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INDUSTRY 4.0: AN OVERVIEW

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A B S T R A C T

Industry 4.0 is a new level of value chain organization and management , which is likely to change the way processes, supply chain, and business models operate , which is why many companies are evaluating the concepts and applications synthesized under the term Industry 4.0 to develop their own business strategies, which under this new industrial disruption, which is founded on some basic principles such as interoperability, virtualization, decentralization, real-time capabilities, service orientation, etc., and where there are, for example, smart factories capable of creating virtual copies of the physical world, monitoring physical processes, self-managing, optimizing, and making decisions autonomously in real time. The need to integrate processes within enterprise between ERP and shop-floor level and also across enterprise boundaries for optimal and collaborative environment, to highlight the importance of real time information access in order to make decision and to show the importance of predictive maintenance in a production environment prompted this research. Information obtained from industries were analyzed. The results however, showed that industry 4.0, if fully adopted would increase production of goods and services and also save time consumed during production stage.

1. INTRODUCTION

The rapid development of information and communication as a result of interconnected digital world characterized by the increase in mobility and quick access to information gave rise to a range of global issues such as: environmental protection, health improvement and the need to eradicate poverty (Khan & Turowski, 2016). Recently, companies have been tasked to adopt a more transparent and responsible approach with the aim of setting up a holistic environment in order to achieve economic growth, social progress, equity, respect and then awareness of the environment. It is imperative for organizations to respond to these challenges and risks while taking advantage of the newly environment (Fonseca, 2018). The virtual world, in a way hitherto unknown, is beginning to permeate everyday life, which is becoming the foundation for the future global world, where all devices will create a combined physical and virtual world, the Internet of things, data and services (Zembski & Ulewicz 2020). The first industrial revolution was a major step in human history as population and average income experienced a substantial growth as a result of technological transition. The second industrial revolution introduced electricity and combustion of engines to the society and caused a shift towards a new economy. However, the introduction of electricity did not create a rapid productivity-shift, as electricity-based technology diffusion was slow through the industry (Kumar & Kumar, 2019). One reason identified by several historians is the fact that staff and managers needed time in order to adjust to the new

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technology. Another reason was that factories needed to be completely redesigned in order to fit with electricity (Nilsen & Nyberg, 2016). The third industrial revolution is referred to as the digital revolution. Some consider this revolution to have started in the middle of the 1990's when personal computers were linked and the first iteration of the internet was taken into play. The impact of this revolution takes its form both in the massive use of social media as well as solar power and artificial intelligence. Still, it is believed that we are in the middle of this transition (Kumar & Kumar, 2019). Industry 4.0, or the fourth industrial revolution, can be defined as "a collective term for technologies and concepts of value chain organization". Since Industry 4.0 involves many thematically overlapping elements and concepts, design principles can better be outlined to further provide common ground for Industry 4.0. Interconnection, information transparency, technical assistance and decentralized decisions have been identified as the most important design principles for industry 4.0 (Nilsen & Nyberg, 2016). The term Industry 4.0 was coined within a strategy-related project by the German government, describing the computerization of manufacturing (Nilsen & Nyberg, 2016). The transition is by some experts considered to follow "Moore's Law", which states that the technology is doubling its capacity and performance every two years (Nilsen & Nyberg, 2016; Wortmann et al., 2017).The concept is very much a reaction to the third industrial revolution described earlier; it is triggered by the Internet which allows a cyber-physical-system (CPS) where humans, products and machines are communicating within a large system. Industry 4.0 is believed to have a considerable impact on the manufacturing industry, as there is a greater need to handle high complexity and a change in demand towards more customized products (Nilsen & Nyberg, 2016; Wortmann et al., 2017). There is a gap between production level and ERP level. A close integration between shop floor and ERP level is often missing. Traditionally, data is not exchanged between shop floor and ERP level in real time and independently. Transferring of data between various systems at production level causes delay. In some scenarios, physical product is transferred on the conveyer belt but updated information was not loaded to carry out operations on the product which results in higher costs. Production status of a product is missing and often not in real time; hence status transparency lacked. Normally, even in state-of-the-art factories, they have only three states to update the status of the product, namely production started, in progress, and finished, and are not well integrated with ERP systems. So, a monitoring solution from factory is needed considering which information to provide, in which granularity, user roles, as same information or process may be applied on the other products. There are also issues due to data exchange with partners in a collaborative environment, e.g., sharing the process status of products and current state of the processes applied on products. Companies also have to consider that sharing information with partners does not result to lose competitive advantage or sharing critical insights. Similarly, in case of machine faults at production level are not reported at ERP level and current state of the production does not reflected. Necessary measures for machine repairs cannot be initiated because of delay in reporting. Therefore, in the present study, parameters such as: interoperability, virtualization, decentralization, real-time capabilities, and service orientation would be used to analyze the performance of industry 4.0, according to figure 1.

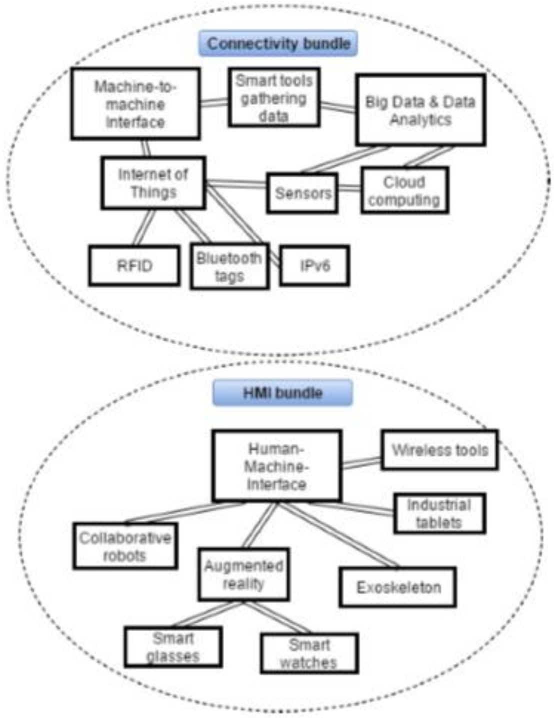

Figure 1. Technology-mapping (Nilsen & Nyberg 2016).

2. LITERATURE REVIEW

The Industry 4.0 technologies are emerging and enabled in technology bundles. The need to focus on two technology bundles: Human-Machine-Interface (HMI) bundle and the connectivity bundle. The HMI bundle is solutions for operator guidance and the interaction between humans and machines. The connectivity bundle consists of elements of Big Data & Data Analytics and Machine-to-Machine, which enable communication between tools and machines.

The direction in which we are now heading is called the fourth industrial revolution, Industry 4.0, that is, overcoming another barrier in which the coexistence of machines, devices and systems become a natural step towards the optimal use of human resources, knowledge and experience acquired over the last 300 years counted from the creation of the first steam engine by Thomas Newcomen in 1712 (Amrutrao et al., 2020) which became the foundation of the first industrial revolution (figure 2).

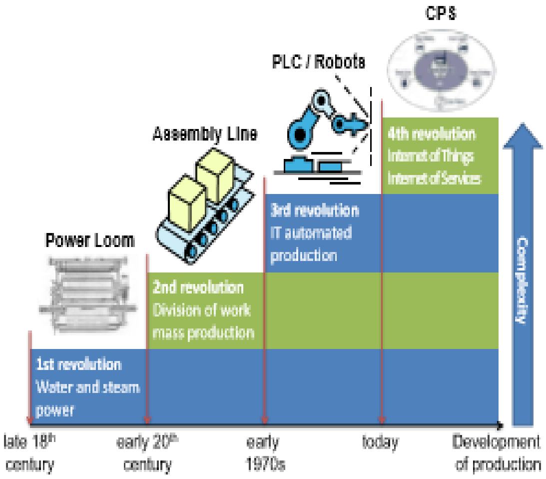

Figure 2. Four Industrial Revolutions (Koleva, 2018)

It will also allow for optimization on the basis of previously adopted criteria such as: costs, availability or consumption of available resources (Krdžalić & Hodžić, 2019). In the era of industrial revolution 4.0, workers should focus not only on acquiring the set of skills required to do the job, but also on preparing themselves to maintain 'competition with robots'. With the extended implementation of digitization and automation, workers will have to equip themselves with the right skills to 'survive' (Sreedharan & Unnikrishnan, 2017).

2.1 Design Parameters of Industry 4.0

The concept of Industry 4.0, emerged in Germany in 2011, referred to as a government economic policy based on high-tech strategies; characterized by automation, digitization of processes, and the use of electronic and information technologies in manufacturing (Amrutrao et al., 2020). Likewise, for the personalization of production, the provision of services and the creation of value-added businesses. And, due to the interaction and information exchange capacities between humans and machines. Throughout history, technological development has had a major impact on manufacturing systems, first with the steam engine and the mechanization of processes, then with mass production, automation, and robotics; and more recently, with what has been called "industry 4.0" and is already considered the "Fourth Industrial Revolution", due to its potential and benefits related to integration, innovation and process autonomy.

The concepts of industry 4.0 and smart manufacturing are relatively new and contemplate the introduction of digital technologies in the manufacturing industry. That is, the incorporation into the manufacturing environment of technologies such as the Internet of Things, Some of these technologies have already been used for years, but in isolation; however, its integration is what transforms the manufacturing industries, into fully integrated, automated and optimized production processes; and with significant results in improving operational efficiency and organizational performance (Krdžalić & Hodžić, 2019). The impact of this technological transformation is such that it is affecting all aspects of the organization, from production and organization to research and development, the cloud, big data, wireless sensor networks, embedded systems and mobile devices, among others (Rojko, 2017) management and customer support, etc. as shown in figure 3.

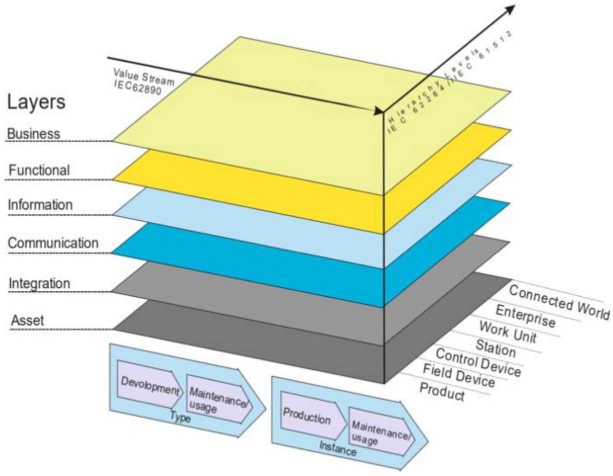

Figure 3. Reference Architecture Model Industries 4.0 (Wortmann et al., 2017)

Likewise, the business vision and performance are changing. Its impact has been such that industry 4.0 is already considered as a systemic innovation process that redefines business models and provides a fully integrated global perspective of the environment and organization (Sreedharan & Unnikrishnan, 2017). Industry 4.0 is underpinned by systems development, the Internet of Things (IoT) and the Internet of people and services (Khan & Turowski, 2016). Coupled with other technologies such as additive manufacturing, 3D printing, reverse engineering, big data and analytics, artificial intelligence, etc., which when working together, are generating significant changes not only in the manufacturing industry but also in consumer behavior and in the way of doing business (Wortmann et al., 2017) And, at the same time, they favor the construction of capacities that allow companies to adapt to market changes (Krupitzer et al., 2020).The conceptualization that exists about industry 4.0 is recent, however, it has been defined as a physical machinery and devices with sensors and software that network and allow better prediction, control and planning of business and organizational results. Also, as a term associated with the technologies and concepts of the organization's value chain (Rojas et al., 2017), which describes a production oriented to cyber-physical systems (CPS); systems with physical and computational capabilities that can interact with humans, that integrate production facilities, storage and logistics systems, as well as the establishment of networks for the creation of value (Nilsen & Nyberg, 2016). From this perspective, the changes that are taking place in manufacturing are the product of the technologies that are being developed for: 1) The digitization of production, 2) Automation, 3) The integration of capabilities (through cyber-physical systems) 4) And for manufacturing like 3D printing, reverse engineering, smart machining etc. So, in this context, Industry 4.0 is a new level of value chain organization and management , which is likely to change the way processes, supply chain, and business models operate , which is why many companies are evaluating the concepts and applications synthesized under the term Industry 4.0 to develop their own business strategies, which under this new industrial disruption, is founded on some basic principles such as interoperability, virtualization, decentralization, real-time capabilities, service orientation, etc., and where there are, for example, smart factories capable of creating virtual copies of the physical world, monitoring physical processes, self-managing, optimizing, and making decisions autonomously in real time (Rodič, 2017). There are six main design parameters of industry 4.0, they include: information transparency, e.g. virtualization, real-time capability, decentralization and autonomous decisions, technical assistance, and service orientation and finally, modularity, interoperability and interconnection as shown in figure 4.

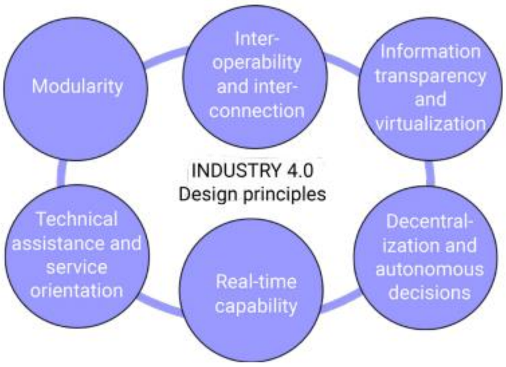

Figure 4. Six Main Design Parameters of Industry 4.0

2.2 Digital Twin

Industry 4.0 envisions interlinked and autonomous manufacturing systems self-organizing the production of small batch sizes down to lot size.

2.3 Cyber Physical Production Systems

Cyber-physical production systems (CPPS) in figure 5 shows the increasing integration of and interaction between the virtual and physical worlds in manufacturing systems. A CPS collaborates computational entities which are in intensive connections with their surrounding physical world and on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet (Saldivar et al., 2015). Cyber physical systems incorporate both CPS and CPPS.

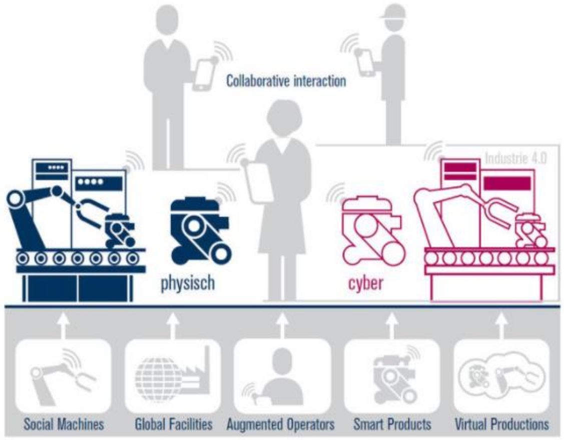

Figure 5. CPS Vision for Industries 4.0 (Wortmann et al., 2017).

Notions such as digital twins used for dynamic simulation and forecasting are not present. (Souza et al., 2020; Panetto et al., 2019), Reconfigurable Manufacturing Systems, Digital Factory (Lalanne et al., 2017; Saldivar et al., 2015) etc. The current section addresses the value chain structure, key players, as well as the key identified constraints. The value chain is based on strong linkages between the software industry and the mechanical engineering sector. It can still be considered that the uptake of CPPS is still emerging throughout Europe. Indeed, although technology needed to build CPPS is today relatively mature, there is still a lack of common standards providing guidelines for the straightforward CPPS deployment into already operating production plants. Systems provided by large companies are already available on the market but are nonetheless too costly and not necessarily adapted to a large number of manufacturing companies, such as SMEs in particular as shown in figure 6.

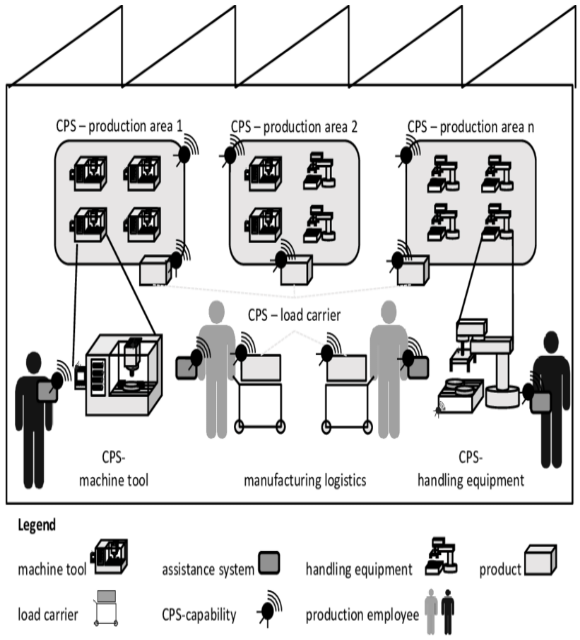

Figure 6. Scenario of the Cyber-Physical Production System (Wortmann et al., 2017).

The emergence of new business models is also noteworthy, as relevant actors along the value chain tend to increase their collaboration through partnerships (Khan & Turowski, 2016). Also, new support services, tailored to end-users' needs are emerging, such as, for instance, in the maintenance sector. The pro-active promotion and awareness raising by public authorities for the greater uptake of smart manufacturing technologies at European, national and regional levels equally play a crucial role (Lalanne et al., 2017).The second layer outlines the key steps of the supply chain following the input-output model. The main inputs of the supply chain come from two distinct industries, namely the IT and mechanical engineering industries. The input of the IT industries is mainly based on the development of software - adapted to the management and control of manufacturing companies' production process. The input of the mechanical engineering industries comprises two types of manufacturing equipment: machines (e.g. lasers, mold machines, machine tools etc.) and automation components (e.g. sensors, actuators, CNC controllers) (Lalanne et al., 2017). Product development leads to the integration of heterogeneous hardware and software components ensuring the deep interaction of information and physical systems (i.e. interaction of all components from embedded sensors, to the company's control and data centers) (Panetto et al., 2019). This system integration results into cyber-physical systems for production performance monitoring such as high-speed production monitoring systems, optomechatronic systems or overall equipment efficiency measurement and management systems. In order to be effective when installed in the production plant, the development of cyber-physical systems needs be tailored to fit the end-user's specific production requirements. Indeed, large companies are already well-engaged in the uptake of cyber-physical systems, yet manufacturing SMEs are significantly lagging behind. Finally, the third-dimension highlights six pillars necessary to the creation and existence of the entire value chain.

3. DESIGN OF A CYBER-PHYSICAL SYSTEM

Cyber space and virtual systems represented by ICT (figure 7) are now getting integrated with physical control and production systems (Saldivar et al., 2015). Systems specification, modelling and design method integration involve many aspects of integration at different levels, including:

- Integration of the physical world dimension, communication dimension and computation dimension;
- Integrated object-oriented methodology, multi-domain methodology, aspect-oriented methodology and formal techniques;
- Integration of different design views;
- Integration of the multiple specification fragments produced by applying these methods and tools; and
- Integration between informal specification methods and formal specification methods.

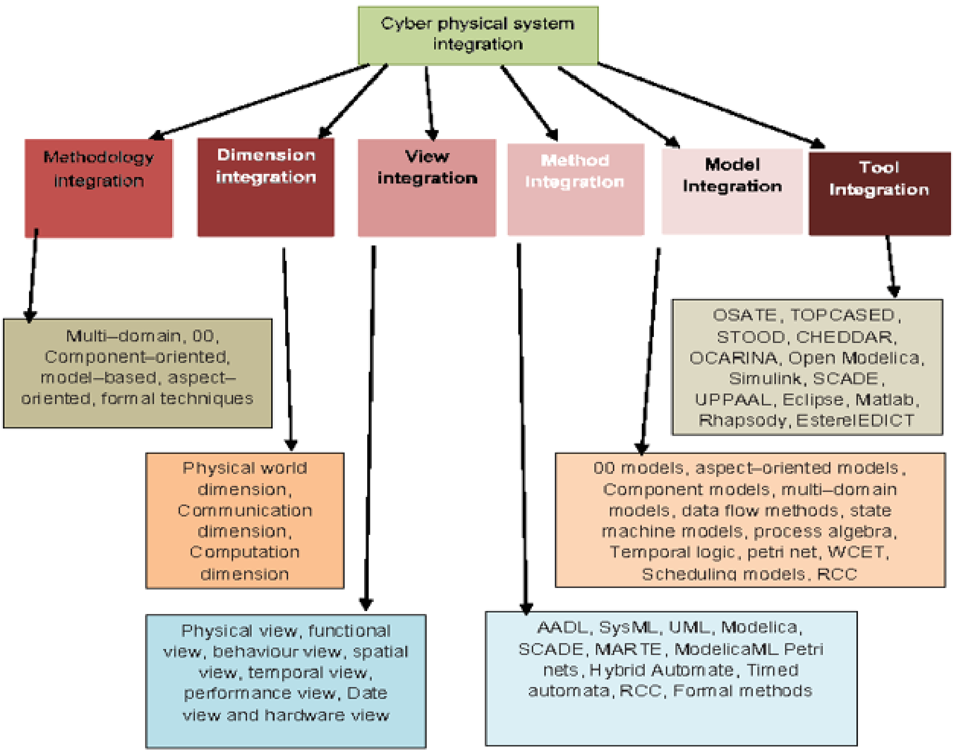

Figure 7. Integrated Approach to Develop CPS (Saldivar et al., 2015).

3.1 Methodology and Challenges

As industry 4.0 and smart manufacturing is relatively new research area, practice-based problems, and poses new challenges, case research strategy is a best candidate for it as discussed in. In this paper, we want to know and understand the stakeholder's expectations, requirements and the potential challenges industry 4.0 poses in the natural settings. Since current challenges, future expectations from industry 4.0 have been limited investigated and lack of case data in production environment from companies.

3.2 Data Challenge

New algorithms, models, products, and visualizations techniques are required to use and gain the actual benefits from the data. Data engineers are required to analyze such data and to find correlation between data streams and to gain new insights from the data which were not thought earlier. Specifically, there is a problem in which plethora of intermediate solution exists for data management within a company; it ranges from storing and exchanging data inform of printouts, emails, excel sheets, proprietary applications, and using heterogeneous database solutions between various departments or production halls. Lack of standardized approach for data management is still one of the concerns in big companies. For example, redundant data is stored in various departments of the company, in different data formats with minor extensions or enrichments. Such data silos raise the amount of data redundancy, inconsistency, and different interpretation of data. Software licenses, updates, hardware, and skilled personnel costs to manage such data landscape heterogeneity area burden in a competitive production environment. Decision made on inconsistent data leads to incorrect decision.

3.3 Data Exchange with Partners

Companies have to exchange data within their factories or departments and make sure the availability of data for other processes in time. External partners also share their data with companies to keep processes optimized, e.g., material logistics data to keep the stock level as minimum as possible. There is also trend that instead of selling manufactured products, companies share their infrastructure or production facilities with other companies for revenue gain. Data transparency is also required in this case where other companies uses infrastructure as a service. Companies have to share the progress status of such products manufactured at their production facilities with other companies and for further processes carried out on products if needed.

3.4 Training and Skill Development

Normally, especially in Germany, companies are facing shortage of skilled staff due to various factors. One of the major factors is aging population. People used to work in production are retiring and also taking production knowledge and experience they gained during their jobs. Other issue is to keep the hired persons within organization, as younger ones want to have incentives, promotion or prefer to change jobs frequently. As majority of the workforce consists of old people who do not want to learn technologies or hinder to have change in their routines work. Introducing new techniques, gadgets, or changing their way is quite challenging as they resistant to such changes. This challenge becomes manifold in case of industry 4.0 scenarios where changes are eminent factor.

3.5 Process Flexibility

As product life cycle in this decade is shorter than before. Individualized and customized products also become reality. Such individualization and customization require flexibility at production level in a cost-effective manner. In order to provide such flexibility, production environment should be adaptable at the process level. Technology, currently used at shop floor level is inadequate and does not support the process flexibility (Khan & Turowski, 2016).Traditionally, processes and systems at production level are developed and managed isolated over the time in various departments. Change management at production level is quite challenging. As processes span in various departments, a clear process ownership is also missing in case of adaptation or changes. Change structure is also needed because sometimes it is not possible to keep the required change in the specific area and will impact the whole landscape due to dependencies. In case of changes, required changes are transferred in form of printouts or using email communication. Often these changes are handled individually in each department without any specific standards which raises the complexity and costs of managing such changes. There is a need to bring process standardization and synchronizations between various company departments to provide flexibility in an effective manner.

3.6 Security

Security is also a top concern now and it will be the major concern in future for industries. Industries want to keep their people, products, and production facilities environment secure from security risks. The trend of using smart devices in production is increasing. On one hand connectivity of these devices provides great advantages to ease our lives. On the other hand, it poses greater risk from security perspective. Monitoring of such devices, used in production, is also a challenge from software and hardware perspective, which is often ignored. All devices whether industrial machines, computer, tablets, or smart phones needs to be updated on regular basis whether to avoid threats or due to configuration changes installed in these devices spread across the geographical location or inside factory. Keeping track of updates and management of such devices is a tedious task too. As some of IoT devices used at production level have very limited processing capabilities which requires new tools or methods, and measurements, to keep the devices secure instead of tradition methods. Serious measures are needed to restrict the threats posed by the malfunctioning or hacked devices. There are already various examples already happened where production facilities are targeted, e.g., security holes exploited in programmable logical controllers deployed in factories (Khan & Turowski, 2016). It is also possible that manufacture dielectronic products may contain viruses from production facility when delivered in the market, which may result heavy fines for company or product returns.

3.7 Future Scenarios for Industry 4.0

Manufacturing industry has to cope with various challenges as mentioned in previous section. Despite of those challenges, in the following, we present some of the future scenarios from industry 4.0 perspectives. The scenarios also reflect the challenges mentioned in previous section. In first scenario, we discuss that more integration of processes is required within enterprise between ERP and shop-floor level and also across enterprise boundaries for optimal and collaborative environment. Second scenario highlights the importance of real time information access to make decision. Lastly, last scenario shows the importance of predictive maintenance in a production environment (Rojas et al., 2017).

3.8 Integrated Processes

Product life-cycle involves series of processes, from design to production, service and feedback from customers. These processes can belong within the same enterprise or distributed across enterprise boundaries. Process integration is quite challenging in this case due to various technologies, interfaces, standards, methods and unique characteristics in each enterprise involved. Involving customer’s feedback or customization direct in manufacturing process will lead to improvement in the product and higher customer satisfaction. Integrated processes across the enterprise will enable to optimize and make decisions in real time. Logistics can be well optimized and out of stock or over production cases, both results in revenue losses can be eliminated. Suppliers can access to live data at shop floor level and know when to provide the required material for better resource planning and will reduce unplanned outage or overstock situations. Existing processes can be optimized and will be executed faster. In case of companies having more than one manufacturing facilities, whether in same geographical location or scattered around the globe, cross plant manufacturing and planning makes more sense if data from facilities is available and integrated. Business processes can be analyzed across plants (Saldivar et al., 2015) to find out which plant is performing better and what we can learn from one plant or how we can develop best practices for specific industry or products for the whole organization. There is also a trend in which instead of selling end products, companies sell their know-how or other services. A company can allow other companies or partners to use state of the art manufacturing facility, competency and knowledge know-how as a service to develop their own product. In this case integrated process across enterprise boundaries is a real challenge where companies have to exchange information and applying processes at hired facility in a secure and confidential way (Wortmann et al., 2017).

3.9 Real-time Data Access to/from Shop-floor Level

Real-time data access in a production is very vital whether it is related to products, processes, or machines operating in the factory. Traditionally, real time information access for processes was not available at shop floor level. In case of change in processes or actions, workers or machines have to wait until instructions are manually transferred or data is loaded in the production system. Future factories demand a close integration between ERP and shop-floor and real time access of data at production level for real time execution and vice versa (Wortmann et al., 2017). Data collected from machines and business processes is filtered, analyzed, and then delivered in required format to provide insights which in return will help to give better process control, optimize, and reduce overhead costs.

3.10 Predictive Maintenance

Maintenance of machines is an important area which every manufacturing company has to address. Manufacturing companies try to carry out planned maintenance based on different strategies like operating hours, number of products processed, or after a certain time. A machine condition monitoring system can be introduced to avoid unplanned maintenance. Machines equipped with sensors generates huge amount of data and records the operating condition in which machine operates. Historical data collected regarding machines operating conditions can play a vital role. Current state of the machine is compared with historical data and with other data in different dimensions (product quality, and wastage data). Models can be developed to predict which part of machine or machine is going to fail or vulnerable (Khan & Turowski, 2016). Machines manufacturers can collect data from machines to provide remote diagnostics and offer maintenance services from their locations. Such data can also be useful for them to know in which conditions their machines are operating and what they can learn from such data (Krupitzer et al., 2020). For example, machine manufacturers can develop next generation of machines for specific industry or buyers’ segments by understanding their operating needs based on history. Remote setting of parameter or operating conditions or providing early warning in case of machine is over used or wrongly used as compared to what it is made for. They can also send their maintenance staff to repair or diagnose the problem. Such data can be collected by the machines and transmitted to the machine manufacturer. Other option is such data is collected by the production facility and then those enterprises can collaborate to produce or offer better services.

4. RESULTS AND DISCUSSION

The rise of industry 4.0 also known as new digital industrial technology is a transformation that makes it possible to gather and analyze data across machines, enabling faster, dependable, more flexible and efficient processes to produce higher quality goods at reduced costs. This manufacturing revolution would increase production of goods and services, shift economies, foster industrial growth etc. (table 1).

Table 1. Components of Industry 4.0

Components of Industry 4.0	Issues Affecting Traditional Businesses	Digital Transformation Requirements
Interoperability	Reduction and networking of barriers	Standardization
Virtualization	Personalization and flexibility	Work organization
Decision making decentralization	Need to individualize mass production	Product availability
Real time capability	Local production	Establishing new models
Service orientation	Low price	Know – how protection
Modularity	Smart goods and services	Availability of skilled workers
Big data analysis	Globalization and decentralization of production	Professional development.

5. CONCLUSION

The concepts of industry 4.0 and smart manufacturing are relatively new and contemplate the introduction of digital technologies in the manufacturing industry. That is, the incorporation into the manufacturing environment of technologies such as the Internet of Things, Some of these technologies have already been used for years, but in isolation. Its impact has been such that industry 4.0 is already considered as a systemic innovation process that redefines business models and provides a fully integrated global perspective of the environment and organization. Industry 4.0 is underpinned by systems development, the Internet of Things (IoT) and the Internet of people and services. coupled with other technologies such as additive manufacturing, 3D printing, reverse engineering, big data and analytics, artificial intelligence, etc., which when working together, are generating significant changes not only in the manufacturing industry but also in consumer behavior and in the way of doing business. And, at the same time, they favor the construction of capacities that allow companies to adapt to market changes. The conceptualization that exists about industry 4.0 is recent, however, it has been defined as a physical machinery and devices with sensors and software that network and allow better prediction, control and planning of business and organizational results. Also, as a term associated with the technologies and concepts of the organization's value chain, which describes a production oriented to cyber-physical systems (CPS); systems with physical and computational capabilities that can interact with humans, that integrate production facilities, storage and logistics systems, as well as the establishment of networks for the creation of value. However, that, it is still in the development process, its benefits allow us to anticipate great changes, since it is associated with the digitization of information and production systems for management activities; automation systems for data acquisition from machines and production lines; with the exchange of information for monitoring and control of processes and decision-making in real time to name a few. In this same order of ideas, intelligent manufacturing is considered as the ability to digitally represent every aspect of manufacturing, from design to manufacturing - using software tools such as computer aided design and computer aided manufacturing (CAD / CAM), systems for product life cycle management (PLM) and the use of analysis, simulation and management software, etc. So, in this context, Industry 4.0 is a new level of value chain organization and management, which is likely to change the way processes, supply chain, and business models operate, which is why many companies are evaluating the concepts and applications synthesized under the term Industry 4.0 to develop their own business strategies, which under this new industrial disruption, is founded on some basic principles such as interoperability, virtualization, decentralization, real-time capabilities, service orientation, etc., and where there are, for example, smart factories capable of creating virtual copies of the physical world, monitoring physical processes, self-managing, optimizing, and making decisions autonomously in real time. The results however, showed that industry 4.0, if fully adopted would increase production of goods and services and also save time consumed during production stage. This study also established good relationship between the obtained results using interoperability, virtualization, decentralization, real-time capabilities, and service orientation as parameters for observing their performance.

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