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Literature review of Industry 4.0 and related technologies

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Abstract

Manufacturing industry profoundly impact economic and societal progress. As being a commonly accepted term for research centers and universities, the Industry 4.0 initiative has received a splendid attention of the business and research community. Although the idea is not new and was on the agenda of academic research in many years with different perceptions, the term "Industry 4.0" is just launched and well accepted to some extend not only in academic life but also in the industrial society as well. While academic research focuses on understanding and defining the concept and trying to develop related systems, business models and respective methodologies, industry, on the other hand, focuses its attention on the change of industrial machine suits and intelligent products as well as potential customers on this progress. It is therefore important for the companies to primarily understand the features and content of the Industry 4.0 for potential transformation from machine dominant manufacturing to digital manufacturing. In order to achieve a successful transformation, they should clearly review their positions and respective potentials against basic requirements set forward for Industry 4.0 standard. This will allow them to generate a well-defined road map. There has been several approaches and discussions going on along this line, a several road maps are already proposed. Some of those are reviewed in this paper. However, the literature clearly indicates the lack of respective assessment methodologies. Since the implementation and applications of related theorems and definitions outlined for the 4th industrial revolution is not mature enough for most of the reel life implementations, a systematic approach for making respective assessments and evaluations seems to be urgently required for those who are intending to speed this transformation up. It is now main responsibility of the research community to developed technological infrastructure with physical systems, management models, business models as well as some well-defined Industry 4.0 scenarios in order to make the life for the practitioners easy. It is estimated by the experts that the Industry 4.0 and related progress along this line will have an enormous effect on social life. As outlined in the introduction, some social transformation is also expected. It is assumed that the robots will be more dominant in manufacturing, implanted technologies, cooperating and coordinating machines, self-decision-making systems, autonom problem solvers, learning machines, 3D printing etc. will dominate the production process. Wearable internet, big data analysis, sensor based life, smart city implementations or similar applications will be the main concern of the community. This social transformation will naturally trigger the manufacturing society to improve their manufacturing suits to cope with the customer requirements and sustain competitive advantage. A summary of the potential progress along this line is reviewed in introduction of the paper. It is so obvious that the future manufacturing systems will have a different vision composed of products, intelligence, communications and information network. This will bring about new business models to be dominant in industrial life. Another important issue to take into account is that the time span of this so-called revolution will be so short triggering a continues transformation process to yield some new industrial areas to emerge. This clearly puts a big pressure on manufacturers to learn, understand, design and implement the transformation process. Since the main motivation for finding the best way to follow this transformation, a comprehensive literature review will generate a remarkable support. This paper presents such a review for highlighting the progress and aims to help improve the awareness on the best experiences. It is intended to provide a clear idea for those wishing to generate a road map for digitizing the respective manufacturing suits. By presenting this review it is also intended to provide a hands-on library of Industry 4.0 to both academics as well as industrial practitioners. The top 100 headings, abstracts and key words (i.e. a total of 619 publications of any kind) for each search term were independently analyzed in order to ensure the reliability of the review process.

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Note that, this exhaustive literature review provides a concrete definition of Industry 4.0 and defines its six design principles such as interoperability, virtualization, local, real-time talent, service orientation and modularity. It seems that these principles have taken the attention of the scientists to carry out more variety of research on the subject and to develop implementable and appropriate scenarios. A comprehensive taxonomy of Industry 4.0 can also be developed through analyzing the results of this review.

Keywords Industry 4.0 · Smart factory · Internet of things (IoT) · Cyber-physical systems · Cloud systems · Big data

Introduction

Although the idea is not new and was on the agenda of academic research in many years with different perceptions, the term "Industry 4.0" is just launched and well accepted not only in academic life but also in the industrial society. While academic research focuses on understanding and defining the concept and trying to develop related systems, business models and respective methodologies, the industry, focuses its attention on the change of industrial machine suits and intelligent products as well as potential customers on this progress.

Industry 4.0 defines a methodology to generate a transformation from machine dominant manufacturing to digital manufacturing. In order to achieve a successful transformation, Industry 4.0 standard should be well understood and a clear road map is to be generated and implemented. There has been several approaches and discussions going on in order to generate road maps some of which are reviewed in this paper. Evaluating Industry 4.0 components and respective features is important to define the basic pillars of a concrete future manufacturing environment. However, the literature clearly indicates the lack of respective evaluation and assessment methodologies. Since the implementation and applications of related theorems and definitions outlined for the 4th industrial revolution is not mature enough for most of the reel life implementations, a systematic approach for making respective assessments and evaluations seems to be urgently required for those who are intending to speed this transformation up. It is now main responsibility of the research community to developed technological infrastructure with physical systems, management models, business models as well as some well-defined Industry 4.0 scenarios in order to make the life for the practitioners easy.

It is estimated by the experts that the Industry 4.0 and related progress along this line will have an enormous effect on social life. This will naturally trigger the manufacturing society to improve their manufacturing suits to cope with the customer requirements and sustain competitive advantage. World Economic Forum prepared a report by taking 800 experts view and provided an excellent set of recommendations and findings regarding the digital transformation. The report claims that the number of robots used in manufacturing will increase to 2.4 million by 2018. This transformation is opening the door to implanted technologies to human body, wearable internet, cooperating and coordinating machines, self-decision-making systems, autonomy problem solvers, learning machines etc. Machines even starting to play the role of a decision board member having all rights to make the decisions. 3D printing is progressing a lot more than expectations leading to print articles used in daily life. They are even used to build artificial organs up. It is expected that 1 trillion sensors will be used in human life by 2025. Smart cities are progressing with a high speed and spreading all over the world. The developments along this line increases the wish to generate smart factories more and more every day. There is a high probability that more than 6 billion connected devices will proactively ask for support in 2018. Global spending on big data is assumed to be well over 200 billion dollars in 2020. By 2020, more than 3 billion workers globally is to be supervised by a robo-boss and %59 of US manufacturer will be using some sort of robotics technology (WEF 2015). The history reveals several industrial and respective social transformation. There had and has been manufacturing efforts in research, development, production and management of complex industrial processes by utilizing innovative production technologies of the time. Transition from agriculture to industrial society (industry 1.0), from industry 1.0 to 2.0, and then to 3.0 was well recognized and accepted by the society.

Similarly, the transition from industry 3.0 to Industry 4.0 requires extensive analysis to understand irreversible changes. There are several elements of this change which triggers the social effects as well. Internet of Things (IoT) is one of them. This technology allows the machines to communicate (M2M). This capability generates a more human free manufacturing environment. Second important motivation of this changes is "autonomy". The systems are becoming more and more self behaving. Some sensors and cyber physical systems (CPS) are another core elements of this transformation. They facilitate easy communication capability between machines. When CPS, IoT, M2M communication and autonomy come together and brings about more consistent, robust, agile manufacturing systems with intelligent capabilities. This definitely leads to improved the motivation to create a dark factory. Another important breakthrough in this transformation is having the capability of the machines communicating with human operators. This naturally requires a philosophical change in setting up new manufacturing facilities and leads to a new manufacturing vision to be based on 4 basic concepts including intelligence, products, communication, information network. SmartFactoryKL (2014) clearly outlines this progress and suggests the following recommendation for better transformation.

- First point is the "*vision*". Industry 4.0 is a part of smart networked world and the philosophy includes novel business, new social infrastructures and real time enabled Cyber Physical System platforms (SMLC 2011). These factors should definitely be taken into account in generating the road maps for digital transformation.
- Second point is so called the "*dual strategy approach*". Since leading supplier strategy and leading market strategy are becoming important day by day, the manufacturing strategy is said to be based on these two.
- Third point is the capability of the companies to outline their "*requirements*". Firms should determine their needs by an in-depth analysis and see their strong and weak points.
- Fourth point is determining the "*priority areas*". A ranking should be made to strengthen the weak spots. All problems must be resolved in sequence with the available resources and the time schedule given. Managing complex systems, delivering infrastructure for industry, safety and security factors, regularity framework is to be the main body of road map for implementing Industry 4.0

As can be drawn from the above recommendations, the superior quality of the manufacturing industry strictly depends on its high quality applied production technology. Industry 4.0 standards ensures this by addressing several high rank research topics including autonomy, machine to machine interfaces, cyber physical systems (CPS), mobile technologies etc. (Bunse 2016). As presented by the German Federal Government, the Industry 4.0 aims to emphasize the importance of production technology, supporting information and communication technology sector. Both, the Federal Ministry of Education and Research (BMBF) and the Ministries of Economy and Energy (BMWi) coordinate the financing activities in this area. The respective initiatives are supported and monitored by so called Industry 4.0 Platform, whose pioneering role is launched by these ministries at the beginning of 2015. The work of the original Industry 4.0 platform, established by ZVEI, VDMA and BITKOM associations, has been extended to a higher level and have a broader political and social basis (BMBF 2014).

In terms of processes, production and users of new technologies, it is still not at all certain whether this initiative is a more revolutionary or a more evolved evolution than the existing concepts. However, generally accepted that it is necessary to introduce new technologies and corresponding new concepts, if respective business process challenges (Alatoibi 2016) are well managed and if increased quality and flexibility are to be addressed in an environment of increasing complexity and with possible solutions to problems of demand and volatile markets (Cheng et al. 2016). The manifold contributions from academics and practitioners have made by the meaning of the term (Bauernhansl et al. 2014) and Industry 4.0 has being becoming a top priority for companies seeking for possible way towards their future. The key promoters of the idea, the "Industry 4.0 Working Group" and the "Platform Industry 4.0", describe the vision, the basic technologies, the idea aims as well as some selected scenarios (Kagermann et al. 2013; Platform Industry 4.0 2014). However, there is still need for a clear definition. Although there are some efforts to provide a basic definition, a generally well accepted definition of Industry 4.0 has not yet been published (Bauer et al. 2014). While some of the researcher focusing their attention on digitization, others consider communication aspect dominating the manufacturing structure. The others opting for intelligence and autonomy of the systems by being the primer features of Industry 4.0. Generating a so called dark factories were also in the focus of some others.

Nowadays, robotics and automation are rapidly progressing due to innovations in sensors, devices, unmanned air vehicles (UAVs), information networks, optimization, and machine learning. Well recognized universities realize this as the potential improve building, healthcare, manufacturing, transportation, safety, and a broad range of other applications. The research therefore concentrates on emerging advances in cloud computing, ensemble learning, big data, open-source software, and industry initiatives in the Internet of Things, Smart cities, smart factories, Industrial Internet and Industry 4.0. etc. As would be agreed by the scientist committee recent developments in non-convex optimization, model predictive control, partially observable Markov decision processes, reinforcement learning, and approximate probabilistic inference hold promise for addressing various problems which would be difficult earlier. Cloud Computing sort of developments can provide access to large datasets and clusters of remote processors to filter, model, optimize, and share data across systems to improve performance over time.

This article aims to provide a baseline for generating a universal definition. Based on the literature review, the authors provide a definition for Industry 4.0 which specifies six design principles that should be considered when applying Industry 4.0 solutions. The article is structured as the following. Chapter 2 provides an overview of the research process and method implemented in this study. Chapter 3 introduces a brief overview of the idea of Industry 4.0, its vision, main objectives, and similar concepts all around the world. "Research process and research method" section summarizes the research process and the research methodology employed. In Chapter 4, all components are explained in detail and the respective studies have been reviewed. This chapter has led to create the definition of Industry 4.0. Chapter 5 explains the contributions of the paper to both the academic and the practical world, suggesting the limitations of the research done and ways requiring further investigation.

Some national initiatives

Although the term Industry 4.0 introduced by Germany, most of the other nationals are also paid attention to digital transformation as a strategic issue for their national developments. Since, it is not possible to review every program running all over the world within this paper, some example programs mentioned below is considered be enough for taking the attention of the reader to the strategic importance.

Some big companies in the USA triggered the start and AT&T, Cisco, General Electric, IBM and Intel founded the Industrial Internet Consortium (IIC) in order to coordinate the priorities for the industrial Internet, and to enable the technical applications required for this in March 2014. This can be noted as the USA understanding of Industry 4.0. Within a two-year period, 250 companies have joined the movement, including some companies even from Germany. The aim of this Industrial Internet Consortium is said to bring together "operational systems" such as machines and industrial plants in the widest sense of the term, and information technology. The consortium intends to create industry standards upon successful applications (IIC 2016). RTI (2014) lists most influential "Internet of Things" companies in USA. Similar initiative such as Advanced Manufacturing Partnership for Southern California (AMP SoCal) all over the country are also appearing. They carry out Industry 4.0 workshops or platforms for the related components.

As reported by Cooper (2017), manufacturing transformation is growing exponentially, driven by a multitude of factors, from technological innovation and evolving customer behavior to regulatory changes and a turbulent global landscape all requiring businesses to innovate with ever-increasing speed. With the advent of the Industry 4.0, UK government took the opportunity to position itself as a global center of excellence for advanced manufacturing and promised a more joined-up industrial strategy to help meet current industrial challenges; to address the competitiveness of the UK economy, by focusing on measures that will increase productivity and drive innovation-led growth. Similarly, a report published by EEF (2017), clearly states that more visionary thinking is necessary for performing the transformation to so called fourth industrial revolution (4IR). Current challenges require government and industry together for overcoming the difficulties. It is stated that the report has been developed through focus groups, interviews and surveys to build up a picture of what manufacturers make of the 4th industrial revolution noting that this initiative is not just about technology and the report goes into some of the changes that industry leaders will need to make within their company including giving IT a more strategic business planning role, changing company culture to enable higher levels of innovation and adopting a visionary approach to leadership.

Taiwan keeps motivation at the highest level in the development of the Asian Silicon Valley project and the upgrading its Smart Machinery Industry through its national development plan for 2017–2020. The focus point of this plan is reported to be the development of new hardware solutions and stimulating entrepreneurship especially to build smart cities. The National Development Council (NDC) put their plan of building the Digital Nation in the center with the following ambition:

- Construct an innovative digital foundation.
- Train cross-discipline talent.
- Build a service-oriented digital government.
- Develop an equal, vibrant network society.
- Create an ecosystem for industrial innovation which will stimulate the Taiwanese economy and create new high-level jobs.

NTIO (2017) reports that the government has allocated 100 billion Taiwanese dollars—about 3 billion Euro in order to execute this ambitious plan. NDC is also said to be working to set up a private equity fund in order to invite private partners to contribute financially to this transformation as it will provide them with interesting new business opportunities. For example, The Taiwanese investment firm Fu Hwa Securities already launched a 625 million US$ global investment fund focusing on the development of the internet of things (IoT), in order to support the development of self-driving cars, big data, smart logistics, cloud computing and advanced manufacturing.

As response to German effort, Japanese companies launched the "Industrial Value Chain Initiative (IVI)". This initiative aims at creating standards for technology to connect factories and to combine efforts to internationalize industrial standards from Japan. İn 2015, 53 companies took part in this initiative. This number is reported to reach more than 140 in 2016 (Nishioka 2016). This initiative supports building collaboration scenarios and use cases (some meta models) of connected manufacturing among different enterprises based on a loosely defined standard and provides and manages a repository of loosely defined standard models that can be continuously changed in accordance with unexpected future requirements. The idea is to move from intranet to internet—from having proprietary communications structures within organizations to having communications structures with outside organizations. The program is extended along 4 different areas including;

- Area 1: Reaction on changes in globally and locally connected factories.
- Area 2: Emerging IoT technologies for production line management.
- Area 3: Platform for connected world in design and manufacturing.
- Area 4: New era of Human centric manufacturing powered by IoT.

Japanese take this initiative one step ahead and introduced Society 5.0 in the 5th Science and Technology Basic Plan. It is defined as a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space. The progress of the society is simply classified as the following (Kaidanren 2016);

- Hunting society.
- Agricultural society.
- Industrial society.
- Information society.
- Super smart society.

South Korean government also introduced a transformation scheme so called "manufacturing innovation 3.0 strategy implementation plan." The use of "manufacturing innovation 3.0" was meant not to have the intact copy of the Industry 4.0. A clear strategic goal to promote manufacturing and information technology (ICT) integration, thereby creating a new industry, to enhance competitiveness of Korean manufacturing industry, is put forward. Positioning Korea as an information technology power, with basic manufacturing and information technology industry integration was also one of the other aim of this program. Itis reported that South Korean government also plans in 2020 to build 10,000 intelligent production facilities aiming to spend about 24 trillion won (US $23 billion) of funds. 10% of this will directly go into the South Korean government and the rest were to be adopted to attract private capital investment to solve (Sangmahachai 2015).

French government launched "New Industrial France" initiative in 2013 aiming to be an innovation leader and to push the technological frontier to create the products and the uses of tomorrow. The government is intended to seize the opportunities created by the industrial revolution that is sweeping through the economies which requires unprecedented effort in terms of research and investment. It is reported by the Department of Economy and Finance that the Government maintained the research tax credit and introduced the higher depreciation allowance on industrial investments, a one-time-tax incentive to support investment. This last measure was in addition to the €2bn in loans made available by Bpifrance to companies investing in Industry of the Future projects (DEF 2016). This report also explains that a genuine industrial policy was also taken as strategic movement towards shaping the nation's industry. It is also reported that this program supported over a Thousand projects with 47 key technologies. The following 7 areas are considered to be important for improving the industrial over France;

- Digital technology, virtualization and the Internet of Things.
- The human factor in manufacturing plants, robotics, augmented reality.
- Additive manufacturing (3D printing).
- Monitoring and control.
- Composites, new materials and assembly.
- Automation and robotics.
- Energy efficiency.

This initiative also reported to provide modernization support to 1500 SMEs.

China generated a 3-stage industry strategy, taking the nation from innovation "sponge" to innovation "leadership". It tries to generate formidable players in industries where innovation is the main business driver. The innovation, in this context, is considered to be about meeting unmet consumer needs or driving efficiencies in manufacturing. It is reported by McKinsey (2017) that in the last year, China spent nearly $200 billion on research and development, the second-largest investment by any country in absolute terms (and about 2% of Gross Domestic Products). China's universities graduate more than 1.2 million engineers each year—more than any other country. And it leads the world in patent applications, with more than 825,000 in 2013, compared with about 570,000 for the United States. It seems that China aims to have a big leap in science-based innovation. In this approach, new products are developed particularly through the commercialization of research results. The innovation in this respect is supported by the Nation for the industries such as pharmaceuticals, biotechnology, and semiconductor to play the key role in sustaining innovation leadership all over the world.

Turkey pays attention to the digital transformation and took that into the government agenda. Science and Technology High Commission gathered under the chair of the Prime Minister in 2016 and took the decision "to promote and spread intelligent manufacturing systems with the coordination of all related sectors by defining the key technologies along this line and change the funding priorities respectively. Cyber physical systems, artificial intelligence, sensor technologies, internet of things, big data, cyber-security, cloud computing etc. are to be prioritized. TUBITAK (Turkish Science and Technology Research Council) is authorized to fund the respective projects which is continuously running calls for projects.

Similar governmental support program can also be seen in different countries all over the World. However, the reviewed provided above is considered to enough to take the attention of the reader to governmental supports.

Research process and research method

In order to carry out this extensive review, the authors benefited mainly from eight publication databases (CiteSeerX, ACM, AISeL, EBSCOhost, Emerald Insight, Taylor Francis, Science Direct) and Google Academic to cover related publications in engineering, manufacturing and management in both academic and business areas. Some other literature found on internet is also reviewed for their contribution to related topics. This literature survey intents to highlight the central aspects of Industry 4.0 to generate a common definition well accepted by both research and practical communities. This survey is conducted by first searching the term "Industry 4.0". The related terms such as M2M, Internet of Things, Cloud computing etc. are than searched. Top 100 headings, abstracts and key words for each term were independently analyzed to ensure the comprehensiveness and reliability of the review process.

Industry 4.0 components were originally thought of as Cyber Physical Systems (CPS), Smart Factories, and Smart Products. Topics such as cloud system, Data Mining, Machine to Machine (M2M) interfaces, Enterprise Resource Planning (ERP), Internet of Things (IoT), Virtual Manufacturing and intelligent robotics were also included. These headings were analyzed in detail within the scope of their relation to Industry 4.0.

After an initial analysis of the literature, a list which includes the keywords as shown in Table 1 is generated. These keywords are used to classify the related literature. Note that the concept of "Industry 4.0" is a collective term that encompasses many modern automation systems, data exchanges and production technologies. This revolution is a collection of values of objects, internet services and cyber-physical systems. At the same time, this structure plays a major role in the formation of intelligent factories (mainly unmanned ones) and respective transformation from traditional manufacturing to smart manufacturing. This transformation is considered to result in more efficient business models as it allows each data to be collected and analyzed in a well-organized manner.

Production in an Industry 4.0 system is analogous to the system in which machines offer services and share information in real time with products. Industry 4.0 also includes some additional features such as; facilitating system monitoring and diagnostics, the system is environmentally friendly and sustainable through resource saving behaviors, more efficiency systems. The titles on the list make the systems more environmentally friendly.

Table 1 Key words list

Key words	Number of publication reviewed
Industry 4.0 in general	132
Cyber physical systems (CPS)	81
Cloud, cloud systems	53
Internet of things	110
M2M, machine to machine	12
Smart factory	45
Data mining, big data	38
ERP and business intelligence	55
Augmented reality, simulation	21
Virtual manufacturing	23
Intelligent robotics	30
Others (projects and national initiatives)	20
Total # of publication	620

Background analysis

The first industrial revolution was the introduction of mechanical production facilities starting in the second half of the eighteenth century and being intensified throughout the entire nineteenth century. From the 1870s on, electrification and the division of labor (i.e. Taylorism) led to the second industrial revolution. The third industrial revolution, also called "the digital revolution", set in around the 1970s, when advanced electronics and information technology developed further the automation of production processes. An initiative called "Industry 4.0", in which representatives of business, politics and academics gathered (Kagermann et al. 2011), promoted the idea of digitization together with some autonomy and self-behavior of the machines as an approach to strengthening the competitive power of the German manufacturing industry was then introduced. Figure 1 depicts the industrial progress in historical perspective.

When the developments of human history are examined, it can be seen how effective the evolution and change of production techniques are in most of the revolutionary developments. In the first phase of the industrial revolution, the combination of steam, coal and iron has opened the "railway age" with its significant political, economic and social consequences (Adeyeri et al. 2015). While coal has provided the

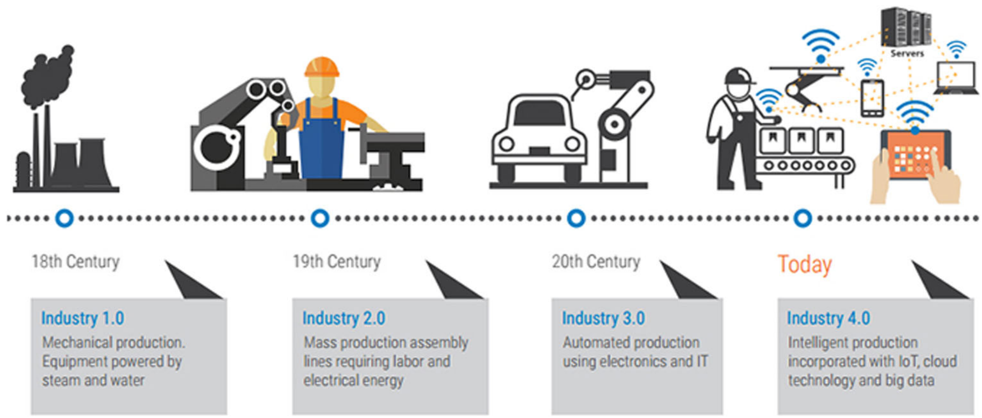

Fig. 1 Historical perspective of industrial revolutions. Reproduced with permission from BCMCOM (2017)

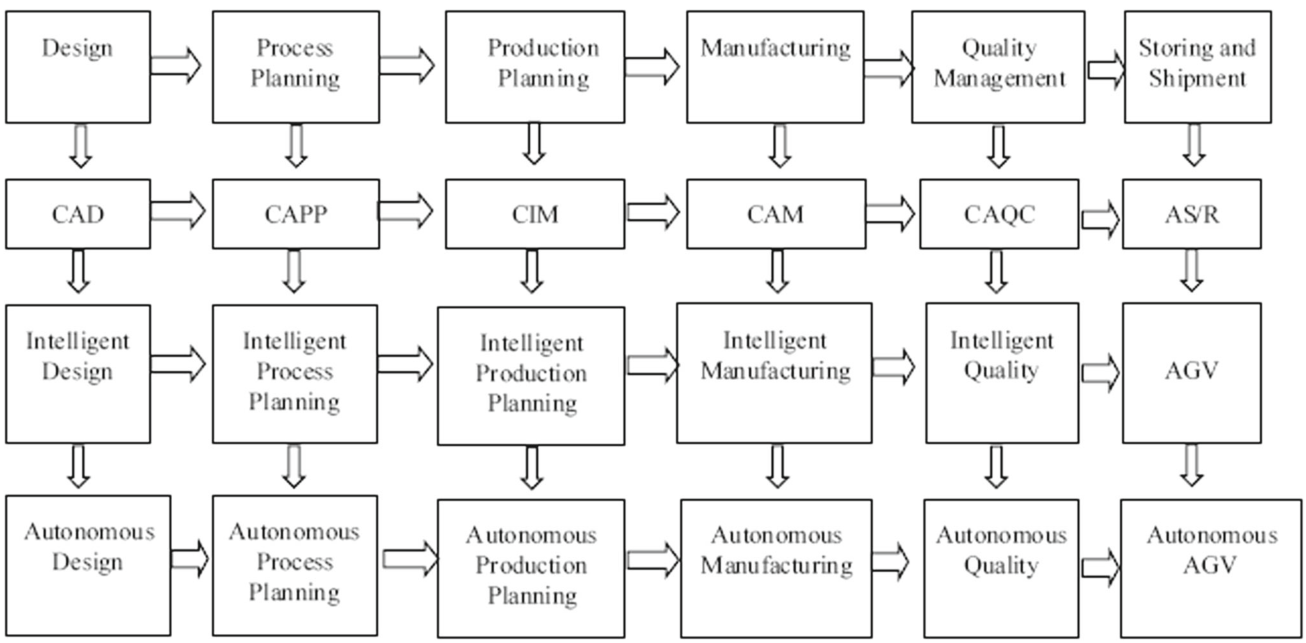

Fig. 2 Change in manufacturing systems. Reproduced with permission from Oztemel (2010)

required power to vehicles moving in railways, the railroads, in turn, are used to transfer the coal to the places that are too far away. During the second phase of the industrial revolution changes in basic raw materials and energy sources emerged (Bauer et al. 2014). As steel, electricity, petrochemicals as well as coal and iron went into production, industrialization took on the shape as still seen today. Iron played a major but non-dominant role in the second phase of the industrial revolution. It is assumed that the discovery of computers and advanced technological developments constituted the third stage of the industrial revolution (Bauernhansl 2014). This was also pointed out by Chang et al. (2012) when they discuss contemporary IT-related issues, policy trends and new industrial services which will lead to successful transfer toward intelligent ubiquitous society.

In terms of manufacturing, Lucke (2008) pointed out the importance of manufacturing systems and technology standing on a new frontier, facing up to the challenges posed by the ever-evolving requirements of global sustainability. Kowalska et al. (2018), Layuan and Chunlin (2002), Lee et al. (2013) represents a technologically optimistic future where objects will be connected to the internet and make intelligent collaborations with other objects anywhere, anytime. The change and transformation from the first revolution to the fourth one is depicted in Fig. 2 as provided by Oztemel (2010). As can be seen form the figure, the manufacturing facilities are being and will be equipped with more and more self behaving capabilities in the historical progress. This is not the prediction about the future. But in fact, it is becoming the reality to some extend as the manufacturing systems emerges. The main idea behind Industry 4.0 is based on those studies where previous applications encouraged the scientist to talk about not only on digitalization but also developing intelligent, integrated and fully autonomy factories (smart or dark factories).

The term Industry 4.0 was first introduced in 2011 as "Industrie 4.0" by a group of representatives from different fields (such as business, politics, and academia) under an initiative to enhance the German competitiveness in the manufacturing industry. The German federal government has supported the idea by announcing that Industry 4.0 will be an integral part of the "High Technology Strategy for Germany 2020" initiative which particularly aimed at leading the technological innovation. Subsequently, the "Industry 4.0 Working Group" developed the first application proposal, which was later published in April 2013 (Kagermann et al. 2013). This understanding clearly supports the idea of generating dark factories or smart factories, which have already begun to emerge, adopt a completely new approach to production and manufacturing processes. Naturally, the products have also been becoming intelligent to cope with both functional and utilization requirements. The manufacturing lines seems to be involving more and more of these products as they can be uniquely identified and can be found at any time and state of their own history.

Similarly, embedded manufacturing systems with different technologies and methodologies are becoming vertically linked more and more to business processes. They are tied horizontally to disparate value networks that can be managed in real time on an order to logistics basis. In addition, both require end-to-end engineering throughout the entire value chain (Fallera and Feldmüllera 2015). The industry word has begun to be used for the first time in Germany and has gradually been passed on to other countries with similar meanings and words (Lasi et al. 2014). It is therefore worth looking at comparable ideas from a global perspective. For example, General Electric gives a similar idea under the name "Industrial Internet" (Bungart 2014; Evans and Annunziata 2012). This is defined as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes (Corcio 2016). It was reported that the US Government supports research and development activities in the area of the Industrial Internet with a 2 billion dollars fund for Advanced Manufacturing (Sun 2012). Other similar ideas can be found under "Integrated Industrial Terms" (Bürger and Tragl 2014), "Intelligent Industry" or "Intelligent Manufacturing" (Hermann et al. 2016). Similarly, a fully automated manufacturing environment is also defined and a reference model so called REMIMS is introduced by Oztemel and Tekez (2009a). A systematically knowledge exchange mechanism between various manufacturing agents are also provided to facilitate autonom manufacturing environment (Oztemel and Tekez 2009b). Figure 3 schematically represents a fully agent based nested autonom manufacturing environment proposed as REMIMS (a Reference Model for Intelligent Integrated Manufacturing Systems).

Similar understanding and trend in generating fully autonom factories produced the concept of "dark factories", in other words factories where lights are extinguished and the manufacturing environments are equipped with fully automated systems and do not require the presence of any human beings. Many of today's factories have dark factory features, but the work of the employee such as removing parts is still in place where typical human power is required. In order to prevent the gap between the activity and the supply/demand of today's consumer sector, many factories begun to use demand management for growing demand. This is achieved within the possibilities of technology at their capacities aiming to increase the financial strength of the factory. There is little or no human intervention in the dark factories, from the entrance of the raw material to the factory to the exit of the product factory (Lee 2008).

The fourth industrial revolution encourages the idea of unmanned factories and promotes global understanding to emerge along this line day by day through recommending more firmly connected companies and countries worldwide through supply chains and sensor networks. Although products may be difficult to trade across some national borders, Industry 4.0 can be means to overcome the obstacles (if any) by allowing companies to transfer the ideas as well as respective systems including the software with protected manufacturing networks. For example; 3D printing technology brings unlimited design for systems with spare parts, and industrial equipment. The success achieved with Industry 4.0 depends on opening the possibilities of data and using analytics with creative and effective methods (Bauernhansl et al. 2014).

There has been several motivation and progress in business which also effected the direction of especially manufacturing and, in turn, the society. These are summarized in Fig. 4 as depicted in the report by TUSIAD—Turkish Industry and Business Association (TUSIAD 2016) by referring to Boston Consulting Group (2016). Many trends that can be gathered in four main themes have begun to shape the business world. Regional trends—Increase in social interaction and trade between countries, Economic trends—With rising emerging strong economies and flows of financial resources Increasing globalization, Technological trends—Increased connectivity and development of platform technologies, Meta trends—Increasing concerns about increasingly scarce resources, environment and safety (Kagermann 2014).

These trends call for a value chain beyond a single enterprise, in which sensors, machines, work pieces, and IT systems will be connected. These connected systems should interact using standard Internet-based protocols and analyze the data to predict failure, to configure themselves, and to

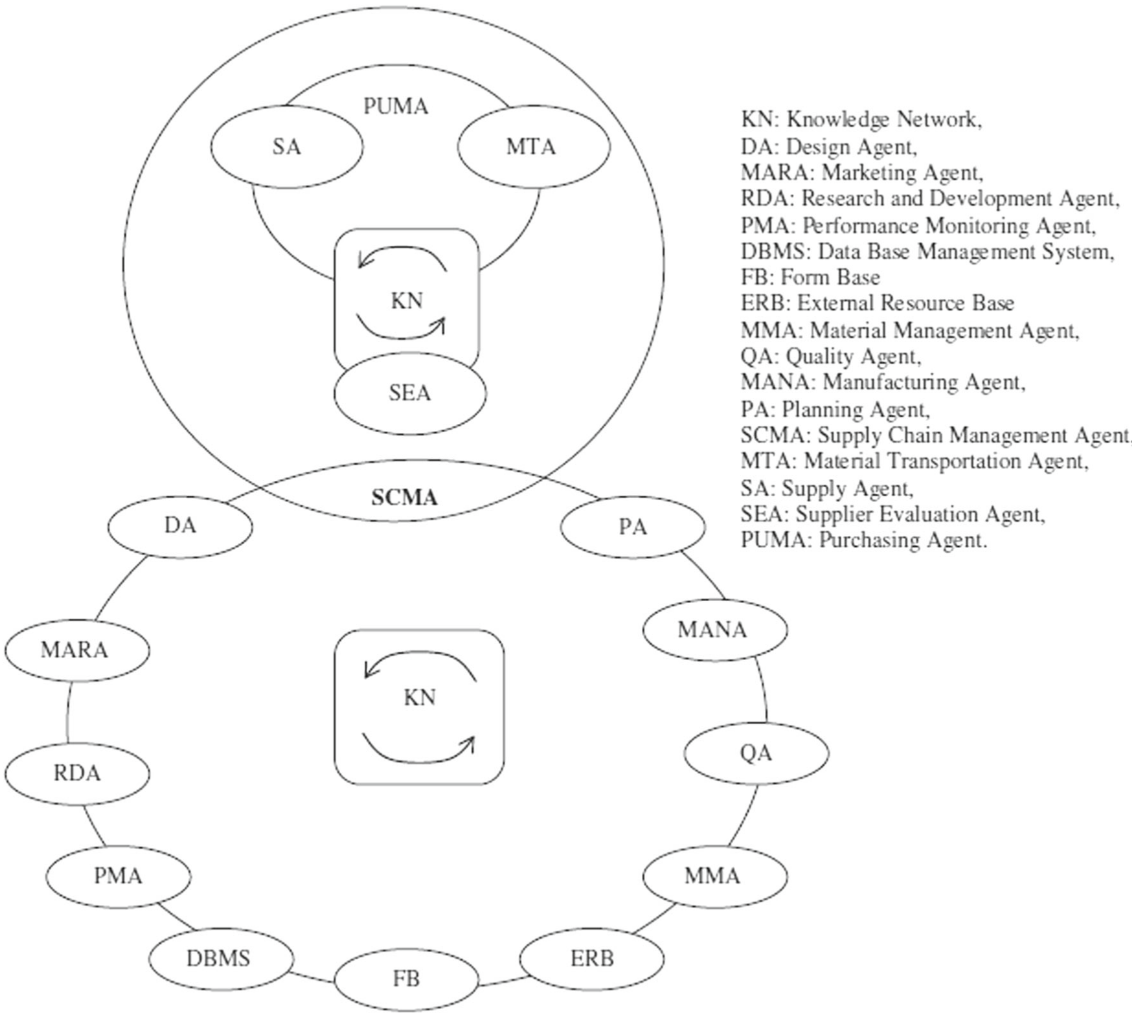

Fig. 3 A nested agent based autonom manufacturing environment architecture. Reproduced with permission from Oztemel and Tekez (2009a)

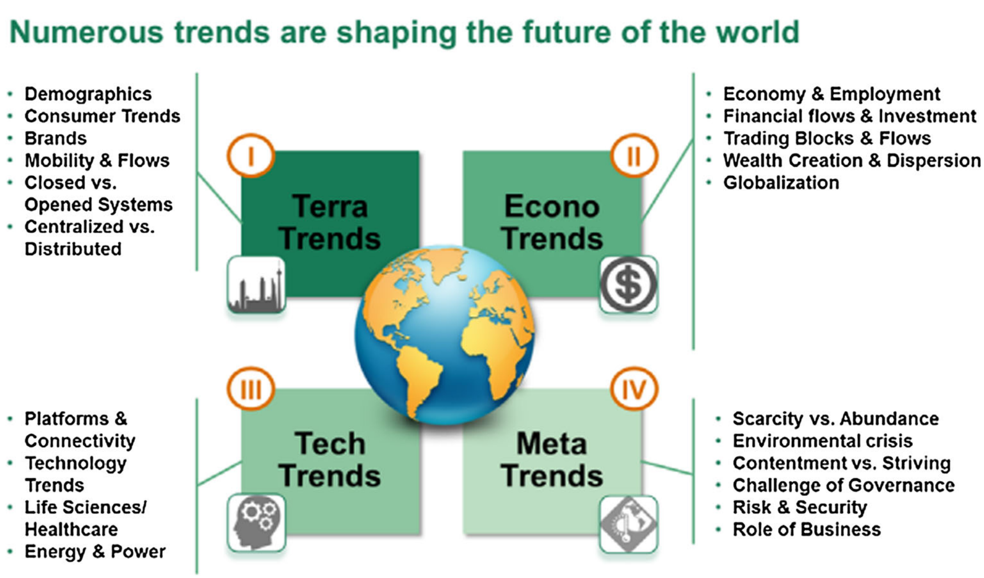

Fig. 4 Various streamlines of economies effecting business. Reproduced with permission from Boston Consulting Group (2016)

adapt the changes. Industry 4.0 aims to make it possible to prepare and analyze data from the machines for this purpose. This enables more faster, more flexible, and more efficient processes to produce higher-quality goods. It will increase manufacturing productivity, better economics, greater industrial growth, and a new workforce profile (Schlick 2014).

Based upon the understanding outlined above, catching Industry 4.0 up will likely require significant changes to company's practices and related attitudes yielding the re-development and re-establishment of complete product and service solutions to the customers. Being able to achieve this, will naturally generate a progressive environment in establishing partnerships with various skills and capabilities to enrich the manufacturing competency (Shafiq et al. 2015).

It is now well accepted by the introductory information as such that the Industry 4.0 provides a new vision for the manufacturing systems. This vision definitely produces a manufacturing environment composed of product, intelligence, communication and networking (Lasi et al. 2014). It is no doubt that with the introduction of Industry 4.0, new business models have to be emerged. There are now companies having the largest part of business in their sector with only running a software (without any extra investments). Some examples of these sort of companies may include UBER a well-known taxi company, facebook a communication and social interaction platform, airbus, travel and tourism agency, Alibaba a famous e-commerce company etc. (Lee et al. 2015a). These types of companies are heavily dependent upon their information network and IT automation. However, the competition along this line will make those providing better facilities which are more suitable to the demander to become more powerful in the market. This can only be sustained through autonomy and self-decision-making capabilities empowered by Industry 4.0 (Lee et al. 2016).

About the literature reviewed

As stated above and provided in Table 1, the literature search on Industry 4.0 is thoroughly based on same key words including Cyber-Physical Systems (CPS), The Internet of Things, Smart Factory, Big data, M2M and Cloud Systems. Keeping the idea of Kagermann (2014) saying that the paper writers view big data and cloud computing as data services that use data generated by Industry 4.0 applications but not as independent components of Industry 4.0, into account, the "Big Data" and "Cloud Computing" is also considered to be searched in this review with their relation to the topic. With these in mind, 9 basic Industry 4.0 components will be reviewed in this respect (see Table 1). The intention is to provide the most-read definition and describe each component's connection with Industry 4.0. Table 1 also indicates number of references reviewed for each component.

General introduction of Industry 4.0 and respective studies

Industry 4.0, the fourth phase of Manufacturing and IT (Drath and Horch 2014) is one of the pioneering research area especially in the last half of a decade. For the first time in the history of the industrial revolution, a prejudice is envisaged that shapes the future of researchers and companies in this area in a planned manner (Kagermann et al. 2013). That is to enhance and improve the efficiency of operations and, ultimately, the productivity of new business models, services and products that will have tremendous economic impact relative to other industrial revolutions (Bauer et al. 2014). Heng et al. (2014) studied Germany's Industry position and capabilities for dijital transformation. It is estimated that the initiative by Germany for constructing Industry 4.0 will contribute up to € 78 billion to German GDP by 2025 (Lichtblau et al. 2016). This indicates the importance of this philosophy in industrial life of the nations. Figure 5 shows the basic components of Industry 4.0 systems as introduced.

From a different perspective, Sangmahachai (2015) defines the framework as given in Fig. 6, focusing the attention on Cyber Physical Systems and the internet of things as well as virtualization, modularity and real-time operation and interoperability of the services. Some of the research including Riedl et al. (2014), Rosas et al. (2017), Schuh et al. (2014b) and Schweer and Sahl (2017) studied Industry 4.0 components and focused especially on CPS and IoT system capabilities. Ong et al. (2008) used Augmented reality applications in manufacturing and their survey analyzed performance for Industry 4.0.

Industry 4.0 also aims to generate smart factories. Figure 7 depicts Industry 4.0 components including smart factories in a secure cloud environment. Feeding smart machines with smart material may lead to the generation of smart products. Cyber physical systems are to utilize M2M communication and utilizing application platform. More than one company could be generated and maintained in one secure cloud network.

Similarly, a lot of researcher studied this concept from various aspects. To mention some; Qin et al. (2016) prepared a fundamental framework for Industry 4.0 system. They analyzed Industry 4.0 process in four layers; factory, business, products and customers. Adeyeri et al. (2015) presented an overview Industry 4.0 focusing the attention on agent based systems. Filippi and Barattin (2012) classified activities in Industry 4.0 aiming to support respective transition. They intended to provide a road map for the companies to get ready for the future. Sogoti (2014) prepared a report for Machine to Machine communication in Industry 4.0 based manufacturing environments. They explain the importance of machine communication through realizing the unavoidable progress along this line. With the similar idea in mind,

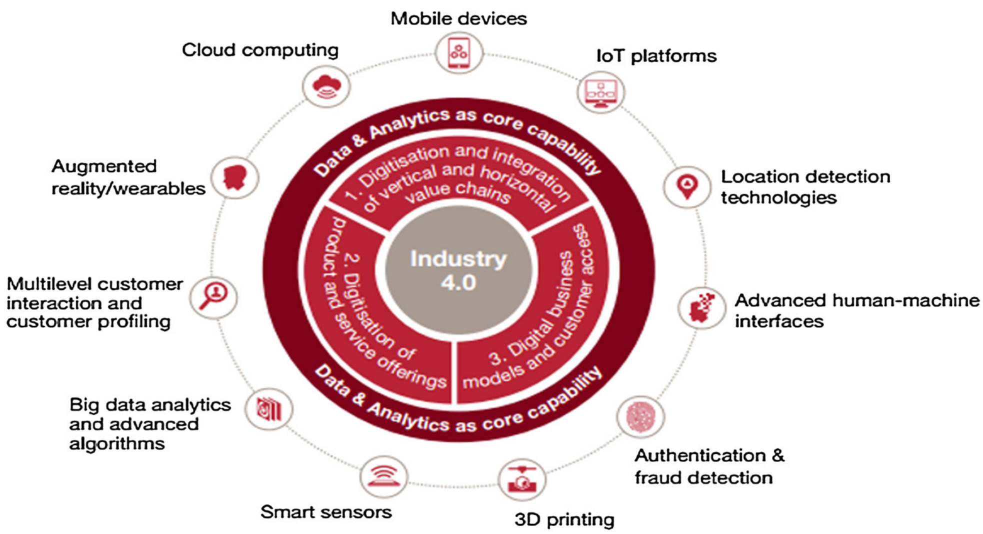

Fig. 5 Basic components of Industry 4.0. Reproduced with permission from Lichtblau et al. (2016)

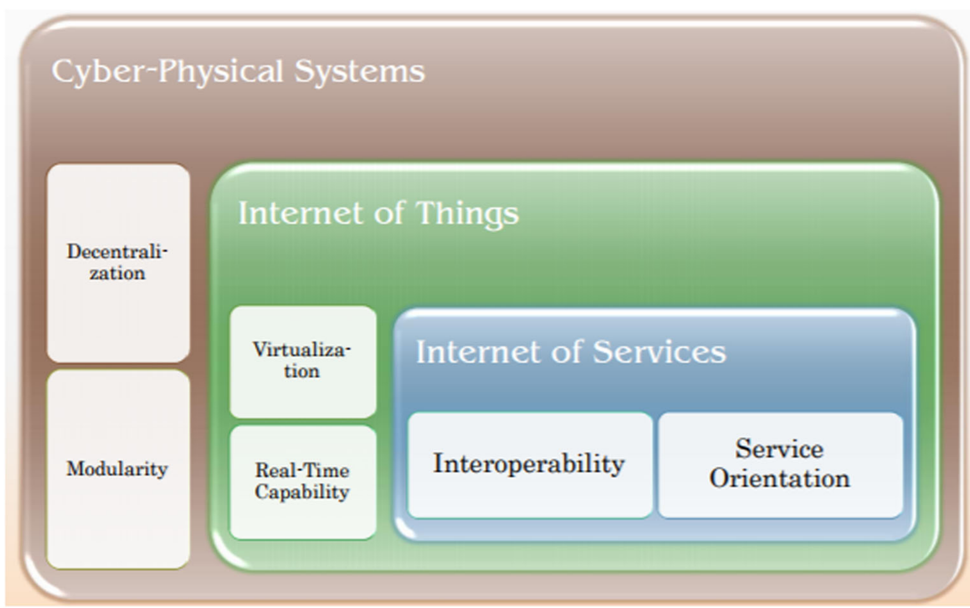

Fig. 6 Industry 4.0 framework as depicted by Sangmahachai (2015)

Lee et al. (2015a) proposed a model for CPS within Industry 4.0 factory.

A unified 5-level architecture is proposed as a guideline for implementation of CPSs. Pan and Kraft (2015) analyzed the data for Industry 4.0 eco-park. They concentrated on importance of analyzing the data and the way to handle big data is elaborated. Analyzing data for Industry 4.0 has also attracted some other researchers. For example, Tuncel and Polat (2016) analyzed the data for 250 firms with different scales and they identified basic Industry 4.0 components as listed above. Tekez and Tasdeviren (2016) proposed a model that assesses leanness out of four perspectives, three level structures of leanness criterion and twenty-eight main criteria are recommended for achieving this. Schouh et al. (2015) introduced an empirical investigation and evaluation of particular influence in production systems. They presented effect of influence in an authentic production setting. Cost-qualification and production relationship was investigated.

Some of the studies such as Schumacher et al. (2016), Lee et al. (2015b) created and used several scenarios for problem oriented learning of future production systems addressing the importance of learning systems within Industry 4.0 like

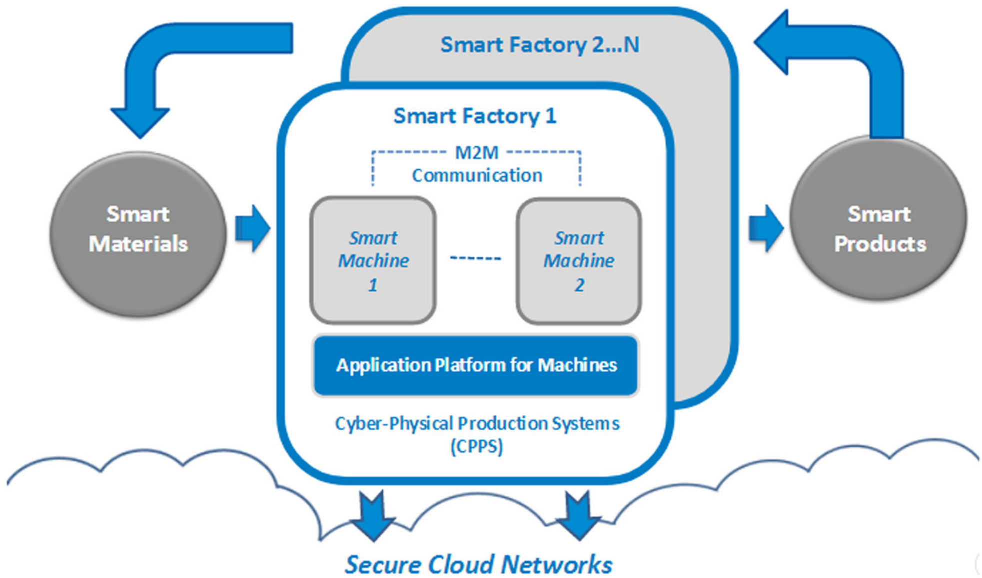

Fig. 7 Industry 4.0 smart factory pipeline—cloud based secure network. Reproduced with permission from GTAI (2017)

manufacturing environments. Unlike the others, Ruivo et al. (2012) used value chain approach for Industry 4.0 features. They studied measuring of ERP performance, this is also important for Industry 4.0 concept. Zezulka et al. (2016), presented introduce specialists from industry into the important phenomenon of the recent technology and applications of Industry 4.0. Vogel-Heuser et al. (2016) studied Industry 4.0 and Cyber Physical Production Systems, and investigated applicability of the concepts of self-configuration.

More generally, Liao et al. (2017) prepared Industry 4.0 literature review for past and future analysis. Zhou et al. (2015), Zhang et al. (2014), Zailani et al. (2017), Thuemmler and Bai (2017), Vogel-Heuser and Hess (2016), Ji et al. (2014), Jing et al. (2014), Leppelt et al. (2013), Li et al. (2011), Lian-yue (2012), Lin et al. (2017c), Liu et al. (2017b), Longo et al. (2017), Ong et al. (2008), Paelke (2014), Palanisamy (2008), Pisching et al. (2015) studied Industry 4.0 performance and future concepts. Their concepts are different from each other but all papers have future points of Industry 4.0 concept. Gaikwad et al. (2015) presents not only the problems and challenges come in IoT and Smart homes system using IoT but also some solutions that would help to overcome on some problems and challenges.

Hofmann and Rüsch (2017) studied logistics management and Industry 4.0 interaction and status. Hossain and Muhammad (2016) prepared a model framework for health monitoring in Industry 4.0 concept. Inderfurth et al. (2001) studied remanufacturing systems in Industry 4.0 system. Jeschke et al. (2017), Lee et al. (2014) studied industry concept and models for future manufacturing systems.

In addition to those mentioned above, some related articles can be listed as the following;

- Stock and Seliger (2016) presented a review of Industry 4.0 based on recent developments in research and practice.
- Suh and Lee (2017) studied an industry of mobile system highlighting the importance of mobile system for digitalization. This study is interesting for providing information to sustain mobility of Industry 4.0 environments.
- Bourke and Mentis (2014) introduced an assessment framework is introduced to support teachers to appreciate the functionality of an integrated assessment approach to document student learning and outcomes. Their education model used Industry 4.0 components.
- Unity Consultancy and Innovation presented a report for system engineering features of Industry 4.0 taking the attention of the research community to especially on design principles (UNITY 2015).
- Rosendahl et al. (2016) used value network in legacy system. They introduced several approaches for focusing on the design of a completely new component structure for Industry 4.0.
- Some of the research such as ICV (2016) concentrated on future industry systems focusing the attention on the transition to Industry 4.0.
- Kagermann et al. (2011) researched new trends focusing the attention towards emerging Industry 4.0.
- Adeyeri et al. (2015) prepared a model for new industry age aiming to quite the manufacturing industry towards the future. Like this, Mckinsey (2016) found important points for new industry age highlighting the transformation road maps. Not so much different, Klaus (2016) prepared a report introducing Industry 4.0 components. They showed their new projects for the new industry age pointing out digitalization and machine prone manufacturing word.

- Thames and Schaefer (2016) described a basic software-defined cloud manufacturing architecture based on leveraging abstraction between manufacturing hardware.
- Accenture (2016) published a report about Industry 4.0 revolution. Their report provided a maturity model taking their processes into account.
- Brettel et al. (2016) studied production flexibility and manufacturing strategy. They allocated the literature stream of production and manufacturing flexibility in the framework of Industry 4.0. Lin et al. (2016a, b) proposed a simple approach for the transition of medium-sized factories towards Industry 4.0.
- Cheng et al. (2016) pointed out new techniques for efficient and effective manufacturing systems.
- Peres et al. (2016) generated a new data exchange format for the Industry 4.0 manufacturing environments. They managed to generate a format for better performance on systems.
- Zarte and Pechmann (2016) proposed a methodology to use IT technology for shop floor for the sake of digitization of industries.
- Sun (2012) intended to highlight application of RFID technology for Industry 4.0 and IOT systems. His research also included international logistics expectations of new industry age.

Moreover, some researcher such as Schumacher et al. (2016), Xinga et al. (2009) and Lichtblau et al. (2016) take the attention to the maturity level of Industry 4.0 implementations. They developed and used so called maturity models. Their models measured the performance of the manufacturing industry with respect to Industry 4.0 principles and features. Additionally,

- Matutinovic et al. (2016), introduced endogenous and exogenous variables that provide negative feedbacks to material growth and push the economic system into the mature stage of development.
- PNC (2016) presented a report for maturity model and respective features in Industry 4.0.

On the other hand, Hecklau et al. (2015) prepared a human resource model and a strategic approach for employee qualifications described in this context. A comprehensive descriptive model was developed by Albert et al. (2016) to represent the relevant systems as well as their interfaces within digitized manufacturing environment. They also developed the model to be descriptive enough by pointing out other documents explaining the system objectives. Sipsas et al. (2016), presented an Industry 4.0 system that provides decision support for operators and maintenance personnel, where maintenance immediate response (preditictive maintenance) is taken as the prime importance. They also proposed several quality layers within their models to generate a sustainable maintenance system. The research along this line produced some other interesting studies such as;

- Weyer et al. (2015) proposed a procedure to standardize Industry 4.0 systems.
- Ivanov et al. (2015) developed an algorithm for Industry 4.0 factory for creating an effective management.
- Shafiq et al. (2015) facilitated in real time critical, creative, and effective decision-making system for virtual engineering factories.

Some of the research like the one carried out by Reuter (2016) pointed out a general Industry 4.0 framework for a specific company. Along this line, Intel published a report about IOT in new industry age (Intel IOT Report 2016). This report also introduced new intel projects within the framework of Industry 4.0. Song and Niu (2017) prepared some strategic plans aiming to support great chances for the recovery of coal industry. Chi et al. (2011) studied machine communications and Human to human characteristics. They used simulation for optimize service performance. Tsai et al. (2016) investigated two different big data problems for Industry 4.0, distributed procedure based on the data parallelism and MapReduce based procedure under the cloud computing platform. Theorin et al. (2016) investigated future manufacturing systems and a so-called Line Information System Architecture (LISA) highlighting specific framework of Industry 4.0. Shafiq et al. (2015) enhanced manufacturing systems with predicting capabilities, facilitating decision-making in engineering processes knowledge handling. Shah (2016), Sun et al. (2015), Shrouf and Miragliotta (2015), Song et al. (2017) studied internet of things technology for applications and production performance. Spath et al. (2013) and Sundmaeker et al. (2010) studied Iot and challenges in terms of architecture, connectivity, efficiency, security and provision of services among many others. Vachon and Klassen (2008) and Vandaie (2008) studied ERP performance, role of organizational knowledge, manufacturing performance in Industry 4.0 revolution.

Some of the researcher pointed out the importance of intelligent systems in designing Industry 4.0 systems. Lee and Lapira (2014) showed new methods for Industry 4.0. They emphasized the use of artificial intelligence for management systems along this line. Yusof et al. (2013) and Tavana et al. (2013) analyzed business intelligence of systems for generating better smart factories. Wang et al. (2015b) presented their simulation results to assess the effectiveness of the proposed negotiation mechanism and deadlock prevention strategies. They implemented multi agent systems for feedback generation. They observed performance of some parameters significantly effecting the performance of the system. Similarly,

- Fallera and Feldmüllera (2015) proposed a learning factory model for SMEs.
- Jeng et al. (2016) designed fabrication of a temperature diagnosis system for intelligent rotation.
- Ramezani and Jassbi (2017) used a Hybrid Expert Decision Support System (EDSS) model, Neural Network (NN) Expert System (ES) for detecting unnatural processes and to estimate the corresponding parameters. They implemented their model in Plaster producing company.
- Jiao et al. (2015) studied group decision making and heuristic-nonlinear-aggregation for generating well performing decision making system.

Not only the industry paid attention to Industry 4.0, there has been some studies outlining the national initiatives. Although there have been similar activities all around the world, some of them are particularly devoted to the concept of Industry 4.0. For example,

- Zhang (2016) introduced Industry 4.0 projects carried out in China.
- Turkish Industry and Business Association, published an introductory report on Industry 4.0 and provided a road map for Turkish industry (TUSIAD 2016).
- German Ministry of Education (2016) prepared a report for Industry 4.0 recommendations. They showed new technologies for future schools.
- Bently (2016) prepared a report for Oracle Company. This report includes UK Manufacturer Industry 4.0 readiness report. Internet of Things for UK education system is also elaborated as given in UK Government Office (2016).

Industry 4.0 is not only discussed and reviewed within the scope of manufacturing. There has been some research out of this scope as well. For example, Lom et al. (2016) proposed the conjunction of the Smart City Initiative and the concept of Industry 4.0 in this respect. Rennunga et al. (2016) generated a framework for service industry and examined the relevance of services for the future project. Pfohl and Yahsi (2016) investigated the relationship between Supply Chain Management (SCM) and Industry 4.0. They also tried to conceptualize new concept of SCM 4.0.

This review would not be complete if the studies on Industry 4.0 and respective education systems are not mentioned. Baygin et al. (2016) highlighted the importance of Industry 4.0 components for education and proposed a methodology for getting benefit along this line. Similarly,

- Richert et al. (2016) prepared empirical studies for new education systems and technologies.
- Miškuf and Zolotová (2016) used deep learning for designing new education system.
- Giasiranis and Sofos (2016) prepared a road map for educational transformation. Their education plan included imbedding new technologies in the scope of the curriculum.
- UK Government Office (2016) described Internet of Things (IoT) systems for education system. They intended to highlight the impact of Industry 4.0 on education and showed the utilization of especially IoT in designing the education systems.

As some of those listed above, there is a huge amount of studies going on all around the world about Industry 4.0 and related topics. The literature mentioned above is considered to be enough for outlining the respective studies of Industry 4.0. However, the review of the studies carried out on specific component of Industry 4.0 as well. Some of those are mentioned below.

A set of goals to achieve Industry 4.0

Although there have been some studies for generating a clear road map for those industries wishing to implement digital transformation, some hint and directions are provided by the literature. For example, Drath and Horch (2014) described a basis for achieving the Industry 4.0 by outlining eight planning goals. They are;

- *Standardization of systems and creation of a reference architecture* Many standards have to be developed so that a network between different factories and companies can be interconnected and integrated (Dudek et al. 2015).
- *Performing efficient management* The future plants will have larger and complex systems that need to be managed efficiently. Appropriate plans should be made and an explanatory model should be developed to optimize management (Oesterreich and Teuteberg 2016).
- *Establishing a comprehensive and reliable industrial broadband infrastructure* Industry 4.0 imposes stringent criteria in communication networks for the sake of being reliable, comprehensive, and high-quality (Hermann et al. 2016).
- *Setting a safe and secure environment out* Care should be taken to ensure that the production facilities and the products themselves do not pose a threat to humans and the environment and should prevent unauthorized access or misuse of the products (Intel IOT Report 2016).
- *Organizing and designing the work* Industry 4.0 is all about making more demands on production management to achieve content, processes and environmental changes, humanitarian, automation, green production and management (Ivanov et al. 2015).
- *Personnel training* Businesses have an obligation to educate their employees. Lifelong learning and ongoing

professional development programs are needed to help workers cope with new demands of work as well as baseline skills (Kagermann 2014).

- *Creating an organizational framework* The new innovations bring new challenges such as organizational data, responsibility, personal data and trade restrictions. There are requirements for standards, model contracts, agreements, supervision and other appropriate control measures (Kagermann et al. 2011).
- *Increasing the efficiency of resource utilization* The use of new materials, new processes, new technologies, and other measures may improve resource utilization efficiency while reducing and balancing resource use caused by environmental pollution and imbalance (Kagermann et al. 2013).

Additionally,

- *Self-behavior* Industry 4.0 should aim to generate self-behaving systems where minimum human interaction is possible (Oztemel and Tekez 2009a).
- *Product and Process interaction* Equipping the products and machines and enriching them with autonomy behavior generate a well operating product and process interaction.
- *Big data analysis* Having the capability to handle big amount of data and performing well defined analysis to be able to run the overall system aligned with the manufacturing goals.
- *Adaptability and flexibility* Performing analysis on big data enrich the systems interoperability as well as responsiveness to the changes.

Industry 4.0 components with respective literature

The flowing chapters of the paper is providing the information on the basic components of Industry 4.0 together with the respective literature. First, a basic introduction of Industry 4.0 is provided and respective studies are highlighted.

Cyber physical systems (CPS)

Cyber Physical Systems (CPS) is the integration of computing and physical processes which are essential components of Industry 4.0 implementations. They integrate imaging and control functionalities into the relevant systems. The important feature of these systems is to respond any feedback generated. They allow instantly control and check of process feedbacks for the sake of generating expected outputs. Bergera et al. (2016) introduced general definition of cyber-physical sensor systems. Special types of embedded systems, based on powerful software systems, enable the integration in digital networks and create completely new system functionalities as part of the cyberspace. This implies that cyber-physical systems enable completely new system functions and applications such as condition-based maintenance.

Generally speaking, a typical CPS may perform the following functions in manufacturing.

- Process monitoring.
- Being applicable in different domain contributing to generate a large scale system.
- Integrating different disciplines in different domains.
- Handling an effective dependability.
- Substantial user interaction.
- Alive performance monitoring.
- Real time configuration, deployment and decommissioning.
- Self-behaving and decision making.
- Distributed an interconnected communication.

The development of a CPS is characterized by three phases. First-generation CPS includes identification technologies such as RFID tags that allow unique identification. Storage and analysis should be provided as a central service. Second-generation CPS is equipped with some sensors and actuators with a limited number of functions. In the third generation CPS, in addition to setting up the equipment the data is stored and analyzed. The CPS is equipped with multiple sensors and actuators and is designed to be network compatible (Bauernhansl 2014). CPSs have some functionalities such as easier access to information, preventive maintenance, predefined decision making and optimization routines. It is reported that, a CPS may effect consumption awareness and increase consciousness. Laboratories can be remotely used. Increased dissemination and social financing for innovation is to be enriched with those (Jianjuna et al. 2016). On the other hand, the CPS have some security problems in such a way that the increasing utilization will clearly provide increasing risks. It was highlighted that CPS equipment also brings disruptive societal changes due to intelligent assistive pr autonomous surrounding may create mental diseases. This may create some prejudice for adopting new technology and may limit the acceptance and usage Mucci et al. (2016). Persson and Håkansson (2015) prepared a communication protocol for cyber-physical systems for wireless technologies and cloud system information exchange between objects.

Cyber Physical Systems consist of two important elements;

- A network of objects and systems communicating with each other over the internet with a designated address and,
- A virtual environment that is created by computer simulation of objects and behaviors in the real world.

With these, Cyber-Physical Systems promises to mean the creation of solutions that we could not even imagine today, the improvement of resource utilization, and the improvement of productivity.

There has been numerous studies on generating and utilizing CPS mostly within the framework of Industry 4.0. Mikusz (2014) presented an interesting study on conceptualization of the industrial software-product-service and theoretical considerations on the concept of industrial product-service systems and substantiated by suggested future research directions. Mucci et al. (2016) concerned on the adaptation of CPS in terms of their performance, flexibility, and reliability. They also provided a systematic literature review by searching four major scientific data bases, resulting in 1103 candidate studies and eventually retaining 42 primary studies including for data collection. The review process is carried out by looking at the various aspects of the focus of the studies appeared on the relevant publications.

Bagheri et al. (2015) used an adaptive clustering method as an advanced analytical method for interconnected systems in Industry 4.0 production concept. Angeles (2005) used RFID (Radio-frequency identification) technology for supply chain management. They studied RFID effect in Industry 4.0. Baheti and Gill (2011) used CPS for controlling systems. This study is important for Industry 4.0 control approach. Erol et al. (2016) and Foehr et al. (2017) presented a methodology for Cyber-Physical Automation System and all components Architecture for Industry 4.0 concept. Some of the research presented results for Industry 4.0 components and supply chain management and performance in Industry 4.0 (see for example, Foerstl et al. 2015; Gunasekaran and Kobu 2007; Lim et al. 2017; Linton et al. 2007; Machowiak 2012; Madani and Rasti-Barzoki 2017; Ou et al. 2010; Pagell and Shevchenko 2014; Pokharel and Mutha 2009; Song et al. 2017; Prajogo et al. 2012, 2015; Riel and Flatscher 2017; Sedera and Gable 2010; Shaikh et al. 2017; Testa and Iraldo 2010; Viswanadham 2002; Vlacheas et al. 2013). Gaikwad et al. (2015) used survey method for understanding IoT and CPS effects. Gelbmann and Hammerl (2015) suggested innovative business models for devising sustainable product-service. Gorecky et al. (2014) studied machine interactions and Industry 4.0 era. Kim et al. (2013) used parallel scheduling for CPS system and analyzed a self-driving car and used cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Hassanalieragh et al. (2015) used CPS and Iot for health systems monitoring process (Ângelo et al. 2017). A comprehensive review of existing literature about compounding of medicines is provided and six digital services identified: Supply management, Product traceability, Quality management, Order management, Digital assistant, and Product experience.

Some research concentrated on philosophical understanding and meaning of CPS and describing various the features of CPS (see for example, Hartunga et al. 2015). In another study, Industry 4.0 and cyber-physical production systems on the technology side are determined, and several approaches for learning factories are proposed by Seitza and Nyhuis (2015). Greenyera et al. (2016) presented an approach for the distributed execution of such specifications (embedded control systems: development steps, specification languages, and analysis tools) based on naive and inefficient broadcasting.

Setting CPS equipment is an important issue in designing Industry 4.0 environments. Zhang et al. (2010b) used RFID in real time manufacturing information for tracking infrastructure (RTMITI) to address the real-time communication of manufacturing data. They also used RFID for work in process inventory and cost reduction. They provided a case study when developing the proposed framework and explain corresponding methodologies. Using heterogonous physical devices for communication, computation, sensing, and actuating manufacturing equipment is examined and some recommendations are generated (Klimeš 2014). A priority-assignment policy that lowers the system operation cost in terms of efficiency of CPSs are proposed (Lee and Shin 2017). Kolberg et al. (2016) showed a framework named cyprof for designing the CPS. This framework aimed to reduce engineering efforts for CPS projects. Smirnova et al. (2015) managed to interlink the appropriate smart room devices which are able to interact in cyber space while physical devices interacting in physical space. Herterich et al. (2015) connected equipment paves and provided an additional opportunity for the service business among the lifecycle and pivots of traditional maintenance, repair and overhaul (MRO) services.

Most of the time, simulation technology is utilized in setting up Industry 4.0 with respect to employing CPSs. To mention some of those studies, Sacala and Moisescu (2015) facilitated the integration of real world simulation with virtual environment simulation. Core data requirements and the "network of networks" that serves as the underlying simulation structure for utilizing the CPS are described by Perkinsa and Mullera (2015). Wua et al. (2015) compared simulation results against historical performance data for cyber-physical systems, building information modeling, wireless sensor networks. They explained working mechanism and implementation's feasibility of this concepts. Canedoa and Richterb (2014) designed a space exploration model using multi-disciplinary simulations capable of performing detailed multi-domain design space exploration of realistic automotive architectures. Galaske and Anderl (2016) prepared a simulation for each disruption event and finding the best possible strategy for decision making on production process. Matena et al. (2016) performed a set of simulation of the robot communication systems utilizing CPS and described robot communication via dynamic collaboration group. They showed that their simulation enabled fast prototyping and easily implemented autonomous components.

Generating a framework and architecture definition took the attention in research community. For example, Lee et al. (2015a) discussed a systematic architecture for applying CPS in a manufacturing system called 5C (Configure, Cogniton, Cyber, Conversion, Connection). Similarly, Alam and Saddik (2015) described the key properties of the CPS and prepared composition of fuzzy rule base with the Bayes network that further enables the system with reconfiguration capability.

CPSs should deal with big data and make decisions without delaying respective manufacturing processes. Being aware of this, Spezzano and Vinci (2015) proposed to use a density-based data stream clustering algorithm, built on the flocking model, for the monitoring of big data. With the similar idea in mind, Rago (2015) prepared a model so called "Hierarchical Formal Concept Analysis" (HFCA) for data analysis and use of contextual objects and attributes structured in specific contexts in utilizing CPSs. Schuh et al. (2014a) showed the utilization of data interpretation algorithms and an electronic tool book for data storage and management. Petnga and Austin (2013) showed mostly appropriate CPS for safety and performance dependent applications. This can support the idea of generating correct responses to feedback and machine based queries.

When setting up CPSs, information security is considered to be another area of research. The behavior of a septic a middleware technology and its cost for handling the interaction of distributed nodes are analyzed by Vallsa et al. (2017). This study is important in order to set up a secure information and data exchange in manufacturing suits. Similarly Ning and Liu (2012) concentrated on migrating to a secure CPS. They explained that the migration maintenance strategy makes migration load tradeoff and components to be migrated and replaced within the deadline time.

Gawanda and Roya (2015) used a geometric method to detect anomaly in a control system behavior. They introduced a methodology to prevent cyber-attacks to some extent. With this context, Dagli (2016) took the attention to the security of the systems and defined a model which is based on how the current challenges related to cyber security. Similarly, Wardell et al. (2016) presented a method that reveals cyber security vulnerabilities in Identification Code Service (ICS) through the formal modeling. Friedberg et al. (2016) showed the dependencies between cyber security vulnerabilities and system safety. They investigated systems theoretic process analysis (STPA) and defended the benefits of their approach. Vincent et al. (2015) researched cyber-attacks and prepared a process design for real-time attack detections in quality control systems. This cyber-attack detection is also important for Industry 4.0 systems. Jones et al. (2016) used the term Information Environment (IE) and The U.S. Department of Defense (DoD) for the information environment is the aggregate of systems aiming to assure the secure communication.

When discussing the CPSs, it should be necessary to consider their effect on robotics systems and robot suits in manufacturing. Along this line, Michniewicza and Reinharta (2016) defined a robot cell during the design phase of the product with a CAD program. Their set up are based on utilizing CPSs for better communication and information exchange between robots.

Generating intelligent and smart equipment for self-behaving manufacturing systems was also elaborated in the literature. Although generating intelligent behavior such as the one provide by Cheng-Yu et al. (2010) was at the top agenda item of the research community, recently CPSs become at the heart of those studies. For example, Jatzkowskia and Kleinjohanna (2016) proposed a robot cell with real time self-reconfiguration capability fostering effective communication within Cyber-Physical Systems. By looking from a bigger picture point of view, Monostori (2014) underlined that there are significant roots in CPS. He presented some important concepts such as intelligent manufacturing systems (IMS), Biological manufacturing systems (BMS), Reconfigurable manufacturing systems (RMS), Digital factories (DF), Production network and Holonic manufacturing systems (HMS). Note that these paradigms are important for assuring the performance of CPS through implementation. Grzenda et al. (2012) used imputation algorithm which is based on a genetic algorithm and aims to improve prediction accuracy. A bag of multilayer perceptions is also used to model the impact of deep drilling settings on borehole roughness. Lei et al. (2013) defined of how cyber-physical systems can be used to automatically provide suitable services in a smart learning environment.

Like those mentioned above, some papers were dealing with product design. Jeang (2015a) generated a product design model which allows the designer to perform capability analysis. Brandmeier et al. (2016) provided a model product design process through implementing cyber-physical systems within production facilities.

CPSs are also studied in terms of generating efficient and effective specific functionalities. For example, the application of new technologies in computing and communication in the cyber-physical systems of traffic control is elaborated (Jianjuna et al. 2016) discussed. Haquea and Aziz (2013) proposed a false alarm detection architecture in designing CPS for healthcare applications. Jäckel et al. (2016) introduced a set of parameters as well as the influence of varying boundary conditions on joining the result for self-pierce riveting using CPSs. Schuhmacher and Hummel (2016) generated an arising complexity to plan, control and monitor changeable work and logistic systems. They recommended decentralized control by utilizing CPSs. Similar to other components of Industry 4.0, some research is devoted to human resource requirements. For example, Dworschak and Zaiser (2014) found links between technology forecasting and early identification of skill needs in developing CPS. Some of the other studies worth to mention can be listed below.

- Müller (2016) prepared a reference model for clustering information and its methodology is implemented by tools of the digital factory which relate to modules of CPS.
- Beckera and Sterna (2016) provided a list of current and future tasks that can be carried out by CPSs instead of human being.
- The resolution of wireless sensor navigation is also studied and it was shown that it is possible to set up a wireless sensor navigation of less than 0.67 m for smart factory (Wan et al. 2011).
- Zhang and Jiao (2009) used demonstrated how these net definitions (colored Petri nets, object-oriented Petri nets, changeable Petri net structures, and net nesting) are applied to the specification of production process variants at different levels.

Last but not least, assessment of CPS implementation was also on the agenda of the research. Nguyen et al. (2017) provided an assessment model of the state of the art in model based security engineering for designing CPS. Along this line, Du et al. (2015) also performed an assessment study, using Lagrange multipliers and gradient method for respective evaluation. These studies clearly indicate that it is possible to establish manufacturing environments based on well suited CPS equipment. Ermilova and Afsarmanesh (2007) studied and prepared a model for software that supports variety of VBE (Visual Basic add-in model) functionality. They claimed that the models will make it easy to design an adaptable, replicable and sustainable Profile and Competency Management System (PCMS). This study provides information which could be important for virtual organization and profile modeling.

Cloud systems

The term "cloud" is used for applications such as remote services, color management and performance benchmarking applications. It has taken the remarkable attention of information technology community and its role in other business areas will continue to grow. Along with the continuous technological improvements, the machinery, data management and functionality will continue to shift from traditional approaches to cloud-based solutions. The cloud allows the delivery of much faster than standalone systems, quick updates, up to date performance models and other delivery options. The industry has seen a major change in using cloud solutions and this will continue to grow and pose a high challenge to other means of data storing. Cloud technology is the simplest online storage service that provides operational convenience with web-based applications that do not require any installation (Nuñez et al. 2017). Note that, the system of storing all applications, programs and data in a virtual server is called cloud computing. It facilitates operation by ensuring that customers and employees reach the same data at the same time. Cloud Systems reduces costs, eliminates infrastructure complexity, extends work area, protects data, and provides access to information at any time. There are four types of system mainly (Li et al. 2017).;

- Public Cloud.
- Private Cloud.
- Hybrid Cloud (combination of public and private cloud) and,
- Community Cloud (this refers to the co-operation of any service on the cloud with a few companies).

The cloud systems are good source of solution to handle the Big Data (large data). Note that the big data can be structured or unstructured. Since traditional computers may not be capable of handling big data, it would be much easier and more efficient to perform the respective analysis with the cloud system. Data analysis and cloud system should therefore be unavoidable components within Industry 4.0. The integration of cloud-connected robots into real life and respective effect is quite extensive. For example, high efficiency of small companies will use cloud-connected robots in manufacturing plants. The production speed and quality will increase not only the big companies but also the small companies will benefit from the passage to the 4th Industrial Revolution. Taking the above explanations into account, there has been some research along with utilizing cloud systems in Industry 4.0 environments. Some of them are reviewed below. There have been some studies along this line. For example, Bellini et al. (2017) generated a Cloud Project in the cloud facility of a national cloud service provider within the scope of data in Industry 4.0. They proposed a knowledge processing engine capable of running on cloud and handling big data. The system they suggest can generate knowledge out of data and process that for the sake of generating better manufacturing environment which also complies with industry 4.0 standards. Sharma et al. (2016) prepared a taxonomy and literature review for cloud systems. Chen (2018) studied an intelligent cloud system to support manufacturing activities. The methodology provided can be used to facilitate industry 4.0 implementations.

Since, the cloud system is an indispensable component for the new industry era, any work on this subject directly contributes to the structure of the Industry 4.0. This topic is considered to be important especially when data management and analysis is the main focus of operational systems. An example of such a system is elaborated in Kba (2015). This can be handled more effectively under cloud implementations. That is, therefore, one of the main reason for the cloud systems to attract the researcher of Industry 4.0. Chang et al. (2016) analyzed big data on the cloud for sustaining better access and they studied data infrastructure of cloud systems for assuring perform effective data manipulation. The methodology proposed is also beneficial in designing data analysis and interpretation systems of Industry 4.0 implementations. Some researcher such as Higashinoa et al. (2017) investigated Complex Event Processing (CEP) and Stream Processing (SP) and Big Data velocity dimension and presented a simulator for this systems in cloud technology, Badawi et al. (2017) developed a model for utilizing collected data for positive effect of the participants' physical activity level. They suggest that cloud system need big data management methodologies and all components of Industry 4.0 should be compatible with those described. Ding et al. (2017b) proposed as an attractive platform for increasingly diverse applications running on clouds. Li et al. (2017) showed preprocessing step in the future to monitor land-cover change. Their model is capable of operating on cloud and detecting cloud shadows in multi-feature combined imagery.

Some research on cloud systems concentrated on cloud structures and design related issues as well as efficiency and effectiveness of utilization. Jararweha et al. (2017) introduced a so called Software Defined Cloud (SDCloud) system which is a novel cloud management framework that integrates different software-related cloud components to handle complexities of implementations. Carniani et al. (2016) presented an advanced authorization service based on a Usage Control model in order to allow and monitor the software access in cloud environments. Similarly, Chen and Chiu (2017) presented a simulation model in their cloud project for simulating a mobile factory.

On the other hand, Smara et al. (2017) developed a Fail-Silent Cloud module which have the ability of Self-Fault detection in operating the cloud systems. Amatoa and Moscato (2017) showed orchestrations action, along all the "aaS" layers of Cloud Architecture. This makes it easy to integrate other components to cloud based systems. Forti and Munteanub (2017) developed a cloud incident management, a 'continuous approach' for setting and executing reliable cloud native applications. Nuñez et al. (2017) recommended elicited accountability metrics for relevant empirical validation of cloud systems. They emphasized that Cloud technology is the simplest online storage service that provides operational convenience with web-based applications. Tao and Gao (2017) developed a system known as MTaaS aiming to provide an infrastructure-as-a-service (IaaS). Anitha and Mukherjee (2017) implemented the monitoring model (MaaS) in a cloud environment and justifed the performance of their approach by experimental results together with methods.

Furthermore, some studies on cloud systems took the attention of the researcher on data security which is an essential requirement in sustaining Industry 4.0. Some examples of the studies along this line can be given as the following. Singh and Chatterjee (2017) developed a system capable of determining trustworthiness of Cloud Service Providers. This is an interesting study as it provides some information regarding the robustness and security of information on cloud. Stergiou et al. (2018) presented and reviewed new security techniques in cloud databases providing hints and clear roadmaps for the developers. Sotiriadis and Bessis (2017) developed an inter-cloud bridge system for evaluating the performance of inter-cloud services separately and as a whole. Wang et al. (2017a, b) studied the possible trends of using fuzzy sets in big data processing, problems of big data and fuzzy sets and their integrations with other tools.

The hardware required to run cloud systems and related issues are also subject to the research. Kozhirbayev and Sinnott (2017) utilized servers in efficient and scalable ways through the exploitation of virtualization techniques. Zhang et al. (2017) prepared a virtualisation access model running on cloud that provides the real-time, accurate, value-added and useful manufacturing information for optimal configuration and scheduling of large-scale manufacturing. Saikrishna and Pasumarthy (2016) managed to measure performance of a web server running in cloud, and presented focuses on the use of virtual resources as a management concept. Similarly, Yang et al. (2017) built a web page to allow the users to easily access and control the cloud virtualization and compared a range of existing container-based technologies for the Cloud. On the other hand, Michona et al. (2017) studied simulation process and its accurate predictions making this feature a helpful means for user. Picciali et al. (2017) compared several design alternatives for mapping information on social media. The system collected and analyzed in real-time the tweets issued in an entire region. Yaseen et al. (2017) presented a methodology so that the CPU (computer performance) is minimized to achieve high performance in running the cloud systems. Junghanns et al. (2016) studied an architecture based on a novel secure cloud gateway that allows client systems to store sensitive data. And investigated the code quality and the respective performance. Ojha et al. (2017) developed a model for energy optimization and introduced the respective framework and duty scheduling mechanisms in order to conserve energy in the sensor-cloud framework. Deng et al. (2015) used value model for cloud service and reflected the value between different participants in cloud systems. This study reflects the value linkages among different participants. Huang et al. (2017) proposed a methodology relationship of modular architecture for disassembling components over the cloud for the sake of generating environmental friendly products.

Some researchers take the attention of science community to Mobil systems integrated with cloud. For example; Oesterreich and Teuteberg (2016) proposed an interesting approach for the cost- and capacity heterogeneity of a Mobile Cloud Network infrastructure. Nawrocki and Reszelewski (2017) took the attention on mobile cloud and recommended a Mobile Cloud Computing environment which is said to be a good way of constraining resource demands. They recommended that applying common Cloud Computing patterns to Mobile Cloud Computing environment is good enough for constraining the resource demands in Industry 4.0. Risso et al. (2016) presented a cloud-based mobile system to support and improve homecare for respiratory diseases. Abdoa and Demerjianb (2017) investigated mobile cloud architectures and compare their performance against existing resource demanding applications. Yang et al. (2017) presented a movie recommendation system according to the scores provided the users. They used virtual machine and different algorithms for assessing the IOT performance. Mobile-Edge Computing (MEC) technology is used in the public cloud which guarantees the high efficiency requirements of the transmission of the multimedia.

Naturally, performance of cloud systems was and still is on the agenda of heavy research within the last decade. This issue is also traced for assuring the systems running on Industry 4.0 standards. Ding et al. (2017a) proposed an Industry 4.0 cloud system and they managed to improve the performance of their corresponding objectives. They showed that the cloud system is needed for inter-machine communication, productivity, data estimation as well as system performance. Bui et al. (2013) showed significant result in reducing the energy consumption as well as maintaining the system performance. This study indicated that a consumer can provision computing capabilities automatically without requiring human interaction with each service provider. Zhou et al. (2017) used Zero-configuration (Zeroconf) networking standard. This standard provides a preference model to quantitatively weight the storage performance imbalance when data are distributed on different devices, and then distributes data on storage. Yao et al. (2016) prepared algorithms under different situations. These algorithms are used to highlight the better performance of the proposed approach.

In addition to those mentioned above, Singh and Chatterjee (2017) provided on demand services over the Internet with the help of a large amount of virtual storage. Kirthica and Sridhar (2016) studied the international cloud systems performance. They concluded that high Transaction Success Rate can be achieved while keeping the Turnaround Time as low as possible. They pointed out that this technology will be the baseline for performing better data acquisition, remote monitoring, personnel management, information on safety production and similar ones. Wang et al. (2017a, b) searched System on a Programmable Chip based cloud computing platform. They showed that platform can make increasing of energy efficiency. Rihab et al. (2016) presented a survey focusing on the areas; remote brain, big data manipulation, virtualization. They also focused cloud robot performance. Their conclusion is remote brain, big data and virtualization are important for cloud systems. Chen and Wu (2017) proposed a new approach for effective cycle-time bounding through utilising cloud technology.

Kagermann et al. (2013) found critical data are stored and a notification is send to the physician or caregivers. Industry 4.0 will solve some of challenges of today's world. Cloud-based telepresence portals will be important in near future. Balina et al. (2017) provided a solution to combine the parts of cloud based knowledge management systems with business process information systems. Duan (2017) presented solution to open issues and challenges of cloud systems. He surveyed evaluation approaches and identified possible opportunities for future research. Kim and Jo (2015) presented a methodology to deal with right combination of pricing options. They used new cloud systems algorithms for designing their understanding of Industry 4.0.

Machine to machine (M2M) communication

Machine to machine (M2M), refers to direct communication between devices using any channel, wired or wireless. Machine to machine communication can include industrial instrumentation, enabling a sensor or meter to communicate the data it records to application software that can use it (Biral et al. 2015). Such communication was accomplished by having a remote network of machines relay information back to a central hub for analysis, which would then be rerouted into a system like a personal computer. M2M is the technology that allows companies to establish especially, wireless communication between information centers and machines. For example, GSM connection helps sending SMS to mobile phones when thief enters a house. Making communication technologies, cable or wireless, easy to implement and as cheap as possible has opened up the innovations for the sake of easier life.

Regarding Industry 4.0, M2M is also considered to be an essential component. The research and development along this line is outlined by Ackermann (2013) as a maturity model as given in Fig. 8. As indicated the applications are shifted towards generating the value to the enterprises by introducing new revenue sources as opposed to reducing operational cost.

Ackermann (2013) clearly states that M2M implementations has enabling aspects with various networked businesses including;

- Remote Service as well as Asset Information Management providing the information federation and lifecycle support.
- Connected Vehicles where relations and interactions arises.
- Smart Vending which is retail and supply chain services as well as related sub elements.

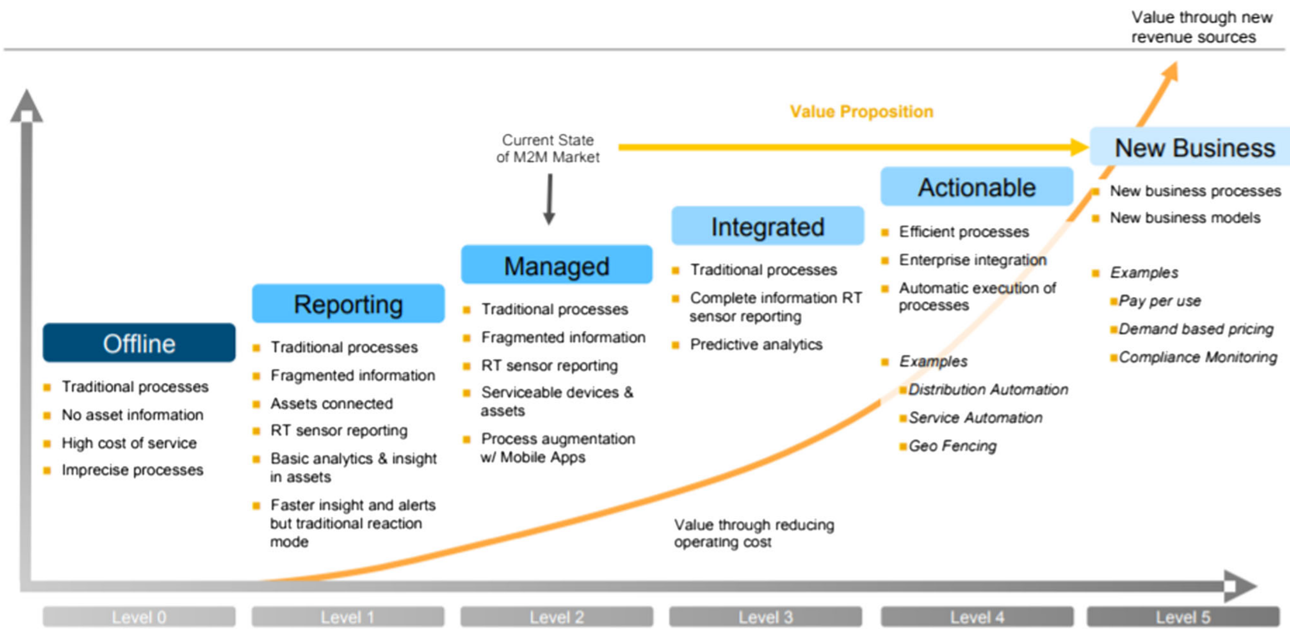

Fig. 8 M2M maturity model proposed by Ackermann (2013)

Besides, under Industry 4.0 environments, M2M technology is poised to reshape various aspects of manufacturing especially on operational efficiency, quality control, decision-making, relationships with customers, and transactional opportunities. Access to real-time, actionable required to establish more smart and agile organizations. This makes the managements to better administer the resources, protect enterprise specific assets, deploy intelligent e-business applications to widen the scope, and quickly respond to rapidly changing environmental requirements. With the right intelligence, delivered in real time and used appropriately, services can be offered and tailored to customers in the best way possible. M2M communication in a smart network allows easy monitoring of resources and provide better utilization. Operational costs can be reduced when paired with smart systems. When M2M is able to use data to automatically trigger and carry out decisions that serve the objectives of business, competitiveness can be positively sustained. There has been various research on M2M. Some of them are outlined below.

Biral et al. (2015) described the main challenges raised by the M2M vision, focusing on the problems related to the support of massive Machine-Type Devices in current cellular communication systems. Dener and Bostancıoğlu (2015) collaborated in performing complicated tasks along with exchanging information. They also studied life of sensor nodes. They clearly stated the way to develop smart environments, smart architecture, smart grid with wireless sensors. Meddeb et al. (2014) described its connection to the ETSI (European Telecommunications Standards Institute)-M2M platform and provided communication and service architecture without human intervention. Not surprisingly, nearly all of the research on M2M concentrated on communication aspects. Gharbic et al. (2014) described OM2M (an open source service platform for M2M) platform, which is an implementation of the ETSI M2M standard. Alayaa et al. (2014) enabled multiple communication protocols binding, reuse of existing remote devices management mechanisms, and interworking with existing legacy devices. Mawlawi et al. (2014) reduced drastically the RTS collision probability and the packet error rate in communication of M2M environments. Elmangousha et al. (2015) analyzed the effect of traffic size in M2M transactions and propose a concept to adapt gracefully to support heterogeneous traffic patterns. Chi et al. (2011) presented the scenarios when Machine to machine come into use. They also show that some technologies proved to be effective to (Human to Human), services.

Some of the research are particularly devoted to the integration of M2M and IoT. Ranjan and Hussain (2016) proposed a set of protocols and its associated mechanism for terminal authentication in M2M systems in the context of IoT. He et al. (2015) investigated possible ways of integration of M2M and IOT.

Similar to CPSs, some researchers take the attention of the community to M2M applications with intelligent or smart features. Thompsona and Kadiyalab (2016) adopt M2M technologies directly, retrofit existing assets, integrate multiple technologies with an M2M smart system. They studied smart systems and sensor combinations. Along with this line there has been some studies in generating machine language for assuring machine to machine communication, especially on knowledge transfer. Oztemel and Tekez (2009b) developed so called knowledge protocols for the robots and software agents to transfer knowledge from one to another. More detailed information regarding knowledge protocols is provided in Oztemel and Tekez (2009c). Similarly, Finin et al. (1995) presented an agent communication language called KQML. This can still be actively used for generating knowledge exchange capabilities between the machines. Some other machine languages such as FIBA, KIF, ACL are also introduced. Lakhmi and Nguyen (2009) provided review and detailed information about these communication frameworks in their book titled as "Knowledge Processing and Decision Making in Agent-Based Systems".

Smart factories

Smart manufacturing is a category of manufacturing aiming to optimize concept generation, production, and product transactions from traditional approaches to digitized and autonom systems. When manufacturing can be defined as the multi-phased process of creating a product out of raw materials, smart manufacturing is the subset that employs computer control and high levels of adaptability in achieving this. It aims to take advantage of advanced information and manufacturing technologies in order to enable flexibility in physical processes to operate in a highly dynamic and global market. At a Smart Factory, the goal is to produce fully flexible production at the highest speed requiring a comprehensive transformation from traditional methods to advanced technologies. Although there will be a change to the machine suits, the main purpose of the research community is to make this transformation according to the "Plug and Play" principle. Plug and Play usually refers to computer peripheral devices, such as keyboards and mice, it can also be used to describe internal hardware. The practical extension of plug-and-play products, when applied to industrial automation, has given way to the new term so called "plug-and-produce".

Smart factories are also known as "dark factories", "lights out factories" or "unmanned factories". These concepts provide little differences as outlined below. Every machine in the production can be broken down into new elements in seconds. A smart factory proposes a system integrated with little intervention of human being. The human is entering into these systems mainly in the problem-solving phases. The concept known as dark (Lights out) or unmanned factories today is an automation and autonomy enriched methodologies as well as equipment used in factories that actively perform the production. The most prominent feature of dark factories is that they do need no human power. In the dark factories, there is not enough time to enter the plant from the raw material to the exit from the factory. That is to say that in these factories, production is carried out entirely with robotic systems.

By referring to smart factories as outlined above, it is obvious that they will have the features required by the 4th Industrial Revolution and respective processes. And these processes, which are of great importance to our future of production, will always have a sensitive place throughout the whole manufacturing cycle. Germany is trying to generate its own cyber-physical systems and leading the 4th Industrial Revolution.

Smart factories are also related to some interesting software methodologies such as virtual reality, augmented reality, simulations and virtual prototyping. These technologies make the users to be able to see and learn about the future of the products in synthetic world before they are produced and presented to the market. Along this line, Siemens launched an Industry 4.0 initiative starting with setting the stage for digitalization in production life cycle. It is reported that, under this initiative, the virtual prototypes will be produced in smart factories. The products will be tested virtually at the same time with the production runs and the design features as well as some functionalities will be determined through purpose based simulation runs (Klaus 2016).

Smart factories, naturally, have some common features as depicted by Remon (2017) and as illustrated in Fig. 9. As shown, there are four basic areas which seems to be exposed to transformation and integrated with each other. They are worker conditions, industrial process, environment emissions and product storage conditions. Cloud and RFID systems will be of great importance to this flow. In smart factories components will be in great interaction and communication over the internet system.

Similarly, there have been various studies focusing the attention on smart factories. The following part of this section provides a review of those.

While some of the researcher such as Puttonen et al. (2016) spend some effort to define methodologies to facilitate web service composition in factory automation, Kusiak (2017a) presented an extensive review of smart manufacturing. He particularly highlighted roots and pillars of this technology. He provided six pillars of manufacturing which is considered to be important in setting up smart facilities such as;

Manufacturing technology and processes

- Materials.
- Data.
- Predictive engineering.
- Sustainability.
- Research sharing and networking.

He particularly takes the attention on new emerging Technologies such as additive manufacturing, hybrid processes, laser and net-shape manufacturing. Smart materials and products are also taken to the center of his analysis. He also considers predictive models and related work as being one of the core activities in generating smart environments. He also clearly stated that different forms and modes of transportation will also be used to support the supply and distribution chains

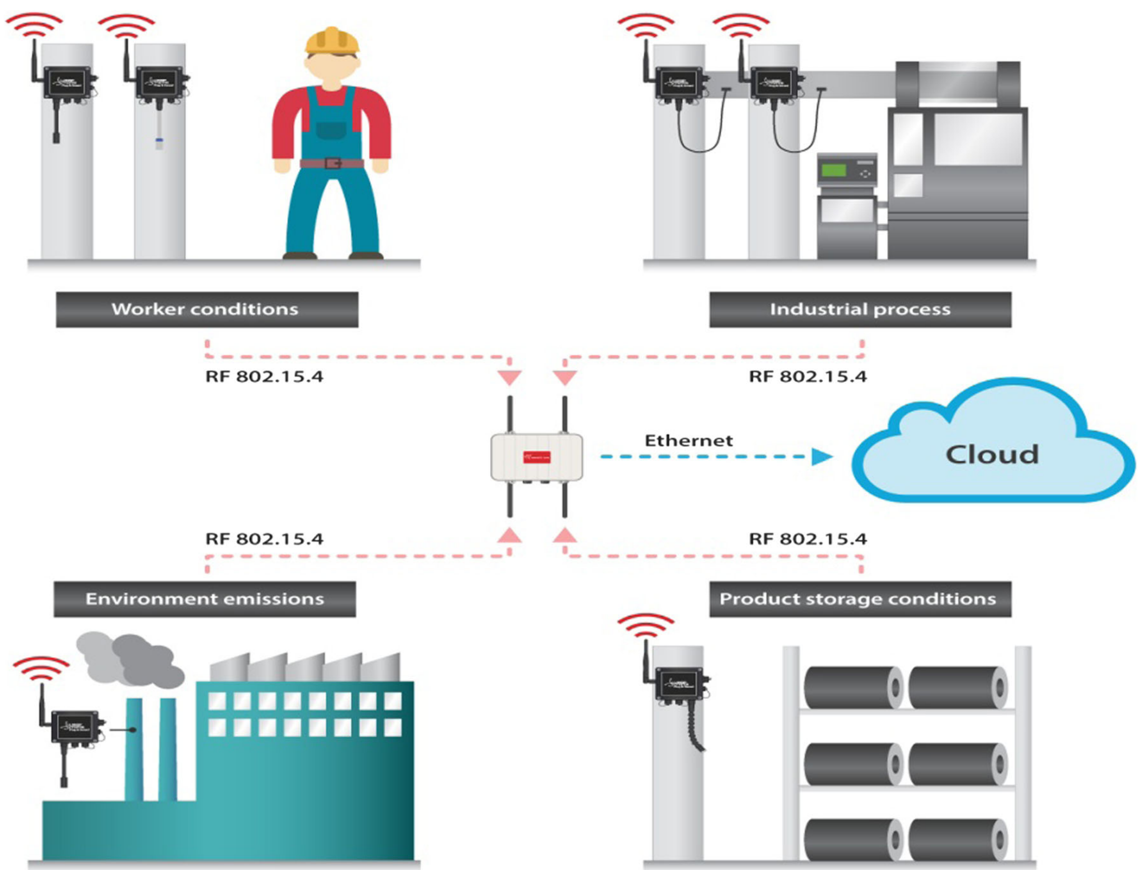

Fig. 9 Smart factory diagram. Reproduced with permission from Remon (2017)

of manufacturing. He thinks that a shared mode of transportation is likely to be applied to move experts servicing the manufacturing systems, as well as materials, parts and products. The paper also provides valuable information for future manufacturing systems with a particular note on how to transform towards more smarter manufacturing environments.

Similarly, Scheer (2013), Scheuermann et al. (2015) prepared a literature review for new Technologies. The developed Agile Factory prototype transfers agile software engineering techniques to the domain of manufacturing. It explores the impact and feasibility of customer changes during assembly-time using a commercially available software framework. Park (2016) proposed the success factors which are critical for the successful introduction of hyper-connected smart factory.

Smart Manufacturing Leadership Coalition (SMLC 2011) published a report a about smart factory systems. The report describes a framework for a proposed path forward for Smart Manufacturing in 10 priority areas as well as potential applications and benefits. The report also provides a set of metrics for possible assessments of smartness. Note that this report also provides hints about infrastructural needs. Jayanthi et al. (2009) showed significant differences among manufacturing practices and competitive capabilities of the four strategic groups mainly, manufacturing strategy, competitive, ecology and complexity titles are investigated. The main motivation behind this study is to provide some guidelines for the companies transforming towards being a smart one. Recently, Strozzi et al. (2017) prepared a comprehensive literature review about Smart Factory. They particularly studied the need of technology providers to focus in large-scale Smart Factories. Wang et al. (2016) proposed a framework for smart factory concept in Industry 4.0. They focused on negotiation mechanism for dynamic reconfiguration and strategy for deadlock prevention. Holm et al. (2016) provided a comprehensive overview of existing techniques of discussion of various localization techniques. Taking the attention on handling operator's activities. Rashid et al. (2012) investigated ERP-Smart factory concept and prepared road map for ERP framework.

Kurth and Syleyer (2016) presented a methodology for standardized automation for comprising single devices. They studied single devices, production lines and higher automation system and business models. Deja and Siemiaatkowski (2013) prepared a conceptual framework for generation of machining process plans for generating optimum part manufacturing. İqbal et al. (2015) proposed a rule-based system for trade-off among energy consumption, tool life, and productivity in machining process. This may help utilize the efficiency of intelligent manufacturing systems. Bryner (2012) introduced future estimates about smart factories. He pointed out that the future manufacturing systems will be interconnected with suppliers, distributors, customers, and business systems via information technology. He also took the attention of the reader to smart ecosystem implying that the smartness will be beyond automation and control of the systems.

Having a smart factory requires distributed an intelligent manufacturing suits. Murray (1999) analyzed intelligent systems for smart factories and scaled performance. He studied intelligent tutoring system characterization of the design and bottlenecks to having widespread use of tools applicable to manufacturing environments. This study clearly indicates artificial intelligence technologies are utilized from various points of viewed of manufacturing such as unmanned training in addition to planning, design, quality, control and scheduling etc. On the other hand, Feldmann (2011) took the attention on various systems running in a distributed environment, composing a manufacturing network. He contributed to the manufacturing strategy process area by investigating and suggesting a model for strategic decision on autonomy in manufacturing networks. Meziane et al. (2014) looked at the network of manufacturing functions in terms of embedding intelligence and increasing smartness. They presented a methodology to implement artificial intelligence techniques in developing smart factories. They provided an extensive review of manufacturing systems and artificial intelligence technologies especially very popular ones such as neural networks, fuzzy logic, genetic algorithms, expert systems, case based reasoning etc. together with relative manufacturing applications. They particularly took the attention of reader to smart or intelligent control, scheduling, design, process control quality as well as maintenance. Similarly, Munera et al. (2015) introduced a scalable and reusable hierarchy to perform factory plans based on distributed services.

In addition to some communication languages and knowledge protocols mentioned earlier, Wang et al. (2015a, b) proposed an intelligent negotiation mechanism for agents to cooperate with each other. Their simulation results showed the effectiveness of the proposed negotiation mechanism. They used a self-organized multi-agent system assisted with big data based feedback and coordination systems. Information exchange is facilitated through integrating ERP systems with manufacturing equipment through CPSs or M2M communication methods. Park (2010) investigated two factors for the success of a hyper-connected smart factory. These are the capability of vertical integration and the capability of integrating product life cycle. First factor helps realize the vertical integration of a production system (Sensor-MES-ERP) while second factor shows the optimization of tailored production through complete information exchange. Similarly, Shariatzadeh et al. (2016) investigated approaches and principles when integrating the digital factory, IT tools and IoT in manufacturing in a heterogeneous IT environment in order to ensure the data consistency. Lin et al. (2016a, b) studied 5G mobile broadband (5G), Internet of Things (IoT), Big Data Analytics (Big Data), Cloud Computing (Cloud) and Software Defined Networks (SDN), measured performance of 5G mobile broadband. This new technology is important for Industry 4.0.

While some of the study are devoted to information exchange and communication, some others focused on hardware and respective set up. Carstensen et al. (2016) presented a smart factory concept for autonomous mobile robots. They aimed to let the factory hub control a group of mobile robots using a self-organizing algorithm for different tasks. They used robots equipped with a measurement system and connected to factor monitoring and planning tools. Their intent was to contribute to the intelligent plant by improving the performance of robot systems.

On the other hand, some researchers took the attention on learning factories. For example, Prinz et al. (2016) presented a variety of learning modules for the smart factory in Industry 4.0. They also described the new job profile of the employees working under Industry 4.0. Brennera and Hummela (2016) used a business model called personalized product emergence process for the learning factory in Reutlingen University. Liu et al. (2017a, b) investigated IOT and Intelligent assembly system for smart factory concept. Their goal was important value for applying the key technologies. They studied a literature review, used featured mapping of resource objects and prepared Dynamic self-adaptive optimization model. Weiss et al. (2016) researched statistical learning models and manufacture of microprocessors. They found many complicating factors: (a) a temporally unstable population (b) missing data that is a result of sparsely sampled measurements and (c) relatively few available measurements. The main idead behind this study is to experiment continuous prediction of manufacturing performance throughout the production lifecycle.

When generating a smart factory, energy management is another crucial issue. This is elaborated and investigated in several studies. Maansman et al. (2014) showed minimizing energy costs while benefiting from the possibilities of local electric storage systems. They studied energy management and efficiency of Industry 4.0 concept in smart factory. Shrouf et al. (2014), they prepared a literature review on smart factories and investigated energy management systems of Industry 4.0. Lee et al. (2016) investigated energy management for Industry 4.0 in smart factory. They used monitoring for controlling the status of energy consumption.

As all other components of Industry 4.0, simulation based studies appeared for smart factories. This is quite normal due to difficulty and cost of implementation of real systems. Simulation also provide virtual control and observation of systems before actual production and physical set up. Park (2010) showed simulation concept of a scaled version of a factory operation with virtual distributed electricity meters. This simulation used Just in Time and Work in process methods for smart factor. This is an essential activity in generating smart companies. Moon et al. (2016) prepared manuscript a simulation model and used for sewing machine and recommended a better modeling tool for simulation of sewing processes. Xu et al. (2011) used visual diagnostic method for measuring assembly line performance. They studied smart factory performance in Industry 4.0 and found out that solution for many problems in the security management. Shamsuzzoha et al. (2016) studied business process monitoring within virtual factory environment. They investigated dashboard features state-of-the art business intelligence and provides data visualization.

Utilizing mobile technology within smart factories also attracted the researcher. Sangregorio et al. (2015) presented an approach to implement a remote maintenance system based on a mobile platform. They particularly recommended mobile platforms for smart factory management in Industry 4.0 and provided some highlights. Gao et al. (2014) investigated 5G communication and connectivity for mobile devices. They studied M2M-Smart factory and Industry 4.0 relations.

Furthermore, integrating various other components such as big data, CPS, cloud, IoT, M2M, RFID etc. to generate a smart factory running under Industry 4.0 principles were subject to the studies. It seems that research along this line will also continue. Kusiak (2017b) proposed a model for smart factory through utilizing big data. He implied that this model will be the baseline for the manufacturing of the new industrial age. MESA (2009) prepared a report for smart factory applications. The applications are grouped into several categories such as smart factory features, IOT applications, M2M operations and cloud systems security. Brioto et al. (2016) investigated Gross Domestic Product and Cyber Physical Systems in smart factories. They studied private cloud systems integration and performance applicable in Industry 4.0 environments. Kokuryo et al. (2016) studied production scheduling under IoT environment. They highlight RFID advantages' and IoT system's opportunities and recommends IoT and RFID using for smart factories. Hwang et al. (2016) prepared a performance measure system for internet of things and smart factory. They studied the effect of the IoT-workability. Corcio (2016) highlighted important points of manufacturing intelligence concluding that the cloud integration and M2M performance are considered to be important components. Unlikely to these mentioned above Intel prepared a road map for IOT systems in smart factory.

Domain based studies (fielded research) on smart factories should also mentioned in this review. Radziwon et al. (2014) aimed to show the usage of adjective smarting respect to technology and with a special emphasis on the smart factory and investigated smart factory opportunities especially for SMEs. Mayer et al. (2016) described use cases from the home automation and future manufacturing domains. They suggested a service composition system for preparing high degree of flexibility, as service mashups can adapt to dynamic environments. Agency (2008) studied about hospital management information systems and smart factory concept. Their project is about future hospitals management systems. Gjeldum et al. (2016) designed process for optimization of a hybrid assembly line that would be scaled and adjusted for industry use.

Augmented reality and simulation

Augmented Reality (AR) is an enhanced version of reality where live direct or indirect views of physical real-world environments are augmented with superimposed computer-generated images. This technology is in the core of Industry 4.0 applications. Real operations and simulation industry together emerged to this new technology which is of great importance to the industrial society. These techniques provide great benefits especially in designing products and production systems. Augmented reality is one of the cutting-edge technologies involved in the Industry 4.0 trend particularly in generating smart manufacturing functionalities. This technology was seen just as a fancy toy until a few years back, but which has now reached the right level of maturity to be employed in a production environment. This was one of the main motivation behind the study carried out by Bower et al. (2014) who investigated AR effect in society and technology. Now, there are so many investments and pilot projects going on out there which are speeding up the process of refining the technology and getting companies ready to improve their processes. This technology prevents errors that could be seen at various manufacturing stages mostly on product design and productivity improvements. For example, Alkoc and Erbatur (1997) investigated simulation for productivity improvement. Their simulation model is used in a prototype advisory expert system which is designed to present the results in a user-friendly.

On the other hand, this technology can be used to make important decisions in investments. It is now obvious that making the right decision is much more effective with simulation applications (See for example, Golparvar-Fard et al. 2009). Interestingly, Liao (2015) reported that augmented reality can also be a remarkable tool offer for marketing and brand recognition. He investigated the influence of marketing strategies on Augmented Reality technologies.

With this technology, graphics, sounds, and touch feedback are added into the natural world. It is a different concept than virtual reality which requires inhabiting an entirely virtual environment. It uses existing natural environment and simply overlays virtual information on top of it. As both virtual and real worlds harmoniously coexist, users of augmented reality experience a new and improved manufacturing systems where virtual information is used as a tool to provide assistance in Daily manufacturing functionalities. Augmented reality clearly implies the upmost utilization of IT technology for the benefits of manufacturing.

There have been some applications of AR mainly in the following areas (inGlobe 2017).

- *Operations* such as Installation, assembly, machinery tool change etc.
- *Maintenance and Remote Assistance* at reducing execution times, minimizing human errors and sending the relevant performance analytics to maintenance managers.
- *Training* for both experienced people and new technicians at the beginning of their learning curve.
- *Quality control* allowing to check whether the items produced respect or not the best manufacturing standards.
- *Safety management* making available the tools to manage risk and safety of operators and equipment working in the facilities.
- *Design and visualization* in providing tools that improve design and prototyping.
- *Logistics* for improving the efficiency of warehouse management operations and logistics supporting operators during indoor navigation and picking operations.

Although some papers such as a comprehensive literature review for Augmented Reality carried out by Berryman (2012) is mentioned, this paper mainly provides some examples of research on AR within framework of Industry 4.0.

It is believed that Industry 4.0 applications will benefit from Augmented Reality especially on just-in-time information rendering and intuitive information navigation as studied by Zhang et al. (2010a, b) Note that they used RFID and Augmented Reality systems together for collecting and processing the information. Similarly, Netland (2016), described AR in terms of implementing in Industry 4.0 environments and listed possible applications in the areas of operations, maintenance, error prevention, and training. A small comparison of augmented and virtual realities is also provided. Onime and Abiona (2016), prepared 3D mobile Augmented Reality (mAR) interface and limited simulations as a replacement for practical hands-on laboratories. This is an important achievement when considering that the augmented reality will be the part of real life manufacturing systems. Jernigan et al. (2009) looked at AR form a different perspective and studied that in terms of theatrical innovation. They encouraged to be innovative in their theater studies. They tried to show that the new generation technologies can lead to major changes in the performing arts.

Although there are some studies as mentioned on the above paragraph, most of the research on AR is mainly triggered by fielded applications. This is quite normal due to the nature of systems to be augmented with simulation. To mention some of those;

- Kim et al. (2005) prepared a simulation-based shipbuilding system in shipyard manufacturing system. They called the virtual assembly simulation system for shipbuilding (VASSS).
- Ignaccolo (2003) prepared a simulation model for airport capacity. This model is more effective for traffic mixes and operational variables.
- Shi et al. (2017) investigated a robot for plastic surgery. Augmented reality assists surgeons to realize positioning. Their model is important future of surgery and health Industry 4.0.
- Ruiz et al. (2013) used augmented reality system for indoor environments, which does not require special tagging or intrusive landmarks.
- Wang and Chen (2009) prepared a framework for intelligent agent based Augmented Reality. They used this system for urban design.
- Issa et al. (2012) reviewed the evidence for the effectiveness of AR applications on rehabilitation outcomes within a physical context.
- Papadakis et al. (2013) prepared model for simulation of the structural crashworthiness of automotive shells.
- Pandya et al. (2005) made a prototype for medical Augmented Reality and extrapolated to current medical robotics.
- Gay and Nieuwoudt (2010) studied trade simulation model for South Africa Fresh Orange Industry.
- McCullough et al. (2008) simulated crawfish production by using a two-stage modeling approach.
- Pence (2010) used a two-dimensional barcode to connect a cell phone or personal computer to information.

Apart from manufacturing, Augmented Reality also creates new opportunities for museums, libraries, schools, entertainment industry etc. There is a huge amount of literature along this line. Since those are out of the scope of this paper, just a few examples on education provided for the interest of the reader. Herron (2016) also investigated Augmented Reality using in education. Carrera and Asensio (2016) used Augmented Reality in Landscape interpretation and this study also important for teaching in the scope of Geography in higher education.

Data mining

Big data is being generated continuously by everything in surroundings. Every digital process and social media exchange produce data. Systems, sensors and mobile devices transmit those. Big data is arriving from multiple sources at an alarming velocity, volume and variety. To extract meaningful value from big data, there is a need for optimal processing power, analytics capabilities as well as information management skills. Hazen et al. (2014), reviewed eight theories that can be used by researchers to examine and clarify the nature of big data impact on supply chain sustainability, and presents research questions based upon this review. Miloslavskaya and Tolstoy (2017) studied appearance of two additional to Big Data concepts: data lakes and fast data. However, these terms can be used interchangeably. Siddiqa et al. (2016) investigated feasible techniques of managing big data management. They prepared a taxonomy for big data literature and provided an extensive introductory analysis. Similarly, Dong (2016), Hashem et al. (2016), Guo et al. (2016) provided readers who are embracing the data-rich era with a timely review on big data and its relevant technology. They used different algorithms for optimization of data analysis applicable to different types of areas and related data. Some of the researcher such as Mokhtar and Eltoweissy (2017) concentrated their research on system integration pointing out the efficiency and effectiveness of data management and decision-making procedures. Marron (2014) provided and analysis on current discussion within and outside of the field of statistics. He pointed out that data heterogeneity and importance of big data for solving industry problems. Lokers et al. (2016) prepared a framework for presenting structure and analyze data incentive cases. Their paper included agro-environmental domain concentrate on the issues of variety and veracity. Geeta et al. (2015) used big data for enhance link analysis considering website structure and web log file. This method is considered to be very useful for data management. Piccialli et al. (2017) this research work is to demonstrate how a specific core technology and cloud platform with micro-services can be designed and used for performing data-intensive computations and implementing services in a real case of social analytics. Shrimali et al. (2017), Wanka (2015) and Hea et al. (2016) observed from experiment that data redundancy can be easily obtained by ignoring/dropping data packets for the information which is not of interest by other participating nodes in network.

Expectedly, some researchers such as, Wamba et al. (2017), Jannsenn et al. (2017), Wang et al. (2017a, b), Hardy and Maurushat (2016), Onime and Abiona (2016), Sookhak et al. (2017), Lee and Shin (2017), Alharthi et al. (2017) indicated that big data is essential for processes and has remarkable impact on systems. They also presented new technologies for utilizing big data. They prepared a new road map for companies to increase their performance. They concluded that the implementation is not easy, due to uncertainties surrounding the reliability of de-identification and the requirements of privacy law, as well as a public service culture which is yet to fully embrace the open data movement. There are also some studies looking at various aspects of data analysis with respective challenges (see for example; Xia and Hea 2016; Macabee et al. 2017). The information provided by these studies are considered to be extremely useful for those who are aiming to design and develop a manufacturing system with Industry 4.0 standards. There are various hints that will enrich the development process from different aspects.

Addo-Tenkorang and Helo (2016) prepared a literature review for big data applications and supply chain management systems in Industry 4.0. Anderl (2014) presented a study on smart products. Ângelo et al. (2017) studied digital transformation for e-labeling systems. Atanasov et al. (2015) used data annotation for internet of things in Industry 4.0 concept. Fleisch et al. (2014) prepared new business models for internet of things and data management. Similarly, Hazen et al. (2016) used big data techniques for supply chain management.

Today, many consultants take the attention to the importance of big data and claim that Data Analytics will be one of the key skills of the twenty-first century. Most critical issue, however, is the shortage of analytical talent that could turn the high-volume data into useful information that will be used for better decision making. The authors of this paper believe that there will fully automated and well capable of automatic and autonomy data analyzers sooner than later within manufacturing environments as it appears the need for those systems are emerging quite fast.

Due to this fact, most of the research on big data is concentrated on data analysis within the framework of smart factory or Industry 4.0. Golova and Rönnbäck (2016), Akoka et al. (2016), Enget (2016), Martinez and Munizaga (2016), Gupta and George (2016) introduced to the concepts of data analytics in conjunction with big data. They studied different techniques but all of them observed big data is a main component for Industry 4.0. Gökalp et al. (2016) presents a framework which offers a higher level to increase adoption of big data techniques. They also recommend to use big data analysis methodologies for Industry 4.0 applications. Koseleva and Ropaite (2017) also studied big data methods and analysis as well as the importance of big data for Industry 4.0 especially for improving the energy efficiency.

Apart from all, there are several researches that are carried out mainly on increasing the performance of the systems through utilizing big data or performance of the Industry 4.0. To mention some, Zhou et al. (2016a) studied big data performance and better algorithms for programming of Industry 4.0 systems. Wang et al. (2017a, b) used data mining for huge systems' analysis. They highlighted that the Industry 4.0

needs data mining for better performance. Zhou et al. (2016b) worked in many unexplored or under explored research areas. They tried to highlight system performance through big data utilization.

On the other hand, literature provides information about the implementation of big data in various applications to be carried out together with other Industry 4.0 components. For example, Sena et al. (2016) pointed out that the big data can nurture alliance in SMEs by creating real-time solutions. They studied Industry 4.0 concept for small factories and highlighted possible applications. Guo et al. (2016) showed providing scholars in the healthcare informatics. Their research include relation between service sector and Industry 4.0. Through elaborating on the application of Industry 4.0 emerging towards the service sector. Ming et al. (2015) studied big data method in Chinese medicine. They claimed that the big data is important for Industry 4.0 and medicine technology.

Internet of things

The Internet of things (IoT) is the inter-networking of physical devices, vehicles, buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. It consists of four major layers: Perception Layer, Network Layer, Support Layer and Application Layer as described by Leloglu (2017). In 2013, Initiative on Internet of Things (IoT-GSI) defined the IoT as "the infrastructure of the information society." (Intel IOT Report 2016). The IoT allows objects to be sensed or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into based systems. Sasikala et.al (2017) provided an extensive review on IoT ad respective countermeasures.

IoT and Industry 4.0 are very close and related concepts. Since the production systems with IoT is interconnected with web-based systems, this generates more effective working environments in a more optimistic way. This also impels key standards playing an important role in the development of new optimizations and strategies. IoT based manufacturing systems make decisions that are quick, more optimistic and faster than those of others. However, this depends upon the architecture and related intelligence embedded into the system. Note that, it is in the hands of human intelligence and knowledge that optimally integrates both Industry 4.0 and IoT to be integrated in the most efficient and effective ways. Shaoshuai et al. (2011) prepared a multi-objective decision making based evaluation model of service quality is proposed. They also studied well-accepted IOT technologies, suggesting their possible extension towards already available cloud service. They expressed that effectiveness of Industry 4.0 based systems are affected by the quality of IoT systems.

In a recent study, Shrimali et al. (2017) optimized trade off in name data network and studied data memory management and data freshness. Huckle et al. (2016) investigated secure shared economy distributed applications. This study is important for understanding relationship between IoT and Economy.

In recent years, there has been numerous studies appeared on literature about IoT as well. Some of them that are reviewed for the sake of better understanding Industry 4.0 concept.

Silva and Maló (2014) presented the business model of outstanding facility in order to provide a generic Business Model for IoT. Burke et al. (2013), researched Radio Frequency Identification (RFID) tags, Quick Read (QR) code labels and IoT systems. They observed customers by using these technologies. Hubert and Chan (2015) described how partners benefit from collaborating within the value network by using IOT systems. Along this line; Ge et al. (2014), Al-Fuqaha et al. (2015), Bello et al. (2017), Raza et al. (2017), Atzori et al. (2017), Li et al. (2013), investigated, in one way or another, the definition and system properties of IoT with respect to Industry 4.0 implementations. In the same manner some of the researcher such as Loseto et al. (2016), Calderona et al. (2016), Ranjan and Hussain (2016), Samaniego and Deters (2016), Atif et al. (2016), Lin et al. (2017a, b), Wang and Wen (2017) presented new trends about IOT applications. They showed IOT system's features. Their common ideas are quite similar to the concept of Industry 4.0. Similarly, some of those particularly devoted their studies towards generating a relationship with Industry 4.0 and IoT. They also discussed new trends and applications of Industry 4.0 and IOT as well. See for examples of those in Davali et al. (2016), Park et al. (2016).

Some of them considered cloud systems and big data applications. Flammini and Sisinni (2012) studied Wireless Sensor Networks and suggesting their possible extension towards already available cloud services. Koo et al. (2015) presents a schematic development of IoT application for Big Data collection. Xiaoyinga and Huanyan (2011) prepared a monitoring system by using wireless sensor network and wireless communication system.

Accorsi et al. (2017) illustrated to showcase the potential benefits and opportunities for more direct integration of the physical food ecosystems into virtual computer-aided control environment. Giusto et al. (2010) describes the pervasive presence of a variety of devices, are able to interact and cooperate with each other to reach common goals.

Providing intelligent communication is naturally on the agenda of research along this line. For example, Chang et al. (2014) discussed current IT-Converged security issues, security policy and new security services which will lead to successful transfer smart space which is a new paradigm of future. Qiuping et al. (2011) and Guoa et al. (2012) defined intelligent identification system and analysis as well as its working principle with IoT implementation. They used a case study in railway logistics. Gubbi et al. (2013) presented a Cloud Centric Vision for worldwide implementation of Internet of Things. Iera et al. (2010) researched Iot performance and capability. Khan et al. (2012) distinguished features and possible future applications. Kiel et al. (2017) researched business models for companies by effecting industrial revolution. Lilis et al. (2017) assessed the opportunities along with the criticism for IoT enabled and controllable intelligent building against the well established, legacy automation systems in a fair and transparent. Majeed and Rupasinghe (2017) derived a conceptual framework to enhance inbound and outbound operations in ERP for Fashion Apparel and Footwear Industry. Pang et al. (2012) and Guide and Van Wassenhove (2009) used value creation for Iot and Supply Chain Management. Pang (2013) used architecture of ın ternet of things for using health sector. Parkhi et al. (2015) researched future supply chain management and use new approaches. Rüßmann et al. (2015) illustrated the effect of Industry 4.0 on productivity. Vermesan and Friess (2013) researched data protection legislation and the cybersecurity strategy proposed by the European Commission.

Some information regarding the infrastructure and physical networks related to IoT design as well as respective performance issues are also elaborated. Moregård et al. (2015) proposed clustering algorithm is evaluated on actual IoT platform. They studied the importance of IOT platforms prone to be used in Industry 4.0 set up. Lia and Yub (2011) studied machine communication infrastructure of IOT systems. Similarly, Eslava et al. (2014) made M2M protocol with an intensive use of Internet of things (IoT). They presented M2M communications channel in IOT systems.

Chen and Jin (2012) investigated the performance of IoT and some definition for Industry 4.0 system are generated incorporating those. Apart from measuring the performance, they also prepared road map for IOT implementation. The implementation of IoT are also reported by various other researchers such as; Kyriazisa and Varvarigoua (2013), Negash et al. (2015), Samani et al. (2015), Nordahla and Magnussona (2015) and Poghosyana et al. (2016) focused their research on various business models of IOT. They studied market analysis of IOT and focused on especially relationship between IOT and M2M. Chelloug (2015) prepared new business model for IOT and show its significant performance. They measured performance for smart factories. Kothandaraman and Chellappan (2016) reported mobile device's performance. They studied Industry 4.0 common mobility concept

Augmented reality and IoT were also particularly discussed in some of the research activities. Alkhamisi and Monowar (2013) used augmented reality for IOT applications. This study provides good hints in setting human–machine interactions up. Liu et al. (2014) proposed prospect on virtual reality technology in substation design which provides a guideline for Industry 4.0 implementations. Yang and Hirohide (2015) expressed elements in virtual world with logical constraints using objects in real world with physical constraints. Zheng (2015) discussed the basic characteristics of augmented reality and introduces a mobile learning tool operational on IoT. This tool is intended to be used for mobile learning tool utilizing both AR and IoT.

Boveta and Hennebertb (2013) and Peng et al. (2013) focused on the energy management of IOT. They highlighted the need for IOT systems and presented a framework for assuring the performance and energy management in Industry 4.0. Al-Ali and Aburukba (2015) prepared a conceptual model for the smart grid within the Internet of Things context. They studied Internet Protocol Version 6 as the backbone of the smart grid communications layer.

Some research for IoT naturally concentrated on information security. Neisse et al. (2014), prepared a security model for IOT. Their model supported specification and efficient evaluation of security policies to enable the protection of user data.

As all other components fielded applications on utilizing IoT are also reported in the literature. Some of them are listed below.

- Verdouw et al. (2015), studied food supply chain by using internet of things and e-commerce. They recommended to use IoT for supply chain management and took the attention of their read to the future process of food supply.
- Liu and Tonga (2012), studied reliability of components and Component-based migration maintenance strategy.
- Yu-fang and Jin-xing (2011) showed the theory and framework of using the Internet of Things technology constructing digital mines.
- Monteiroa et al. (2014) studied and presented different voltage and current values for controlling charging.
- Sampaio and Rosário (2012) prepared model supports the performance of such periodic inspections and the monitoring of interior wall maintenance.
- Gajos et al. (2001) designed IOT system by using resource management. This design is important for new industry age. They prepared principles for building high-level resource management tools for smart space.

This technology attracted some researcher outside manufacturing as well. Santosa et al. (2014), prepared a RFID system that is rapid and precise identification of each smart entities, enriched with the capabilities of IoT, which enables a ubiquitous and quick access to personal health records. Sherbini and Krawczyk (2004) prepared a concept for IOT systems. They studied receiving, analyzing, and reacting are the key criteria of intelligent building. Dasgupta et al. (2016)

configured an IOT platform and studied especially the communication capability of IoT of Google. Steele and Clarke (2013) used sensors for public health IOT system.

Unlikely to others; Kim and Suzuki (2015) diverted the direction of research to community and studied social features of IOT. Industry 4.0 and IOT platforms need social analysis because they will change social life. Sah (2016), aimed to change the way a consumer thinks about IoT and to provide a solid ground to explain how beneficial it is. Virkki and Chen (2013) investigated people's ideas about IoT and personal opinions. Bartezzaghi and Ronchi (2003) showed internet technology's process importance. They analyzed and understand main factors driving the adoption of Internet based tools in customer supplier relationships.

When connecting the equipment in an internet environment, one of the main issue is the "Quality of Service (QoS)" (Karakus and Durresi 2017) which is defined by transmission rates, error rates and other characteristics. The main concern of QoS is the transmission continuity of information in a network with high bandwidth. This transmission also varies in open networks depending on the type of content. As known, 'QoS' is a port priority technique and has been developed with various traffic shaping techniques such as 'packet prioritization', 'application classification' or 'queuing at bottlenecks'. The main purpose is to provide priority delivery services for applications that are trying to control latency and reduce data loss in networks with sufficient bandwidth. Note that, QoS gives network administrators control over network resources and provides performance boost for Industry 4.0 and ensures that applications with critical relative and time sensitivity have sufficient resources.

There have been various studies on QoS. To mention some; Epstein and Givoni (2016) prepared a survey about QoS and used 14 parameters and 13 active service for QoS. Qiao (2009) studied QoS limitations, effective capacity formulation and energy efficiency spectral efficiency. They analyzed the effective capacity as a measure of the maximum throughput under statistical constraints, and analyzed the energy efficiency of fixed-rate transmission schemes over fading channels. Hong et al. (2017) proposed QoS-guaranteed scheduling algorithm that considers the available resources and traffic load of small cell which would easy communication problems. Similarly, Tajiki et al. (2017) formulated the resource reallocation problem as an optimization problem with minimum network reconfiguration overhead subject to QoS. Li et al. (2012) studied a QoS-differentiated system model for sharing resource between different QoS-constrained users in Cloud Computing system. Similarly, Liu and Hu (2006) studied a novel QoS network control system for real-time systems and constraints. Wille et al. (2006) prepared a simple methodology to tackle the packet network design problem, and projected an example of its application to the optimization of link capacities and routing in a corporate Virtual Private Network (VPN). Wang et al. (2018b) studied the suitability of link state to user's QoS requirements by Cauchy distribution model. They also investigated a priority determination strategy based on QoS and energy efficiency, a color management strategy and routing mechanism which consists of Internet packet routing and Data packet routing. Lakshimi et al. (2017) studied a new routing protocol known as clustered QoS routing protocol (CQRP). Tripathy and Tripathy (2018) took the attention on uncertainties and studied dynamic and fuzzy QoS-aware service when different users follow different fuzzy reasoning in various contexts. Ahmed and Kohno (2017) studied Universal Mobile Telecommunications System (UMTS) and Wireless Body Area Networks (WBAN). These technologies are important for the quality of services especially over mobile networks. Hayyolalam and Kazem (2018) focused to systematically categorize and evaluate the current research approaches and strategies on QoS-aware cloud service composition. Wang et al. (2018c) investigated a service recommendation approach based on collaborative filtering and make QoS prediction based on user mobility. Gonzales-Coma et al. (2018) studied Multiple Input-Multiple Output (MIMO) Broadcast Channel (BC) region is studied and the impact of the CSI uncertainty over the overall system performance is evaluated. Further information about QoS is available in the literature each concentrating on a different aspect (see Armentia et al. 2017; Gabrel et al. 2018; Wu et al. 2018; Wang et al. 2015a, b; Albodour et al. 2015; Zhang et al. 2018; Liang and Du 2017; Hu et al. 2017; Lin et al. 2017a, b; Fanjiang et al. 2016; Gursoy et al. 2008; Dechene and Shami 2013; Fariss et al. 2018; Wang et al. 2018a).

Enterprise resource planning (ERP) and business intelligence

Enterprise resource planning (ERP) is a generic name given to information systems designed to integrate and efficiently use all the resources of an enterprise. An ERP software is a system that assists an enterprise in bringing together processes and data that are executed in all over the processes from sales to accounting, from production to human resources, from stock management to purchasing. This makes ERP systems to provide an integrated approach to information utilization. Data are entered the ERP system at the beginning of the foreseeable period, and it is transformed into information by being processed in different departments. Figure 10 shows connection between Industry 4.0 and ERP. As shown in the figure, big data, cloud, Manufacturing Executive Systems (MES) and ERP are integrated. It is important that all processes in the design phase as well as the customer journey are compatible with the Industry 4.0 approach. The ERP process is also an important component in this structure.

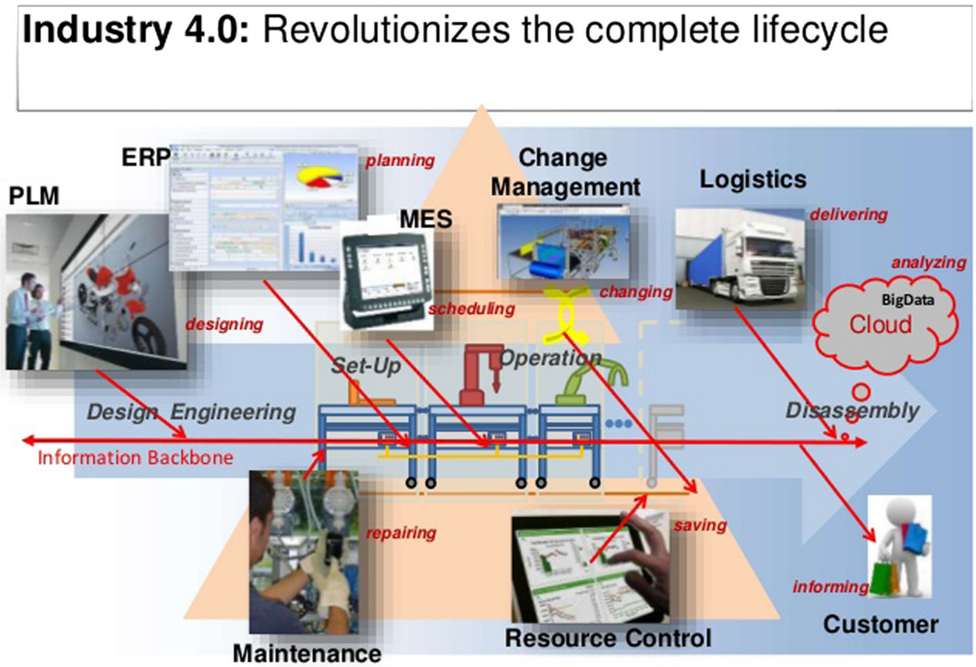

Fig. 10 ERP-Industry 4.0 process. Reproduced with permission from Jaehne and KalalChelvan (2017)

Industry 4.0 concept need connectivity and collaboration parameters. It is important to receive feedback from end users and to provide instant added value to all interested parties, not just suppliers. Industry 4.0 is the collective personalization of the main purpose not mass production. Network systems must be intelligent in order to make personalization possible. A telecommunications operator may be able to monitor network performance at fluctuations in network performance, by using preventive scenarios to minimize the amount of customer dissatisfaction. These characteristic features can be supported by a well-structured ERP system. Keeping this in mind, ERP systems may enrich Industry 4.0 implementations especially with the following benefits.

- Real time data can be analyzed and early indication of exceptional cases would be possible
- ERP systems can provide sales and purchasing transparency via automated business rules.
- Mobil applications may use ERP data to convey the messages not only to the manager but also to the machines running in manufacturing suits to perform expected operations.
- ERP may make the life easy for generating a design capacity within production framework.
- Information can be centrally aggregated and optimized for any batch size.
- Through effective ERP system strategic operation could be easy and the access of information to suppliers, customers, and other partners could be possible for assuring the efficiency of on-line operations.
- Optimum resource utilization could be possible even under varying job descriptions.
- Customers may be able to track the status of their orders on-line receive the information required without delay.

As with the other components, there has been huge amount of research and literature available on ERP systems. Some of them are directly related to Industry 4.0 implementation. For example, Sadrzadehrafieia et al. (2013) categorized ERP into strategic, tactical and operational benefits in each function. They studied ERP performance for Industry 4.0 implementation on dry food packaging. Ince et al. (2013) used to test the research hypotheses for SCM and ERP system implementations. They also studied Turkish companies' digital infrastructure for Industry 4.0. Above all, Tamang and Kumar (2015) studied database management system for automobile industry. Kumar and Zaveri (2016) used Hierarchical Clustering algorithm for Dynamic and Heterogeneous Internet of Things. Their model and system are friendly in business intelligence and ERP. Chatterjee (2015) investigated failed ERP projects and prepared a design model and framework for better ERP projects. Zhu and Dong (2010) analyzed Enterprise Resource Planning (abbreviated as ERP) of Chinese service industry. Carboneras et al. (2003) presented ERP concept production complexity in this industry and the key benefits obtained. Pollock and Cornford (1999) present manufacturing system and ERP importance. All these papers also studied implementation of ERP and ERP-Industry 4.0 connection and explained the rationale for this opinion, different techniques. Lee et al. (2015c) investigated ERP software package and prepared a method for achieving positive results for implementation. This problem is also important for Industry 4.0 ERP concept.

Nofal and Yusof (2013) and Krawatzeck and Dinter (2015) published literature review articles about business intelligence and studied respective actions of BI. They also investigated agile business intelligence and benefits of BI actions. Gudfinnsson et al. (2015) focused volume-operation companies and complex systems companies for using BI systems. They studied knowledge regarding BI usage and maturity in complex-systems companies. Jourdan et al. (2008) prepared a literature review for BI technology. They also investigated some areas that need further exploration. Foster et al. (2015) investigated development of a business intelligence competency center at a multi-line insurance company. They also studied data governance, IT responsibilities and Business Intelligence Competency Center. Gash et al. (2011) investigated cloud systems and BI systems. They focused moving out of a traditional in-house hosted BI environment to cloud system. Olszak (2016), introduced chances and possibilities of BI in organizations. Three theories—the Resource-Based View, Maturity Models, and Critical Success Factors—were used to investigate Business Intelligence issues. Trieu (2017), focused BI business value process has been studied and are still most in need of research and also presented a picture of how organizations can and do obtain value from BI. BI article is important for Industry 4.0 concept for using business intelligence to detect significant events and identify/monitor business trends to adapt quickly to their changing environment or scenario. Business intelligence software will improve the visibility of these processes and make it possible to identify any areas that need improvement.

Some researchers implemented Artificial Intelligence methods to make the systems more and more intelligent. For example, Pimenov et al. (2018) studied artificial intelligence for automatic prediction. They employed a series of artificial intelligence methods including random forest (RF), standard Multilayer perceptrons (MLP), Regression Trees, and radial-based functions. Oztemel (2015) provided a very brief overview of current progress of intelligent technologies for manufacturing society and presented well organized set of information fostering intelligent manufacturing. Jeang (2015a, b) studied robust product design and process planning also showed an economical and quality process capability analysis for product and process design becomes possible at an earlier time in the design stage. Along this line, several approaches such as bi-objective heuristic genetic algorithm (Zhao et al. 2018), nesting problem optimization (Tang et al. 2017), embedded evolutionary optimizer (Tarimoradi et al. 2017) neuro-fuzzy model for surface roughness monitoring (Tsang and Huang 2016) Random Key Genetic Algorithm (RKGA) and Immune Algorithm (IA) for scheduling problems (Mirsanei et al. 2011) are also proposed to be implemented in various manufacturing environments.

Chien et al. (2014) studied digital manufacturing and manufacturing intelligence. This study can be considered as an effective guide for fosterin Industry 4.0. They showed that manufacturing innovation and manufacturing intelligence technologies are developed to empower manufacturing excellence via soft computing, decision technologies, and evolutionary algorithms. Intelligent algorithms and solutions can be embedded in various information systems for enterprise resources planning (ERP), advanced production system (APS), advanced process control and advanced equipment control (APC/AEC), manufacturing execution system (MES), engineering data analysis (EDA), and supply chain management (SCM) to enhance decision quality as well as the design chain management as described by Chu et al. (2013). Note that this is also an essential requirement within Industry 4.0.

On the other hand, some of the research on ERP are related directly to the implementation of ERP software's. Elmonem et al. (2016) prepared a detailed systematic literature review for ERP systems. They also studied cloud systems. They indented to highlight benefits of implementation of ERP. Note that these characteristics is essential in creating an Industry 4.0 implementation. In this line, Lia and Yub (2011) studied increasing the flexibility of ERP system and effectively solve many non-standard and unfixed business problems. This capability is important for Industry 4.0 making the systems to be able to adapt the changes without loosing the information. Similarly, Candra (2012) helped to understand the key success factor in enterprise resource planning implementation. He used survey method and gained some statistical results. The findings of this research indicate the list of factors to be taken into account when setting up Industry 4.0 information network. Similarly, some of them such as Seethamraju and Sundar (2013) focused the attention on agility of the information processing systems. They claimed that poor process optimization prior to ERP implementation are restricting process agility. They studied key defining features of enterprise systems environment which can enrich the information processing capability within Industry 4.0 framework through sustaining enough amount of agility. Elragal (2014) established the relations between big data at the product or tool level, as well as relationship with social media, and with Internet of things. This study is a good example of understanding the huge amount of data generated in Industry 4.0 environments and the importance of related data analysis.

ERP development and respective framework definition were also on the agenda of the related research community. For example, Bouwers and Vis (2009) discussed the requirements for the Software Monitor. They showed a ERP case study for commercial ERP language. They studied ERP's importance of Industry 4.0. Within the same scope, Haddara and Elragal (2015) answered the research question: "Are today's ERP systems ready for the Factory of the Future?" They concluded that their results projected ERP systems are enough for future concept. Azevedo et al. (2014) prepared a case study developed in Portugal, discussing strategies towards using ERP software for system integration projects. There is a need for a similar methodology proposed to integrate the Industry 4.0 systems and components for efficient and effective process utilization. Magdić and Car (2013) introduced a company model used in everyday work of a software implementing. They studied this implementing modification process and they highlighted the significant advantages in various areas, from internal organization, customer satisfaction. Schumann (1999) gave an introduction on ERP and shows the role of MES which is an essential requirements Industry 4.0 and digital capacity. Zhai and Zhang (2009), Tsai et al. (2009) both studied the performance of ERP systems. They suggested better performance ways in implementing ERP software. It is believed that this methodology will easy the Industry 4.0 set ups.

Above all, some studies are also carried out on assuring the infrastructure for easy ERP implementation, which also be very beneficial within the framework of Industry 4.0. Ruivo et al. (2013) packaged ERP contribution makes to their business performance. They studied ERP effects on company's digital capability. They also investigated cloud system's importance for ERP systems and showed the value propositions of ERP delivered SaaS model. Some researcher concentrated on implementing ERP using cloud computing. Johansson et al. (2015) found that a hybrid solution integrating cloud systems with ERP. Chlen et al. (2012), Elmonem et al. (2017), Esfahbodi et al. (2016), studied the Systematic Literature Review (SLR) research method to explore the benefits and challenges of implementing ERP systems over a cloud environment Similarly, Johansson et al. (2015) found that a hybrid solution integrating cloud systems with ERP. They studied how a company determine an effective ERP system. This approach is already being utilized for traditional information processing. However proposed methodology is considered to open the way to Industry 4.0 implementations and make the life easier. Some other studies also took the attention to integration process. For example, Sharma and Gupta (2014), Lorenc and Szkoda (2015), Hufnagel and Vogel-Heuser (2015) presented a modular and parallelizable integration process. They studied planning, coordination, control of logistic flows involved in the flow of materials, finance and information in the entire supply chain. Similarly Framinan and Pierreval (2012), Seok and Nof (2018), Backhaus and Reinhart (2017) as well as Gen and Hwang (2011) provided novel approaches for implementing advanced models for logistics management and optimization of manufacturing.

Some of the research along this line such as He et al. (2015), Ke et al. (2015), Chen and Liu (2012), Orasiz and Yörök (2012), Chen and Wang (2010) and Yeh (2006) are not directly related to Industry 4.0, but the methodology proposed can be very useful in setting up smart factories or in designing digital manufacturing environments. They mainly concentrate on developing key performance indicators for ERP Systems or provided approaches for risk avoidance. An example of generating smart systems for using such a performance system can be found in Tsai et al. (2015). Ruivo et al. (2014) presented integration between systems can positively influence value from IT investments. They investigated assessing the commercial-packaged ERP contribution makes to their business. They showed importance of ERP system on way of Industry 4.0.

Virtual manufacturing

Virtual manufacturing (VM) is the use of computers to model, simulate and optimize the critical operations and entities in a factory plant. Virtual manufacturing started as a way to design and test machine tools but has expanded to encompass production processes and the products themselves. The main technologies used in VM include computer-aided design (CAD), 3D modeling and simulation software, product lifecycle management (PLM), virtual reality, high-speed networking and rapid prototyping.

Virtual manufacturing uses computer modeling technology which is one of the important distinguishing factor. It also provides a system to analyze the manufacturability of part of a process. If virtual manufacturing is design centered, it provides information about manufacturing process (Gaurav 2017). It includes production centered and control centered processes. Generally, it is aimed to test production in virtual environment (Yang et al. 2016). For this purpose, optimization of these criteria can be targeted by taking the product, control or design as the forefront. Figure 11 illustrates this concept by indicating that the process design, facility design, assembly, product design, ergonomic, fixture are important points within a virtual manufacturing environment.

For setting up a virtual manufacturing environment, there is a huge amount of possible use cases involving all kind of operations that can be executed on the shop floor, from core manufacturing activities such as production to support processes such as maintenance. Operations, maintenance, training, quality control, safety management, design and logistics are potential usage scenarios for this approach. People create and manage virtual experiences including object tracking, data management and tasks creation. Enriching virtual manufacturing facilities with augmented reality

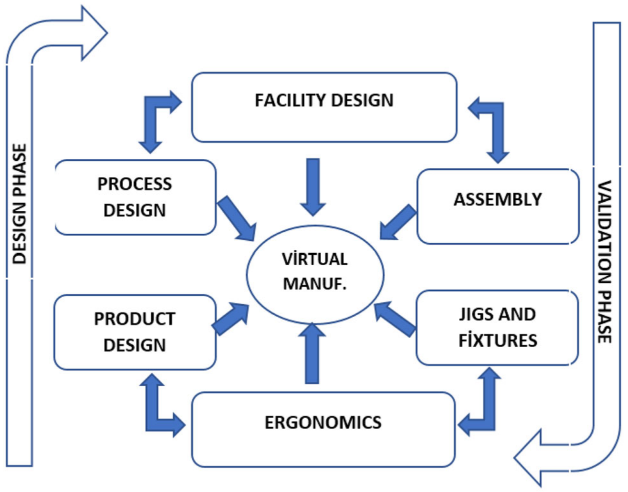

Fig. 11 Virtual manufacturing flow. Reproduced with permission from Gaurav (2017)

capabilities makes the life so much easier for Industry 4.0 developers.

As with the other components, there are some research going on for virtual manufacturing. To mention some, Shahabi et al. (2010), Peng et al. (2007) and Tong et al. (2016), prepared capacity analysis and used decision making methods for virtual manufacturing. These studies can be very beneficial to Industry 4.0 developers as they provide a brief introduction of virtual manufacturing technology and introduces a simulation model of Industry 4.0.

On the other hand, some studies produced systems and methodologies from which Industry 4.0 can benefit. Aalaei and Davoudpour (2016) provided several cases about validity of a proposed solution model developed for goal programming and they solved model for favorite solution. Their model minimized the total cost of supply chain design which includes holding cost, outsourcing cost, maintenance and overhead cost. Yang et al. (2013) used web programming to implement a resource management system with power saving method for virtual machines. Those machines are important for Industry 4.0 because of their specifically designed capabilities like predictive maintenance. Martin and Dantan (2011) generated solutions to the system with models using different algorithms and they intended to generate models which can help Industry 4.0 performance. Wang and Chen (2013) introduced the virtual manufacturing system developed. They studied design criteria for virtual manufacturing.

Both Kusiak et al. (2010) and Francis and Kusiak (2017) studied predictive models, neural networks, autoregressive integrated moving average. They generated a linear regression models outperforming neural network models generated earlier. Theses studies are good examples of Industry 4.0 because of their data management and predictive model approach. On the other hand, Kusiak (2009) provided some recommendations for future technological progress. Data mining approach is promoted as being a point for Industry 4.0 concept. The authors of this paper beleives that those could be a good guideline for generating Industry 4.0 manufacturing environments. Similarly, Kusiak (2013) described and implemented a living Innovation Laboratory. He studied virtual manufacturing concept in this study concluding that all processes and functions could be simulated and tested by means of engineering software.

Last but not least, Kusiak (2012) used data mining algorithms are employed to construct prediction models for wind turbine faults. Heragu and Kusiak (1987) presented expert systems developed for the design problem. Looking at the literature it would not be wrong by saying that most of the studies on virtual manufacturing are one way or another related to the concept of Industry 4.0. Infect most of them already elaborated on this topic from various aspects.

Intelligent robotics

Technology provides more and more suprising products and systems. Flying cars, holographic television, the interconnections of thousands of electronic devices to be implanted into human body will not be a dream soon. Not so long time, human-like robots will be part of the dailiy life. One of the challenge is the communication among them which will be sorted out through recreational activities. This is an inevitable progress for the employment of humanoid robots in factories. Robots are now able to play games, walk around any terrain and perform very complex tasks. Recent innovations have brought about techniques that enable the robots to control their environment. Artificial intelligence will contribute progress of having robot teams cooperating and collaborating in achieving certain tasks defined for a specific purpose.

Some research fostering robotics which can be of use in supporting effective dijital transformation. Du et al. (2017) developed a prototype of Robot Cloud using the popular Google App Engine to demonstrate their design method. Mohammed and Wang (2018) presented a case study of a system to assist the operator in coordinating a collaborative assembly task of a car engine manifold. Yun et al. (2016) identified the importance of the business model in addition to leading firm effect, standardization, and regulation. This can provide a base lin e for dijital transformation. Daim et al. (2018) prepared a decision model and a framework for emerging robotics technology. Filaretov and Pryyanichnikov (2015) studied construction of efficient mobile robots (MRs) and their group control in the virtual laboratory tested in 5 univesities. They presented an elaboration of scientific and educational tasks for the students. Houda and Lakel (2015) presents the implementation of a communication system Bluetooth for synchronous communication between autonomous robots moving between predefined appointments points. Flores-Abad et al. (2014) presented a literature review of the recently developed technologies related to the kinematics, dynamics, control and verification of space robotic systems for manned and unmanned on-orbit servicing missions. This survey provides useful information about various aspect of robotics to be utilsied in Industry 4.0 enviornment Brunete et al. (2017) studied short-term and long-term exploitation of the results which should significantly increase the future robot usage in the machining operations. Bertacchini et al. (2017) designed a social-like interaction where the robot carries out actions with the customer. This is a good example of Man–Machine interaction. Kim et al. (2018) studied a robotic excavator with various hardware and software modules including a task planner, environment sensors, GPS and other sensors to acquire an excavator's status, electronic valves and other mechanisms. Villani et al. (2018) discussed advantageous of robotics, highlighting how collaborative solutions are intended to improve the efficiency of the system where little human intervention is required. Similarly, Mourtzis et al. (2017) proposed a augrmented reality model for supporting robot maintenance. They validated their model in a real-life case study. Xu et al. (2015) introduces the research in application of computer vision technology for generating a real-time tracking capability for the robots.

Some of the researcher including Andrade et al. (2014), Zujevs et al. (2015), Aburaia et al. (2015) studied sensor systems, robotic and autonomous systems and related techonlogies to take the attention of th reader to robotic capabilities.

Recent progress indicates that the robots are becoming key players in various domain suc as education (Ospennikova et al. 2015), strategic tehnology management (Daim et al. 2018), mobile robots (Kermorgant 2018), ship building process (Lee 2014), Colorectal surgery (Damle et al. 2017), service providers (Decker et al. 2017), procurement (Aleina et al. 2018), needle-punching system (Chen et al. 2018), smart home applciations (Do et al. 2018), electronic beacons (Alanso-Martin et al. 2017) and robotic surgery (Iavazzo and Gkegkes 2017) etc.

İt is obvious that the robotic is of great importance in Industry 4.0. Robots can carry out difficult or big things. They can also work in dangerous or unfavorable conditions. They form the standard for routine operations. Despite construction and maintenance costs, robots seem to become the main source of labor force. They can close social exploits by reasonably communicating with people. This will be another main requirement in the following years.

This review would ne be complete if the debate about the robotics having an important effect on society. There is discussion about the effect of robots in society. Some believes that they will outmaneuver human and they will not be kept under control. Second debate is unemployment. If robots are going to do every job human can, then what would human do for living? This question is asked in several discussions. It is for sure that the robots will be everywhere and will take the control of most of the task carried out by human. But this will not be a problem for the people there will be a need for human being to create robots and respective intelligence. The work profile will change and whoever aligns his/her capabilities with the changes and progress will have new opportunities. However, if this alignment is not assured then technological unemployment will be inevitable. On the other hand, the robots will always carry out the tasks using the inteligence provided by human. They will improve their intelligence if human models this capability. This indicates clearly that human will keep overall control if he is willing to sustain and improve. This brings another question out. That is "robotic ethics" which should be the topic of another investigation.

Some Industry 4.0 projects

There has been several projects running especially to prototype Industry 4.0. Some of those carried out by industrial consortiums formed by companies running business mainly in machining industry and universities aiming to generate the factory of the future. European Parliamentary Research Service published a report in 2015 stating that "the Large investments are needed if enterprises are to make the move to Industry 4.0; these are projected to be €40 billion annually until 2020 for Germany alone (perhaps as much as €140 billion annually in Europe). These investments can be particularly daunting for small and medium-sized enterprises (SMEs) who fear the transition to digital because they cannot access how it will affect their value chains." (EPRS 2015). This report also notes that in April 2015, France launched a plan for the Factory of the Future to create demonstration centers (virtues technologies) to showcase new products and services. Particular emphasis has been placed on aid to small and medium-sized enterprises, with €1 billion available in loans to SMEs that want to start robotics, digitalization or energy-efficiency projects. This new plan, and six others in the same industrial support programmed (dealing with robotics, the Internet of Things, Big Data, high performance computing, Cloud Computing and augmented reality), have been grouped together in a larger framework called 'Industry of the future', that focuses on specific products such as an energy-efficient car and an electric airplane.

As some of them already reviewed above, there has been several more projects running for looking at the strategic and organizational effects of Industry 4.0 implementations. Just an example is the project carried out by SMI which started new research project on Industry 4.0 in collaboration with the Canton of Zurich. Specific focus will be given to the strategic and organizational effects on firm's R&D activities and innovation (SMT 2017).

Similarly, some of the projects are focusing the attention to overall digitization projects. For example, I4MS—A European mechanism is a Project trying to open the gateway to access to the latest digital technologies for any industry in Europe, regardless of sector, size or geographical location. To achieve this a digital innovation hub in every region with a competence center at its core is proposed. These hubs are expected to be networked to ensure excellence, shared learning and access from any region. The competence centers which can offer services for the digital transformation of companies including support for research and testing, supporting new product manufacture and showcasing technologies in pilot factories are also recommended (I4MS 2016). This clearly indicates that the topic is on the agenda of overall Europe and in other countries. Some of the projects along this line are very briefly reviewed below. The information is collected mainly from relevant web pages.

ENTOC

This project is carried out to provide the required models of individual components for the virtual commissioning, a standardized description of the components in Automation to enable a continuous tool chain is sought. The standardization helps to ensure that various software tools have a consistent data format. The project team aims to generate an engineering process so that the resulting virtual commissioning is simpler and more uniform. By doing this, real accidental collisions could be prevented, process sequences with regard to cycle time are optimized and control sequences programmed before the real commissioning. Note that this project is being funded by the German Federal Ministry of Education and Research (BMBF). Detail information can be found in ENTOC (2017).

ARIZ

This Project is so called "work in the industry of the future" (ARIZ). One of the main focus is to generate a safe human–robot cooperation. As stated in its web page, ARIZ Project tries to establish a flexible and adaptive production assistant. An adaptive and flexible robot is intended to be used at changing production workplaces. It is supposed to relieve the employees assisting the human and taking over monotonous, ergonomically repetitive tasks from it. In this respect, the safety of the employees has the ultimate priority. Working together with representatives of the trade associations, these safety aspects are being examined. Another aim of the project is reported to be finding out the special qualification requirements of the employees that work with the robots at the production workplaces and to then put an appropriate learning system into practice. This learning system is expected to enable the employees to best prepare for their future task. This Project is also supported by the German Federal Ministry of Education and Research (BMBF). Detail information can be found in ARIZ (2017).

MetamoFAB

MetamoFAB, intends to develop solutions to enable a metamorphosis into intelligent and networked factories. People, machines, workpieces and information technology are all involved in this project. The Project also aims to describe phases of the transition and possible ways of implementation those phases especially in integrating successive cyber-physical systems with existing modernization and development plans. The research project is funded by the German Ministry of Education and Research (BMBF). Detail information about this Project is given in MetamoFAB (2017).

ParsiFAl 4.0

In the ParsiFAl 4.0 research project, several cooperating partners are working on developing thin electronic systems, so-called smart sensor system (S3) labels, with the support of the project sponsor VDI/VDE-IT. The S3 labels are to be based on microcontrollers, sensors, thin displays and integrated communication interfaces, which are all embedded in foils.

The data recorded is expected to be used to evaluate the condition of a component, in order, for example, to proactively service plants. This will allow the maintenance costs for production plants to be reduced considerably. In the logistics and packaging field, this enables the transport route of sensitive goods to be reliably tracked. Similar to other, this project is also supported by the German Federal Ministry of Education and Research (BMBF). Detail information is provided in ParsiFAI (2017).

SOPHIE

SOPHIE is a Industry 4.0 project for connecting the real production and the digital factory in real time. Virtual technologies and process simulations are using for this project. They want to manage enormous amounts of data in a digital factory. Sophie also brings developing and testing concepts. They plan support purposes by using integrating an agent-based software. Also, project brings production simulation and decision-making support for organizational integration. Detail information can be found in SOPHIE (2017).

OPAK

Another project name is OPAK. (Open engineering platform for autonomous mechatronic automation components in a function-oriented architecture) They wants to endeavor to make complexity controllable because production facilities are becoming more and more complex. Projects aims simple engineering processes and components with a digital memory. Also, they have a demonstration system for practical research (OPAK 2017).

ESIMA

ESIMA project is working with other project participants to develop an approach to optimizing resource efficiency in production systems where energy independent sensors play a key role. ESIMA's aim is to measure the energy consumption of machines more easily using wireless sensors. The detail information is provided in ESIMA (2017).

PLANSEE

Power Semiconductor and Electronics Manufacturing 4.0 (PLANSEE), is another Industry 4.0 project for development of the autonomous factory. Areas of research include smart production, cyber-physical production systems, algorithm-based process improvement or secure data traffic over a multitude of interfaces. PLANSEE (2017) provide some more information about the details of this project.

#1 Smart (SMT) factory

This Project intents to break down the Industry 4.0 concept to the specific requirements and processes of its customers in the electronics manufacturing industry. The main goal is to realize a smart factory describing step-by-step transformation into intelligent smart factories. Four central innovation drivers for the #1 Smart Factory is defined mainly, best-in-class equipment, automation, process integration, material logistics. The Project will enable the manufacturers to produce smarter, more flexible any more future oriented electronics. Detail information can be found in SMT (2017).

e-F@ctory

This is a support platform providing information for easing the digital transformation. E-F@actory intends to provide a flexible framework supported by fast connection with reliable data and sensitive control procedures to utilize robust technological achievements. This project also aims to connect Industry 4.0 product manufacturers all over the world. Detail information can be seen in e-Factory (2017).

INESA smart factory

It is reported that INESA Display was selected as a model factory for the Smart Manufacturing Project under the Made in China 2025 plan, and it is intended to achieve digital transformation. To adapt itself to a new era, INESA Display, while continuing to manufacture, is also driving the development of information industry, and it has established a strategic goal of helping build smart cities as part of its business model, thus working to create a new industry that fuses ICT with manufacturing. INESA Display has been making numerous efforts to use IoT and big data. Thus, it holds vast amounts of data on facilities, the environment, manufacturing processes, and so forth as well as generates hundreds of thousands of data items per hour. It is also reported that INESA Display has alleviated the slow speed and instability of communications in its existing large-scale network by building a low-cost system to automatically collect plant energy consumption data, including information on electricity, water, and gas by using unique intelligent network communications technologies, It is noted that this system aggregates and centralizes manufacturing progress data collected through sensors and other IoT devices. To process and analyze the accumulated big data in real time while maintaining a high level of security, a big data analysis platform was built that enables warning signs of problems in manufacturing equipment to be detected. Detail information can be found in INESA (2016).

FUSION

FUSION (Featured eUrope and South Asia mObility Network) is an EU (ERASMUS MUNDUS) project, aims to foster partnerships of emerging Asian countries (Afghanistan, Bangladesh, Bhutan, Nepal, Pakistan, China, India, and Thailand) with the EU countries (Bulgaria, France Germany, Hungary, Italy, Portugal, Sweden, and UK) to reinforce the existing collaborations developed through the EU funded projects. The key objective of the FUSION consortium is to enhance the capacity for international cooperation between universities in the Asian and EU countries by facilitating transfer of people, know-how, culture and best practice in training the next generation of researchers and academic staff in certain thematic areas to foster centers of excellence. Although not so much information provided in their web sites, the user can visit and see some extra information in FUSION (2016).

AWS IoT

AWS IoT is reported to be a managed cloud platform that lets connected devices easily and securely interact with cloud applications and other devices. It is clearly noted that AWS

IoT can support billions of devices and trillions of messages, and can process and route those messages to AWS endpoints and to other devices reliably and securely. With AWS IoT, it is aimed to generate a communication system where company specific applications can keep track of and communicate with all devices within the enterprise, all the time, even when they aren't connected. It offers several other opportunities provided by Amazon to be utilized as mentioned in AWs (2017).

Productivity 4.0

Productivity 4.0 aims at industrial transformation and the creation of greater value added across the entire value chain in key industries in Taiwan. It incorporates the objectives and technologies of Industry 4.0, the European connected industrial automation strategy particularly associated with Germany. It is reported that the Government has planned to spend NT$36 billion (US$1.12 billon) over the next 9 years after the initiation of the project to elevate Taiwan's status in the global supply chain especially on electronics/information technology, metals, transportation, machinery, foodstuffs, textiles, distribution and agriculture, helping to build smart factories to realize massive but diversified production (Sangmahachai 2015). Part of the Productivity 4.0 model is considered to be the rival of a former model for industry wide, connected entrepreneurship, known as the A-Team model. This model played a key part in the establishment of Taiwanese industry in the 1950s and 1960s. Revising and utilizing the A-Team model, and promoting Productivity 4.0 throughout the nations is expected to help numerous small and medium-sized enterprises effectively develop their competitiveness. This Project is also supported by The Ministry of Education by reviewing the comprehensiveness of teaching materials of relevant courses in the formal education system, including technical and vocational schools, universities and post-graduate studies.

New era of human centric manufacturing

This project carried out as part of the Japanese IVI effort (area 4). The idea is to generate a robotics line building for SMEs using cloud knowledge database. Proactive machine communicating with workers in IoT environment is generated to facilitate this. Advanced quality assurance by connecting data—Towards zero failure production was become possible. On the other hand, standardization of working styles in "Man–Machine collaborative factories" is established. Remote consulting service of production engineering by bill of process information is also introduced (Nishioka 2016).

Air liquide: an industry of the future emblematic project

Air Liquid is setting up an operations center in France capable of remotely managing the production, energy efficiency and reliability of manufacturing sites. The Project is reported to have another goal which is to introduce the latest digital technologies (3D scans, augmented reality, touch tablets, etc.) into the daily work of teams at various sites. The new center, which is expected to be operational in 2017, is expected to pilot production and energy consumption, while a site's teams will focus on security and equipment availability. Detail information can be received from (AIR-LIQUIDE 2016).

Conclusions

It now obvious that Industry 4.0 is a philosophical transformation of the society. This transformation is expected to lead to major changes in society, education, economy and trade, just like any other industrial revolutions. By keeping this in mind, this article provides some information about the ongoing debate around Industry 4.0 in both the scientific and the industrial communities. Practical contributions of the paper are twofold: First, given definition for Industry 4.0 helps clarify the basic concept among practitioners. Second, it can be used to support the implementation of six design principles of Industry 4.0 scenarios. It helps determine potential situations and will be a source of guideline during implementation.

Note that, although the component market is dominated by a few big players, there are thousands of production facilities all over the world ready to expand their manufacturing lines to either work along with the Industry 4.0 standards or to produce products to ease Industry 4.0 implementations. There is no doubt about that these factories will continue to produce components in the future because of the spread of electronics in all areas human life through extensive "digitization" of everything possible.

The correct use of real-time information is expected to lead the next industrial revolution. High level of variability is the key to understanding what variability is, in order to reduce it and integrate it into production management tools, leading to high level of confidential information. Today we call for more focus on the basic understanding of production systems and the greater use of industrial data in research to find solutions for tomorrow's "intelligent Industry". Providing intelligence to industry is wide spread out from using support vector machine to energy entropy (He and Li 2016) to utilizing risk-value graphs (Shah et al. 2016), from fuzzy risk manager (Safari et al. 2016) to experimental design using fuzzy desirability function (Pandey and Panda 2015) etc.

As we have seen in the literature review, Industry 4.0 is not just an industrial revolution. A new flow angle that gives direction to the future. A scale showing what the companies digitalism levels are also one of the main areas of research. Assessment of capabilities, compatibilities, and knowledge driven infrastructure along with Industry 4.0 standards has not yet cleared.

It is now obvious that future manufacturing will be more intelligent, more flexible, more adaptive, more autonomy, more unmanned, more sensor based (Industry 4.0 standards). More and more augmented reality will take place in production suits. This will naturally change the man power profile as well. There is a need to carry some research along this line. More over, future manufacturing systems will not only be based upon Industry 4.0 standards but will be more extended towards generating fully automated and unmanned systems with having robots enriched with human-like behaviors.

Also note that the paper takes the attention of research community to digital economy and society by providing fundamental baseline provided by Industry 4.0. It also points out the importance of sustainable economy through innovative manufacturing environment, intelligent mobility and cloud computing capabilities as well as information security, those of which can be considered basic requirements of Industry 4.0

This new trend will not only affect the economy and manufacturing industries but the whole society, education, health and law. It can be considered a well-accepted start that will guide the human live in the future. Today, all of the components considered in this paper are assembled to some degree one way or another to serve economies. It should not be forgotten that the Industry 4.0 is a goal, this definition will be more and more well formatted by the effective integration of all the parts it contains. No matter whether the nations call it Industry 4.0 (as it is promoted by Germany), "innovation leadership" or "Made in China 2025" (as said in China), "Advanced Manufacturing Program" (of USA), 4IR (as taken on agenda by UK), "Industrial Value Chain Initiative" of Japan or some other names they generated by themselves.

This review also found out that there are some studies concentrating on the future of Industry 4.0 and respective progress. Some studies, such as the one provided by Qin et al. (2016) reviewed Industry 4.0 components and elaborated on the innovations along this line. They particularly took the attention of the research community towards future progress by analyzing the research gaps between current manufacturing systems and Industry 4.0. Similar to this study, Henriques et al. (2018) analyzed 56 articles for making the future effect of Industry 4.0 as clear as possible. They defined and analyzed positive variables and their effects. Granell et al. (2016) examined new internet technologies and identified the future changes and challenges of these technologies. They also studied mainstream internet capabilites with sensor and geospatial technologies. Nazarko (2017) explained a bibliometrics and the logical construction method and provided future oriented technology analysis. Sachsenmeier (2016) took the research stream one step ahead and discussed industry 5.0. He showed that the next industrial revolution will evolve over developments in the field of biotechnology. He focused his attention on DNA analysis, bio-circuits, minimal genomes, protocells, xenobiology are investigated. Hsiao (2018) studied difference between technology-enabled and technology-dependent user behavior and concluded that too much emphasis on the role of technology with too little attention on motivation would distort the behaviour of technology user. Vaidya et al. (2018) studied new trends, applications, challenges and issues in Industry 4.0 by investigating the future of various components of Industry 4.0. Shallock et al. (2018) paid attention to the design of a learning factory for Industry 4.0 that addresses the growing demand for future skills of production staff. Potts and Cunningham (2008) introduced four models of creative industries which could have main effects in designing future systems. These are: welfare model, competition model, growth model, innovaiton model. The common point of all these studies is: Industry 4.0 innovations and the detailed analysis of respective components. There is a consensus that Industry 4.0 will be short-lived and the new industrial revolution will be coming soon after originated from the progress in biotechnology and nanotechnology.

After all, the literature survey implies a fast growing advancements especially on implanted and wearable technologies, unmanned vehicles as well as more humanoid robots. It seems that artificial intelligence will be dominant research area and fielded applications will spread all around the world in any domain requiring human intelligence. AI based systems and robots will e employed in even managerial functionalities of enterprises (i.e. robot member of the decision board). Decision support systems will emerge to intelligent decision makers. Work profile of human being will in turn change along this line and new profession such as data scientists and knowledge engineering seems to be more popular than traditionally famous ones. The society will also be readier to assimilate the changes and accept the societal transformation more willingly.

This review provided some examples of implementation of Industry 4.0 or related components. It also revealed the following advantageous and disadvantageous of this avoidable transformation. Industry 4.0 or related components is expected to generate tremendous amount of benefits some of them are the following;

- Improved innovation capability.
- Easy monitoring a diagnosis of system multifunction.
- Increased self-awareness and maintenance capabilities of systems.

- High productivity with environmental friendly products.
- Improved flexibility with decreased costs.
- More faster production development process with new business ad service models.
- Unbiased, real time and knowledge based decision making.
- Nationwide participation for contributing to the economy.
- Increased e-business with more spread markets and access to global markets.
- More easy access to public services (education, health, local service etc.).
- Penetrated products and service increasing life quality.
- Smart cities/buildings/factories and distance control.
- More customized products.
- Easy to access personal information.

As with the opportunities and benefits listed above, there are some disadvantageous human being has to deal with. Some of those are;

- Not much privacy to be sustained.
- Increased cyber-attacks, and reduced information security.
- More distractions leading to hazardous accidents.
- Increased plagiarism and difficulty to keep intellectual properties.
- Dissemination of worn knowledge and improved manipulation.
- Restricting the access to knowledge (mainly for misleading the society).
- More demand on 7/24 running services.
- Not being able to remove or hide unwanted information flow.

Spending more time, and performing active research will produce solutions to most of the above problems. However, they will still survive as being undesired situations here and there all over the world.

Generating a well-accepted definition was also the prime objective of this research. A comprehensive definition is required covering various aspects of the transformation. Based on the reading the authors of this paper recommend the following definition.

> Industry 4.0 is a manufacturing philosophy that includes modern automation systems with a cretin level autonomy, flexible and effective data exchanges encoring the implementation of next generation production technologies, innovation in design, and more personal and more agile in production as well as customized products.

This definition clearly indicate automation (M2M, IoT) implementations with autonomy decision making capability (smart factories), effective data exchange (ERP, Cloud), supporting the innovation and invention of future generation technologies (augmented reality) as well as more personal utilization of data (mobile systems, big data).

This study aimed at defining the boundaries and characteristics of Industry 4.0. There is still a high uncertainty and fuzzy understanding among the manufacturers with respect to the way to implement Industry 4.0 philosophy. They wish to learn what are the basic requirements for a better transformation. In today's manufacturing environment, companies have to keep on top of their agenda the continuously innovating the products or modernizing (digitizing) the production processes. Note that, the transformation process still continues with a remarkably high speed. That is to say that, industry 5.0 is ad the edge of scientific improvements. It may start to take root in factories today and the collaboration between man and machine may continue to advance. Industry 5.0 may enhance both machine and human roles in the manufacturing industry, leaving the monotonous, recurrent tasks to the mechanical world and opening up the creativity side to the biological systems. More intelligence can make the systems to be more capable of performing activities and robots to be more humanized. This is a clear and obvious area for the research community to concentrate.

Finally, this review is also intended to provide an insight for Industry 4.0 implementation and generating respected road maps. This implies the need for a taxonomy of Industry 4.0 which will be the topic of the following paper the authors of this paper intend to produce.

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