a specific part of a process at a given time when it's being measured. This is where Industry 4.0 technologies such as IoT, RFID technology come into play as they can collect real-time data about any process and provide complete transparency for every stage of value stream mapping.

Production Leveling or Heijunka

Heijunka is a process in the lean methodology that aims at maintaining a constant rate for manufacturing products. This in turn enables other steps of the process to be executed at a constant rate as well. This process depends largely on customer demand and modern technologies such as Big Data Analytics can help in making more accurate demand forecasts resulting in stable production planning.

4.4. INDUSTRY 4.0 IMPLEMENTATION TO MANUFACTURING PROCESSES

The essence of the new revolution in society and manufacturing is achieving fully automated production and implementing changes in the way production processes are managed. These revolutionary changes involve the requirements for human resources responsible for implementing and working with these changes and striving to further develop them. The main concept of Industry 4.0 is the computerized interconnection of manufacturing machines, processed products, raw materials, and other systems and subsystems within an industrial enterprise (including ERP systems, business systems, etc.). The idea of Industry 4.0 strongly supports and develops the concept of the Factory-of-the-Future (FoF), which emerged from the generalization of Computer Integrated Manufacturing (CIM) through the advancement of computer and communication technologies and artificial intelligence methods.

With data and connectivity at its core, Industry 4.0 is about the merging of physical and digital worlds to gain analysed, actionable data insights. There are a number of technologies or trends driving this 'fourth wave' of technological advancement.

These are:

1. Internet of Things (IoT)
2. Big data and analytics
3. Additive manufacturing or 3D printing
4. Advanced robotics
2. Augmented and virtual reality
3. Cloud computing
4. Machine learning and artificial intelligence
5. Horizontal and vertical system integration (including Information technology (IT) and Operational technology (OT) integration)
6. Simulation.

Industry 4.0 draws on Lean's foundations in continuous improvement but brings big data to the table. The ability to connect devices, sensors, machines, and software enables this rapid collection of data in real-time. This gives managers the ability to improve processes or predict failures before they occur, meanwhile machines can automatically optimise themselves, diagnose problems or configure more efficiently.

Stakeholders interviewed by Australia's Advanced Manufacturing Growth Centre (AMGC) described Industry 4.0 as a way of thinking or a cultural journey companies go on with tangible and intangible outputs, particularly the value that can be created in the digital realm.

In the following lines of this chapter, the concept of Industry 4.0 is further elaborated, both from a general perspective, where this concept is compared to the current state, and from a technological perspective, where the basic models of the Industry 4.0 platform are introduced. Additionally, insights from the realms of digitalisation, the digital economy, and new business models are included [12].

4.4.1 The basic principles of the Industry 4.0 strategy

To clarify, it is appropriate to first explain the essence of Industry 4.0 and how it differs from the current state of industrial production. In the concept of Industry 4.0, three interconnected factors mutually influence each other, namely:

- Digitalisation and integration of manufacturing and business relationships and supply chains.
- Digitalisation of production and services.
- New business models.

Currently, these activities are interconnected through a variety of communication systems. However, in the future, the most progressive communication technologies are expected to be the Internet of Things (IoT), Internet of Services (IoS), and Internet of People (IoP). With these technologies, all entities throughout the entire lifecycle can communicate with each other regardless of business or national boundaries. All entities along the production chain will have real-time access to the necessary data. This can bring advantages such as machinery manufacturers designing their machines with components that are still being developed by their suppliers, or companies being able to predict equipment failure in advance [12]. Below are several key principles on which the concept of Industry 4.0, according to Professor Mařík (Fig. 4.4), is based, and which need to be respected for its implementation:

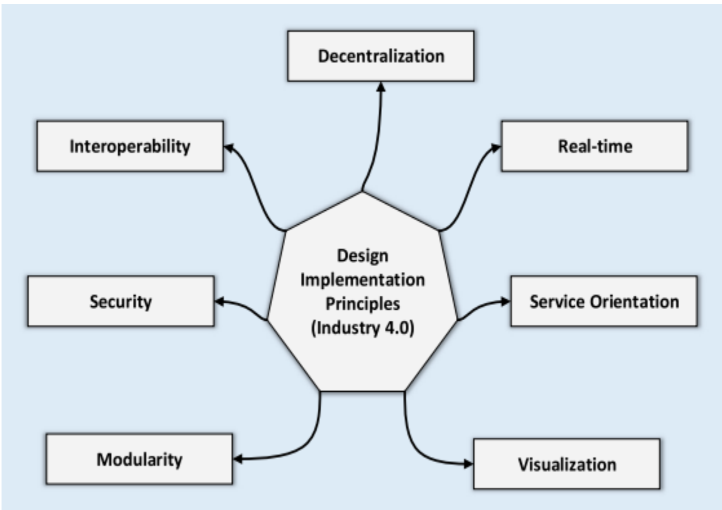

Fig. 4.4 Seven design implementation principles for industry 4.0 systems
Source: adapted from [13]

- Interoperability: the ability of cyber-physical systems (CPS), humans, products, and all systems and subsystems of Smart Factories to communicate with each other at the interface of IoT and IoS.
- Virtualization: the ability to connect physical systems with virtual models and simulation tools.
- Decentralization: the fact that decision-making occurs autonomously and in parallel in individual subsystems.
- Real-time capability: adhering to the requirement of real-time information is a crucial condition for communication, decision-making, and control in real-world systems.

- Service orientation: the preference for a computational philosophy of offering and utilizing standardized services, leading to Service-Oriented Architectures (SOA).
- Modularity and reconfigurability of systems: the ability of a system to autonomously reconfigure based on the recognition of a given situation and the modularity of system components [13].

4.4.2 Model RAMI 4.0

The RAMI 4.0 model represents a 3D architecture model of the Industry 4.0 platform. It was first presented in 2015 and is authored by German institutions BITCOM, VDI/VDE, and ZVEI. This model (Figure 5) was created with the purpose of representing all the traditionally interconnected aspects of production. The model consists of three axes: one vertical and two horizontals. The vertical axis represents the aspects that are considered in Industry 4.0. These aspects are defined as individual layers (Figure 4.5):

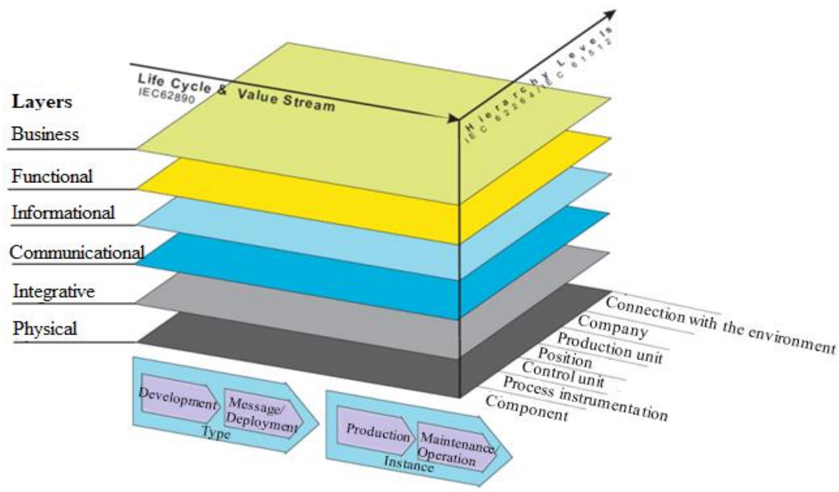

Fig. 4.5 RAMI model

Source: [12]

1. Physical Layer: Represents the physical entities such as components, machines, documentation, and so on. These components are connected to the virtual reality through the integration layer.
2. Integration Layer: This layer provides information about the physical entities in a format suitable for further processing. It further transfers the information through the communication layer.
3. Communication Layer: This layer standardizes the communication through universal formats within the information layer.
4. Information Layer: Stores and preprocesses data in universal formats for the functional layer.
5. Functional Layer: This layer provides an environment for describing functions, process behavior, and services within horizontal integration. Maintaining data integrity within this layer is crucial.

6. Business Layer: This layer ensures the integrity of functions in the value stream, enables mapping of business models, and encompasses the overall process. It includes legal and regulatory requirements of the environment and establishes connections between different business processes [12].

The left horizontal axis of the model represents the product lifecycle with its value stream. The axis is divided into two phases - type and instances. In the first part, the product is in the development and testing phase. The second phase represents the product during its serial production. The digitalisation of the entire development-to-sales chain offers significant potential for improving the product, machinery, and other levels throughout its lifecycle [12].

4.4.3 Model Industry 4.0 component

The Industry 4.0 Component Model is the second significant model created by BITCOM, ZVEI, and VDMA. It was developed in July 2016 and is directly derived from the previous RAMI 4.0 model. This model primarily targets manufacturers and system integrators, serving as a tool to aid in the development of components for Industry 4.0. It enables a better description of the characteristics of cyber-physical objects and processes, hardware and software components of future production, as well as the communication between virtual and cyber-physical objects and processes. Figure 4.6 depicts the Industry 4.0 Component Model, which illustrates the transformation of a standard component in the production chain into an I4.0 component (referred to as an Industry 4.0 component).

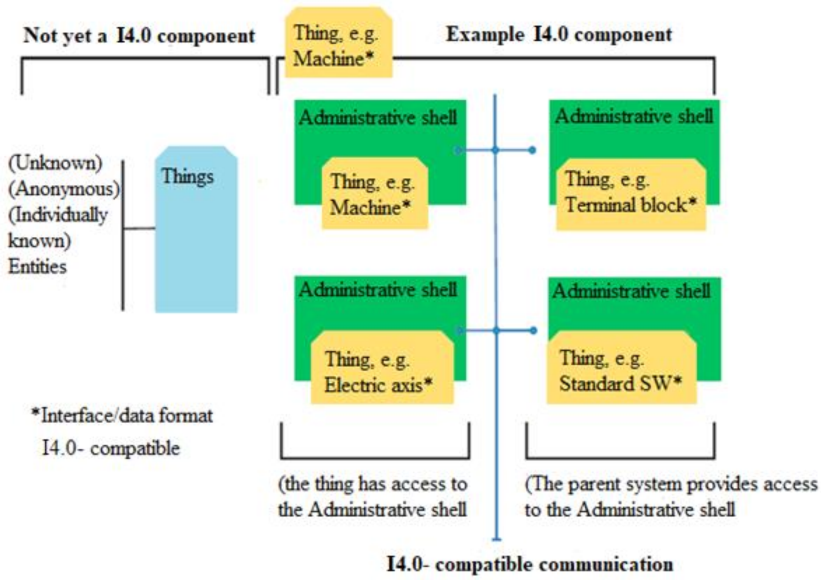

Fig. 4.6 Model Industry 4.0 component

Source: [12]

This transformation involves acquiring various communication properties that enable seamless integration and interaction within the Industry 4.0 framework. A brief explanation of the model is as follows: An object represents a standard technological object (such as a machine part, a whole machine, software, etc.) that initially lacks Industry 4.0 component properties. To qualify as an Industry 4.0 component, the object needs to be equipped with a data container called the administration shell. This container contains both the virtual representation and the technical functionality of the object. Communication capability between individual components is of utmost importance in Industry 4.0 systems. Therefore, to meet the requirements of Industry 4.0 component properties, at least one information system must be connected to the object. Components are mapped through their administrative shells, and their interconnection is established in the virtual realm of the Industry 4.0 system. The entire physical factory is further represented as a digital factory in the form of a repository, which serves as a knowledge store throughout the factory's lifecycle. The principle is illustrated in Figure 4.7.

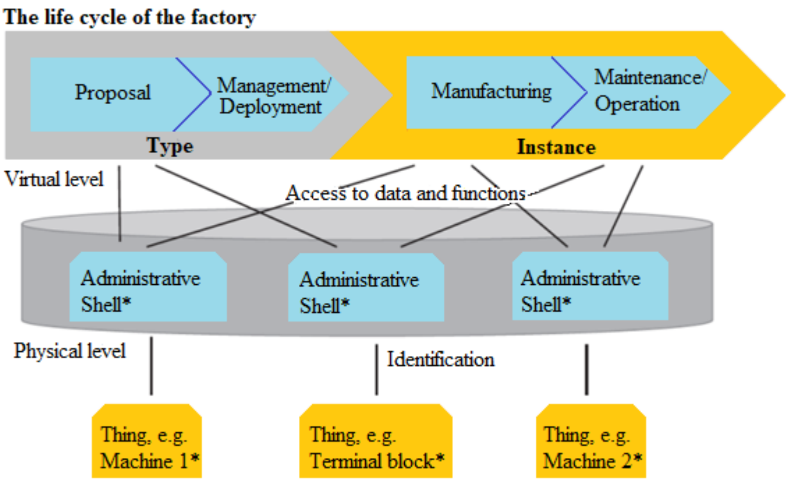

Fig. 4.7 The knowledge warehouse of a digital factory

Source: [12]

4.4.4 Digitalisation

The term "digitalisation" is understood in various ways today, and its meaning depends on the context in which it is mentioned. The fundamental meaning of this word can be the conversion of something tangible into a form that can be further processed by computer systems, i.e., computer code. In the context of Industry 4.0, digitalisation has been frequently mentioned recently, encompassing the digitalisation of everything – from documents and production information to manufactured components and communication with end customers. However, in the case of Industry 4.0, digitalisation should not be perceived as the ultimate goal or outcome of the ongoing production revolution, but rather as the path that needs to be taken to achieve the desired results. This path is essential for maintaining competitiveness, both among individual companies and among global economies and nations. The specific significance of digitalisation in various areas will be addressed in the following chapters.

4.4.5 Digital Economy

Industry 4.0 and the Digital Economy are closely interconnected concepts. The Digital Economy is also a product of the fourth industrial revolution. In general, it refers to a concept that enables us to shift certain activities from our everyday lives to the internet, reducing costs and increasing convenience. This term signifies a revolutionary way of resource allocation that maximizes the utilization of modern information and communication technologies. Thanks to these technologies and a proactive approach towards them, the overall structure of company management is changing, and new industries are emerging. It is a process based on the interconnectedness with the concept of the information society, permeating throughout society, and internet connectivity is crucial for its functioning and development.

In the initial phase, the digital economy primarily focused on the digitization of business transactions, leading to the creation of digital infrastructure. This paved the way for the next phase, known as e-business, which encompasses a set of processes enabling various forms of online trading and entrepreneurship. An important characteristic of this concept is its ability to ensure secure financial transactions, protect sensitive information, and implement measures against counterfeit electronic signatures, among others. These features facilitated the expansion of online commerce and the emergence of e-commerce platforms, which, in turn, gave rise to additional e-services such as card payments, PayPal, and online advertising.

Currently, the digital economy serves as a means to transform tangible goods into virtual ones. It represents an economy with minimal or zero marginal costs due to factors such as production automation, decentralized energy systems, and the shift towards renewable resources. As a result, the costs of producing non-digital goods are expected to decrease significantly, approaching near-zero levels.

4.5. PROCESSES FOR DATA COLLECTION IN INDUSTRY 4.0

4.5.1 Internet of Things (IIoT)

Internet of Things (IoT) is a rapidly growing technology that has drastically contributed to the Industry 4.0 realization. IoT pursues to pervade our everyday environment and its objects, linking the physical to the digital world and allowing people and “things” to be connected anytime, anywhere, with anything and anyone ideally using any network and service. IoT is regarded as a dynamic and global network of interconnected “things” uniquely addressable, based on standard and interoperable communication protocols and with self-configuring capabilities. Despite still being at an early development, adoption and implementation stage, Industry 4.0 and IoT can provide a multitude of contemporary solutions, applications, and services. Hence, they can improve life quality and yield significant personal, professional and economic opportunities and benefits in the near future [14].

The Industrial Internet of Things (IIoT) poses large impacts on business models (BM) of established manufacturing companies within several industries. Arnold et al. (2016) in paper aimed at analyzing the influence of the IIoT on these BMs with respect to differences and similarities dependent on varying industry sectors. The study contributes to the current state of management literature by revealing the following valuable insights with regard to industry-specific BM changes: The machine and plant engineering companies are mainly facing changing workforce qualifications, the electrical engineering and information and communication technology companies are particularly concerned with the importance of novel key partner networks, and automotive suppliers predominantly exploit IIoT-inherent benefits in terms of an increasing cost efficiency.

The IIoT integrates recent trends from the ICT area into industrial production systems [15]. Essentially, it characterizes the proceeding digitized connection of industrial manufacturing. Correspondent to its official definition, the IIoT is constituted by the real-time capable, intelligent, horizontal, and vertical connection of people, machines, objects, and ICT systems to dynamically manage complex systems [9]. In this context, it refers to recent developments regarding the creation of a novel manufacturing paradigm and environment comprising intelligent and self-controlling objects: Smart products are constantly identifiable, steadily locatable, as well as aware of their latest condition and alternative paths to their destination [15, 16].

According to Osterwalder and Pigneur [17], "Business model describes the rationale of how an organization creates, delivers, and captures value". Figure 4.8 illustrates the nine elements constituting the BMO.

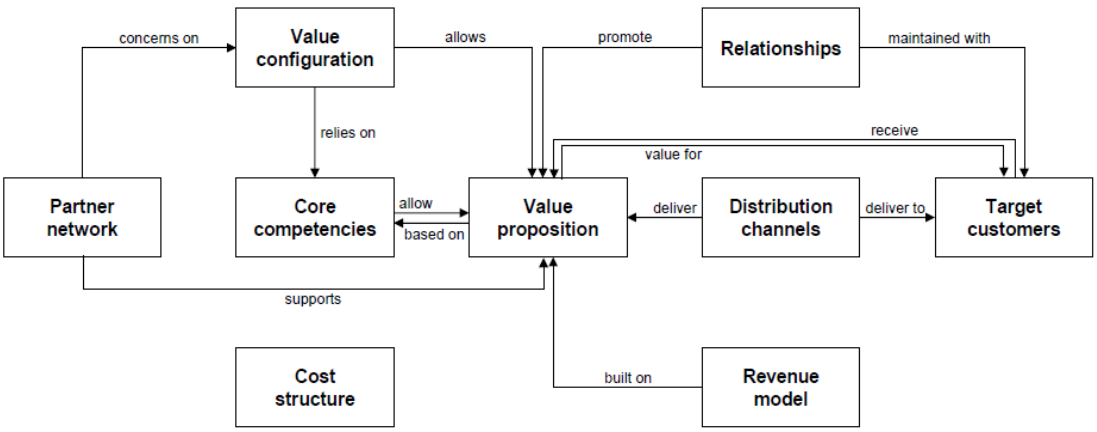

Fig. 4.8 Elements constituting the BMO

4.5.2 Big Data processing in Internet of Things

Big data production in industrial Internet of Things (IIoT) is evident due to the massive deployment of sensors and Internet of Things (IoT) devices [18]. However, big data processing is challenging due to limited computational, networking and storage resources at IoT device-end. Big Data Analytics (BDA) is expected to provide operational- and customer-level intelligence in IIoT systems.

Although numerous studies on IIoT and BDA exist, only a few studies have explored the convergence of the two paradigms. In this study, we investigate the recent BDA technologies, algorithms and techniques that can lead to the development of intelligent IIoT systems. BDA processes are executed as a result of multistage highly interdependent application components (Fig. 4.9). These components are categorised as follows.

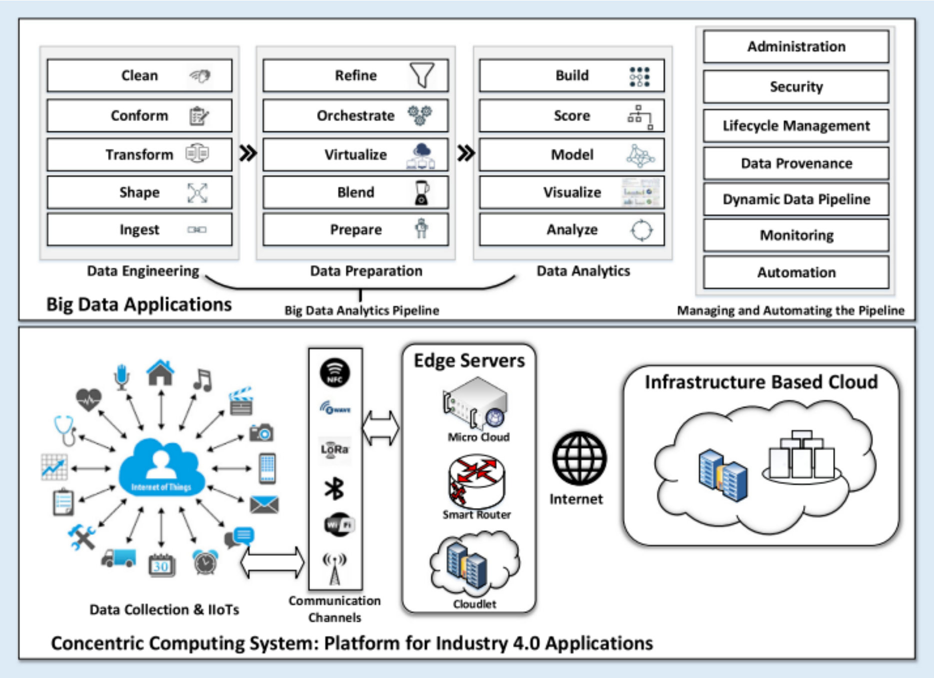

Fig. 4.9 Multistage execution, automating and management of BDA

Source: [19]

In the following text we will explain the individual elements BDA multistage execution, automating and management according to Figure 4.9 [19].

Data engineering

Data engineers build computing and storage infrastructure to ingest, clean, conform, shape, and transform data. IIoT systems produce and ingest big data from inbound enterprise operations and outbound customer activities. The raw data at the earliest stage need further processing to improve the quality and establish the relevance with IIoT applications.

Data preparation

Big data emerge in raw form with large volume and enormous speed, and data scientists spend 70%–80% of their time in data preparation activities. Big data are refined using statistical methods to handle unstructured, unbalanced and nonstandardised data points efficiently. In addition, data refinement helps summarise voluminous data to reduce overall complexity. As a result, the spatiotemporal attributes of big data in IIoT systems vary. Ultimately, data locality is necessary to reduce in-network traffic and latency in big-data applications.

Data analytics

The analytic processes in IIoT systems are executed in multiple phases. Data scientists generate learning models from highquality well-prepared data. After the model is developed, model scoring operations are performed by giving sample datasets and finding and ranking the attributes in datasets/data streams. The correctly tuned models are deployed in production environments to find the knowledge patterns from future data.

Managing and automating the data pipeline

Although existing literature still lacks the concept of automated data pipelines in IIoT systems, BDA processes are executed as a sequence of operations during data engineering, preparation, and analytics. Therefore, a holistic approach is needed to execute and administer BDA processes across all layers of concentric computing systems. Life cycle management is needed for full process execution from raw data acquisition to knowledge visualisation and actuation.

Many studies attempt to define characteristics of BD, including the procedure for collecting data and analyzing it to extract valuable information. IBM focuses on three Vs: volume, velocity and variety for their applications. Some studies add veracity to highlight the trustworthiness of the data, termed the four Vs. Value is also considered because of the cost-and-benefit relation in data collection and analysis, titled the five Vs. Other characteristics of big data are also mentioned in Fig. 4.10 [19].

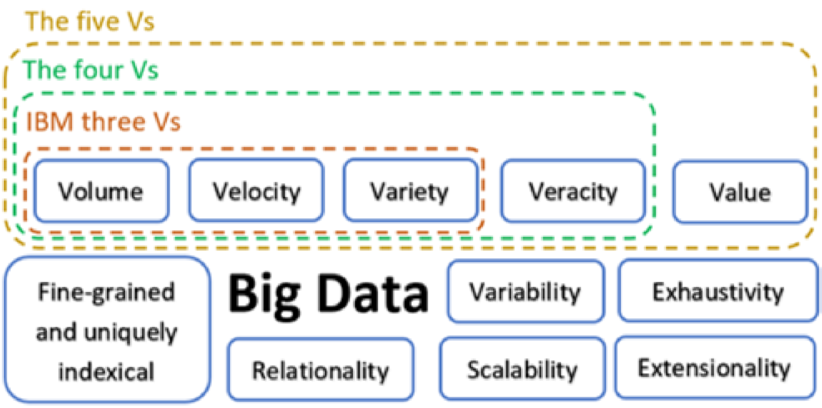

Fig. 4.10 Charakteristics of Big Data

4.5.3 Tools for Big Data application

The Radio-Frequency Identification (RFID) is an example of a technology that is used in IoT. The manufacturing industry will be affected by this change because RFID is used for identifying various objects in warehouses, distribution centres, production shop floors, logistic companies and disposal/recycle stages [20]. The identifiers have smart sensing abilities, and they can connect and interact with other objects, which may create a huge amount of data from their movements and behaviours. These objects are given specific applications or logics, so that they can be followed being equipped with the RFID readers and tags [21]. RFID can also

capture data related to the daily operations so that production management is achieved on a real-time basis [22].
RFID technology plays an important role in Industry 4.0 [23]. It enables the tracking and transmission of data related to materials, supplies, components, products, and inventory management. The first patented RFID technology for retail use dates to 1973. RFID is an automatic identification technology that wirelessly identifies almost any object by using data transmitted through radio waves and stored in RFID tags or chips. The principle of RFID technology is based on communication between an RFID reader and an RFID tag. The RFID reader generates an electromagnetic field in which RFID tags are placed. These tags contain a small chip and an antenna that enables communication with the reader. These tags can be read and written to, allowing for information retrieval and modification. RFID tags, which carry the information, can come in the form of labels (Smart labels) or encapsulated in various shapes, sizes, and materials. RFID readers, available in stationary or mobile form, are used for reading and writing data to RFID tags [24]. The functional principle of RFID is depicted in Figure 4.11.

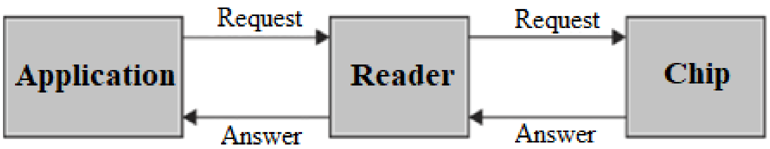

Fig. 4.11 The functional principle of RFID

Source: [23]

4.6. SUMMARY

LEAN 4.0 represents an approach that merges the core tenets of lean manufacturing with the latest advancements in Industry 4.0. The efficacy of LEAN 4.0 can be comprehended by acknowledging that Lean functions as a framework wherein processes are enhanced through data-informed transparency. Consequently, as the quality of accessible data reservoirs increases, the potential for process advancement through ongoing refinement also escalates.
The five principles are considered a recipe for improving workplace efficiency and include:
1) defining value,
2) mapping the value stream,
3) creating flow,
4) using a pull system,
5) pursuing perfection.
The five fundamental principles of Lean offer a structure for establishing a streamlined and productive organization. Lean enables managers to identify inefficiencies within their company and deliver enhanced value to customers. These principles promote the establishment of smoother workflow in operational processes and foster a culture of continuous improvement. By diligently applying all

five principles, an organization can maintain its competitive edge, elevate the value provided to customers, reduce operational costs, and boost profitability.

The synergistic relationship between Lean and Industry 4.0 philosophies presents a valuable opportunity for manufacturing and operations managers to attain elevated levels of production efficiency. Often referred to as 'Lean Industry 4.0', this integration recognizes that as operational processes become more intricate, relying solely on Lean techniques may not suffice in addressing competitive pressures. By strategically deploying a combination of Industry 4.0 technologies, manufacturers can enhance speed, efficiency, and coordination, and even facilitate autonomous factory operations. This amalgamation allows companies to harness the benefits of both Lean principles and Industry 4.0 advancements, leading to significant improvements in overall operational performance.

Lean Manufacturing and Industry 4.0, despite their seemingly different focuses, share the common goal of enhancing the manufacturing process throughout the entire value chain. While Lean emphasizes people and processes, Industry 4.0 centers around advanced technologies. However, the concept of Lean 4.0 merges the principles of lean manufacturing with the tools and technologies of Industry 4.0, enabling companies to achieve superior productivity. It is estimated that nearly 98% of manufacturing companies anticipate increased overall efficiency by adopting modern digital technologies and lean principles. The applicability of Lean 4.0 extends to a wide range of industries, from automotive companies to European food production plants. By delving deeper into Lean 4.0, we can explore its methodology, which combines the foundational principles of lean manufacturing with the cutting-edge technologies of Industry 4.0.

The efficacy of Lean 4.0 can be comprehended by considering the fundamental premise that lean operates as a system in which processes are enhanced through data-driven visibility. It is based on the notion that the higher the quality of available data sources, the more refined the processes can become through continuous improvement. The integration of Industry 4.0 technology brings forth advanced analytics algorithms that enable the analysis of data and identification of inefficiencies within processes. By leveraging state-of-the-art modern technology, Lean 4.0 aims to minimize waste and eliminate non-value-adding procedures in lean production, ensuring that no time is wasted in the manufacturing process.

We identified three areas in our research where Industry 4.0 technologies and LEAN principles meet:

1. Customer Centricity,
2. Continuous Improvement,
3. Integrated Value Chain.

Industry 4.0 draws on Lean’s foundations in continuous improvement but brings big data to the table. The interconnectedness of devices, sensors, machines, and software facilitates the swift and real-time collection of data. This empowers managers to enhance processes and anticipate potential failures proactively. Additionally, machines have the capability to autonomously optimize their performance, diagnose issues, and configure themselves more efficiently. The seamless integration of these technologies enables organizations to leverage data-driven insights and automation to drive continuous improvement and maximize operational efficiency.

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She is the scientist on the global list of top scientists:
Top 2/Elsevier: https://elsevier.digitalcommonsdata.com/datasets/btchxktzyw. Published: 3 November 2022|Version 5|DOI:10.17632/btchxktzyw.5. Table_1_Authors_singleyr_2021_pubs_since_1788_wopp_extracted_202209 (position on the list: 199525)

Michalene Eva Grebski PhD
Michalene Eva Grebski has a multidisciplinary background combining Masters'degrees in Psychology and Business Administration as well as a Doctorate in Management. From 2016 through 2020, she was a faculty member at Northampton Community College (Pennsylvania USA). Presently she is a faculty member at Colorado Mesa University (Colorado USA). Michalene Eva Grebski has co-authored ten books and sixty-one scholarly articles. Her research interest is innovativeness and creativity in education and entrepreneurial networks. She has conducted research related to the development of innovativeness skills and attributes as well as a multidisciplinary holistic approach for enhancing innovative behavior. Dr. Michalene Grebski is a member of many professional societies (American Counseling Association, American Psychological Association, American Association of University Professors, The International Honor Society in Psychology/PSI CHI).

Assoc. Prof. Ing. **Erika Sujová**, PhD., has been working as a university lecturer at the Faculty of Engineering of the Technical University of Zvolen since 2004. In her pedagogical and research work, she focuses on the issues of production process management, quality management, managerial economics, and technical system safety. The main topic of her current research is the implementation of the Industry 4.0 concept into manufacturing systems, which was the subject of her habilitation thesis. She is a co-author of 3 scientific monographs, 2 university textbooks, and numerous scientific articles in CCC, WOS, and SCOPUS databases.
In the years 2019-2023, she has held the position of Vice-Dean for Development and External Relations. In this role, she strived to expand and enhance cooperation between the faculty and manufacturing companies and the business sphere. Another area of her responsibilities includes international mobility for faculty employees and students, as well as supporting incoming foreign guests. She actively works as the faculty coordinator for Erasmus+ and CEEPUS mobility programs.

Professor Wieslaw (Wes) Grebski PhD
Wieslaw (Wes) Grebski is Professor Emeritus at The Pennsylvania State University. He was an Engineering faculty and Coordinator of the Engineering Program at Penn State Hazleton. His research interests evolved from computer-aided manufacturing to sustainable forms of energy. Professor Grebski was always promoting a close cooperation between university and industry. Under his leadership a new Engineering program focusing on renewable energy was developed. He has coauthored two hundred publications and nine books. Professor Grebski promoted different unconventional methods for teaching and learning. He was the recipient of the Milton S. Eisenhower Award. (This is one of the highest recognitions at The Pennsylvania State University.) He has also received eleven other awards for teaching and advising. He has also taught the dual enrollment class, *Introduction to Engineering Design,* as a form of promoting the Engineering profession and recruiting students for the Engineering program. He was a member of the Pennsylvania Academy of Science, American Society of University Professors, American Society of Mechanical Engineers and American Association of Engineering Educators.

SMART MANUFACTURING AND PROJECT MANAGEMENT

The monograph is about the project management (PM) in the concept of smart manufacturing (Industry 4.0 – I 4.0). In the concept I 4.0, that is popularizing in the Fourth Industrial Revolution companies realize a lot of new projects. Each project has a defined scope, budget and a predetermined completion date (fix bid), and its implementation is according to the "waterfall" methodology or the agile approach (e.g. Scrum in IT projects). Smart manufacturing projects are new projects with many risks. Only the next ones succeed. Companies are not the universal path to I 4.0. Each realized project is specific. The authors in the monograph want to add to the knowledge of project management new aspects concerning the development of smart manufacturing projects (SMPs). Due to the wide range of changes in PM, the monograph is only an introduction to project management (PM) in SM. The monograph consists of four chapters dealing with aspects of SMPs. The monograph provides important knowledge about the project management that are realized in new environment of the concept of I 4.0. The monograph complements the knowledge of students and practitioners about PM in the smart environment.

The monograph consists of four chapters. In the first chapter, the authors introduce the reader to the concepts of Industry 4.0 with smart manufacturing projects. The second chapter contains knowledge about PM, which is enriched with information about patent procedures in Poland and the USA. The Human Factors (HF) is devoted to the third chapter. The last chapter deals with the Lean philosophy in the smart manufacturing. The Lean is very important in a process optimisation-oriented approach in Industry 4.0.