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INDUSTRY 4.0: TOOLS AND IMPLEMENTATION

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Abstract

With the increasing demand of customisation and high-quality products, it is necessary for the industries to digitize the processes. Introduction of computers and Internet of things (IoT) devices, the processes are getting evolved and real time monitoring is got easier. With better monitoring of the processes, accurate results are being produced and accurate losses are being identified which in turn helps increasing the productivity. This introduction of computers and interaction as machines and computers is the latest industrial revolution known as Industry 4.0, where the organisation has the total control over the entire value chain of the life cycle of products. But it still remains a mere idea but an achievable one where IoT, big data, smart manufacturing and cloud-based manufacturing plays an important role. The difference between 3rd industrial revolution and 4th industrial revolution is that, Industry 4.0 also integrates human in the manufacturing process. The paper discusses about the different ways to implement the concept and the tools to be used to do the same.

Keywords

Industry 4.0, Internet of things, Cyber physical system (CPS), Smart Manufacturing, Cloud based manufacturing, Big Data.

Introduction

The phenomena of industrialization, which have shaped several centuries of history, have been strongly influenced by technological progress called Industrial Revolutions [1]. The third revolution was introduced in late 20th century and talked about Automation [2]. Most of the companies are still using the principles of the third industrial revolution [3]. "The term Industry 4.0 stands for the fourth industrial revolution which is defines as a new level of organization and control over the entire value chain of the life cycle of products, it is geared towards increasingly individualized customer requirements" [4]. Fulfilling individual customer needs is the main objective of Industry 4.0 but it also affects other areas of the industry like research and development, designing, inventory management, service and customer care [5]. This Fourth Industrial Revolution, will be the most ground-breaking driver of development throughout the next couple of decades setting off the wave of advancement [6]. The term "Industry 4.0" is associated with many other words such as "smart factory", "smart manufacturing", "big data analytics", "cyber-physical system" and "smart machines" [7]. Often referred by many scholars as the epitome of the digitization of manufacturing, this revolution refers to the accumulation of technology incorporate into successive generations of advanced tools and techniques [8].

Industry 4.0 enables the use of all these technologies in a synchronized and efficient manner [9]. Production systems are the core sector of the industries and being the most connected with engineering, the existing systems are to be upgraded in a categorized and organized manner [10]. It can't be totally recognised as a revolution because it does not involve any inventions which are based on any great breakthrough scientific discoveries, it is just the upgradation of the machines from industry 3.0 and integration with cloud computing and big data analysis [11].

Tools for Industry 4.0

The structure of the industry is being reshaped and the competition is being transformed due to the introduction of smart and connected products [12, 13]. The authors suggest that the cloud computing should not be regarded as the alternative solution but it should be regarded as an enabler to Industry 4.0 because the self-learning and self-awareness can only be achieved in Big Data environment with cloud computing being the back-bone of the whole process. The author discusses about the improving the servitization process with the help of IoT [14]. They put forward a simpler definition of IoT that which is depicted in Fig. 1, it is the connection of each and every machine to internet and each other.

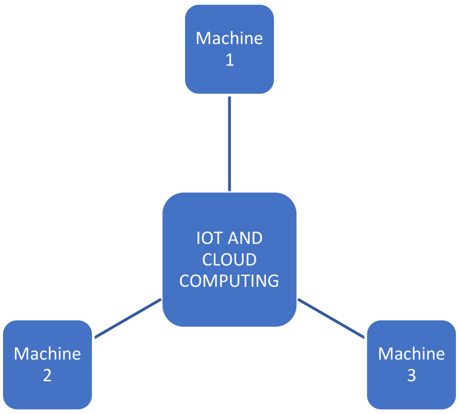

Fig. 1. Basic IoT representation.

The author says that IoT is composed of:
1) Radio Frequency Identification (RFID),
2) Wireless sensor Network (WSN),
3) Near field Communication (NFC).

WSN's are used in remote sensing application and are very cheap in terms of cost as well as power consumption and are very small which enables to use them in small spaces.

Ray Y. Zhong, Xun Xu and Lihui Wang suggests that the completely achieve the real-time production visualisation, IoT enabled Smart Factory Visibility and Traceability platform is needed [15]. iVTP is based on IoT technology and identifies various manufacturing objects. The use of RFID sensors is a great help in converting the resources to smart manufacturing objects. And by the use of laser scanners, these sensors are scanned and iVTP is able to project the real time position of these so-called smart manufacturing objects whose data could be stored in cloud storage, enabling each and every authority of the firm to access the data without wasting time.

The authors talk about implementing the Manufacturing Executing Systems (MES) technology [16]. The basis of MES are, reducing machine downtime, improving delivery times, optimizing production rates, and schedule management of operators as well as the tools they use. The author has proposed a RFID enabled MES for Industry 4.0 environment. MES model is shown in Fig. 2. The key functions of the proposed model are:
1) the data is directly acquired from machines to the supervisors in real-time manner,
2) oversees the production and directly assigns the work order according to the work priority and time taken,
3) monitors the resources and works as an ERP tool and notifies about the low quantity of raw materials [17],
4) also calculates the OEE of assembly line and compares the results with the firm's future goals,
5) corrects and improves the process done automatically.

RFID middleware is a standout amongst the most vital highlights of the MES. It is in charge of administrations that manage raw data just as between gadget correspondence. Two key functionalities are related with this administration – data collection/securing and upkeep management [18]. According to [19], introduction of Automatic guided vehicles (AGV) on the shop floor could lead to a smooth entry in implementation of Industry 4.0. The author has suggested a way where it is needed to lay down specific tracks for the AGVs which could be a little costly [20]. With the introduction of such technologies, the operator skill bar also increases, to work in such human-automation symbiosis [21].

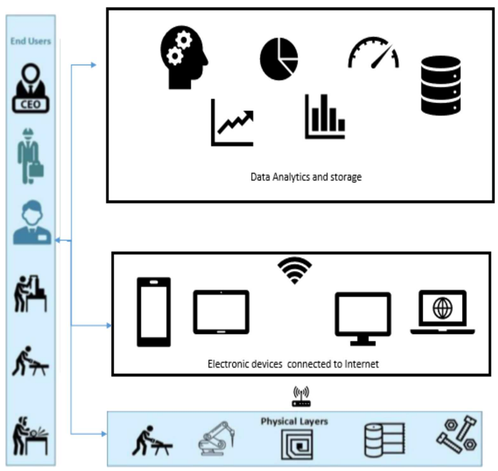

Fig. 2. MES model.

The author highlights the high significance of Artificial Intelligence (AI) and the need of systematic development and Implementation of AI on shop floor [21]. The author has pointed out the key elements of industrial AI i.e. ABCDE. It is represented in Fig. 3.

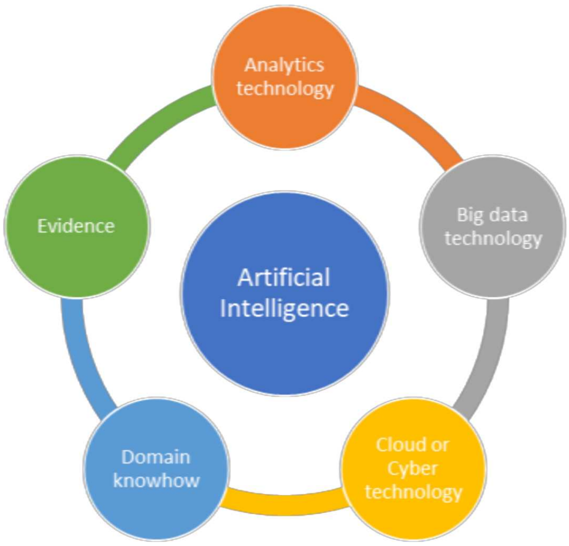

Fig. 3. AI representation.

The analytics technology is the heart of AI, but it cannot work without other elements. Domain knowhow is most of the discarded but it has intangible benefits: 1) the power of AI could be used to find the solution exactly at the point of origin by understanding the problem; 2) to collect right data and right quality by understanding the system; 3) understanding the physical meanings of the parameters [22]. The AI model can only be improved by gathering data patterns and evidence associated with that pattern [23]. And by the combination of all these, AI system could be improved to more accurate, comprehensive and robust.

According to [24], the new emerging technology has a very powerful and a game-changing impacts on manufacturing and business models. With the emergence of Industry 4.0, the models are evolving too. In smart manufacturing, main focus is about optimizing the production process by using all the available advanced technologies and information. Real time data can be collected via the use of RFID technology [25]. This allows the organization to detect the disturbances in the manufacturing process line, which in turn allows higher OEE and better decision making.

According to Miranda [26], with the introduction of new concepts and technology, mechanical engineers need to change their way of working. In the era of Industry 4.0, decision making would be based on data collection and its extensive evaluation from many different sources [27]. According to [28] using key performance indicators (KPI) would not be a wise choice because it is based on some implicit assumptions. It does not involve overall evaluation and it cannot successfully show the overall intensions of the organizations. There is a possibility that even if the partial productivity of the company is higher than its competitive company, the overall productivity may be lesser.[29] The author defines the BIG DATA with basic 5Vs i.e. volume, variety, velocity, value, and veracity, as shown in Fig. 4.

Big data can be generated continuously through getting continuous feedbacks from the shop floor machines [30, 31], but the problem is that only the small amount of collected data is useful and the organizations have limited processing power and storage and even there is a vast difference between industrial big data and other social network big data and must be treated in a different way. The storage of raw data is very difficult and its preservation is complicated as well as volatile [32].

Before using the collected data, it needs to be processed. The steps are shown in Fig. 5.

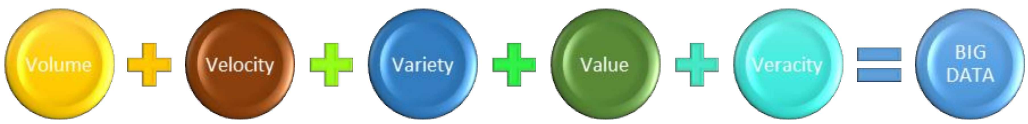

Fig. 4. 5Vs of Big Data.

Fig. 5. Steps to refine Big Data.

The author [33, 34] suggests to first understand the difference between data and information. Information is the processed and useful data which can be used by the organisation, whereas data is just the set of symbols, signs and raw facts. The processing efficiency can be regarded as data productivity and can be compared to overall effective efficiency (OEE) of manufacturing process to understand it [35]

$$\text{DPI} = (\text{Data Availability} \times \text{Data Quality} \times \text{DSS Performance}). \tag{1}$$

Data availability identifies all the data which is available to the organisation at the time of decision making. Data availability factor is the ratio of "*generated data*" to "*interesting data*". The reason for this loss is due to poor storage and infrastructure.

Data quality factors are the ones which are complete, correct and received on time. These losses occur due to slow connections and low sensor efficiency.

The DSS performance refers to the valorised, aggregated and used data. These losses occur due to poor algorithm, poor data integration and poor management. Useful data extracted from collected data is shown in Fig. 6.

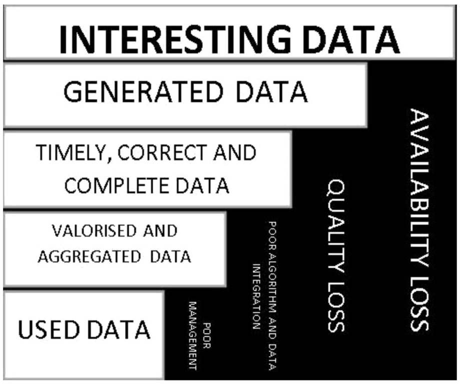

Fig. 6. Data Productivity index representation.

Along with increasing OEE of the manufacturing unit, the organizations should also try to increase the data productivity [36]. The data mining algorithms could be used for better result and dig inside the data and extract even hidden data which is valuable to the firm [37].

Vallhagen [38] has explained that with introduction of Industry 4.0, production systems will have more complex flows and therefore a great requirement for mathematically modelled and progressive planning and scheduling techniques will be required, which will always be in a state of constant change. The author has proposed an infrastructure to achieve great improvements in production efficiency which includes AI scheduling system [39, 40].

For businesses having utilitarian plants along with expanded digitalization levels, there will always be a chance for utilizing information in control frameworks as well as ERP frameworks for ideally designing the plants to increase manufacturing at the same level of investment. Most workshops have uncommon highlights in their arranging circumstance, so the planning instrument should be adjusted to the present circumstance [41]. Hence, programming that encourages the important adjustments that is required in every workshop ought to be created. It should comprise of the data interface with the workshop control system, the user interface as well as the mathematical optimization model development.

Christoph Liebrechta talks about the manufacturing systems 4.0 under ambiguity and has laid down 5 stepped evaluation method [42]. Initially it is very important to set the evaluation scope. Based on the organisation's need of CPS and its competitive advantage strategy, all the criteria including money as well as other value adding criteria are selected for evaluation. Based on these criteria, several data are composed together for an evaluation model. This evaluation model is used to integrate etymological uncertainty, qualification of criteria, monetarization of non-fiscal criteria and versatile presentation techniques. This simulation helps in evaluating the manufacturing systems that are being implemented.

For quality check and control, tools such as high-resolution camera could be used, attached with the IoT sensors which continuously uploads data in the cloud storage for the authorities to access and keep a look on it [43].

This new era of Industry 4.0 will bring out smatter generation of machine tools which are easily accessible from anywhere because of its connectivity and synchronisation with the CPS [44].

Implementations

The goal of the industry 4.0 paradigm is to setup a network among machinery to allow them to communicate and allow them to make minor decisions without any human interaction. A decentralized self-organization aided by CPS should replace the traditional production order [45]. In order to attain that level, the author suggests three dimensions of integration: (a) Horizontal Integration (b) Vertical Integration and (c) End-to-End Integration. According to McKinsey, Industry 4.0 implementations can possibly generate a value worth efficiency improvement of 15 to 20 percent. [46]

Horizontal integration refers to the factory-level integration wherein machinery interaction is carried out through the application of sensors. Vertical Integration implies an interaction between various departments within a plant and End-to-End integration comprises of interactions amongst clients, suppliers and the firm [47].

For enterprises in the production sector, providing a series of customizable products which possess a superior build quality but are price-competitive is necessary. The concept of a smart factory is crucial at that stage. It encompasses the concepts of standardisation and modularisation to techniques ranging from MRP and ERP tools. A characteristic system outline of the smart factory comprises of four primary layers – a physical resource layer, a cloud-based layer, an industrial network layer, and a regulatory control terminal layer. A smart factory could also be recognised as a "dual closed-loop system" [30], as shown in Fig. 7. The initial loop contains of the physical resources and the cloud while the other loop comprises of the regulatory control stations and the cloud.

For an efficiently modularised factory, the system should be divided to form a series of subsystems (modules) which have low levels of interdependencies. All smart objects that are present in the factory must possess adaptive learning abilities which pave way for a highly flexible manufacturing system. New product development's lead time could be decreased drastically with the use of flexibly regulating combinations of standardized modules and the time-to-market is can also be shortened significantly [48].

A key requirement for successful collaboration between several companies is the correct definition of mechanical, electrical and communication standards for each specific subsystem of the supplier. This standardization is essential to ensure interoperability between all the different modules of the production line. This allows technology suppliers to collaborate with other similar suppliers and offer the opportunity to develop the interaction of components from different suppliers in real conditions [49].

Furthermore, a restructuring of labour division within the manufacturing division will also take place [14]. Even though the machines will replace labour work, but the labour work will be shifted in terms of content but it will still remain inimitable, primarily owing to a growing need of customization which in turn leads to a growth in the demand for coordination. Factory workers must be skilled in making decisions. The role of operator is being changed with the introduction of self-controlling systems connected through the Internet and human, to system maintenance job in case of unanticipated events.

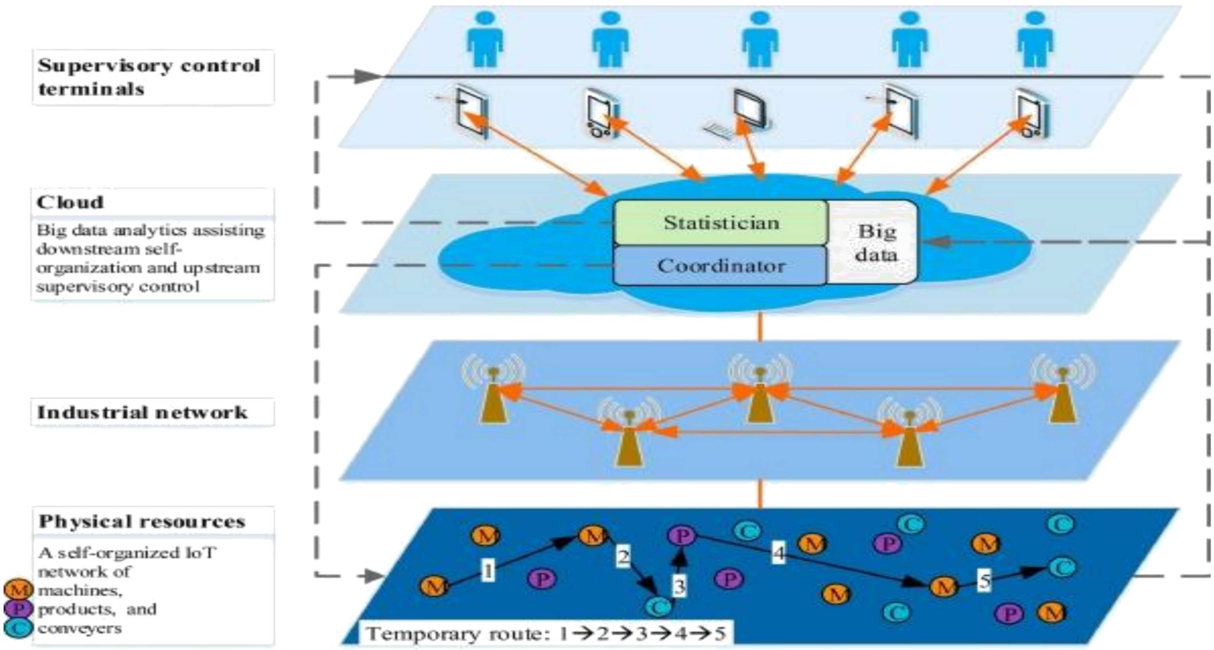

Fig. 7. Smart factory framework for Industry 4.0.

Furthermore, product planning is a crucial decision in the implementation of Industry 4.0. With every aspect of the manufacturing process getting automated, process planning should also be automated and therefore interconnected to all different parts of the supply chain as well as the process itself. Thus, process planning morphs into a wider term – Product planning. The product planning system may be divided into three steps – primary process selection, operation sequencing and machine selection-scheduling. This is represented in Fig. 8 [50]. Product planning software uses predictive analytics, such as Big Data extraction in combination with decision support systems to make optimal decisions. Techniques like CAPP and ERP are highly utilized for this step. According to a group of researchers [5], Industry 4.0 must be implemented with the proper application of 4 design principles – Technical assistance, decentralized decisions, interconnections and information transparency as in Fig. 9.

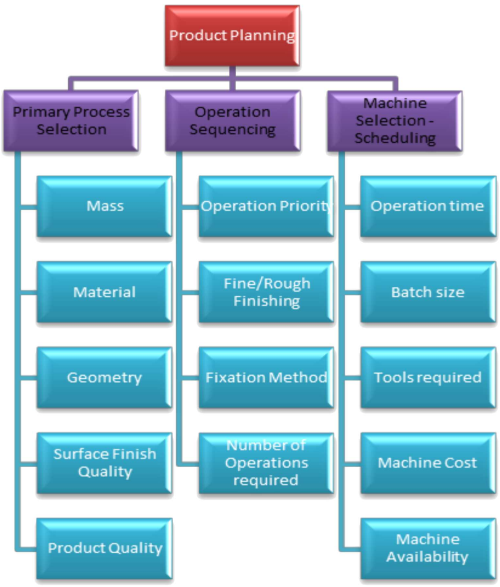

Fig. 8. Overview of product planning system.

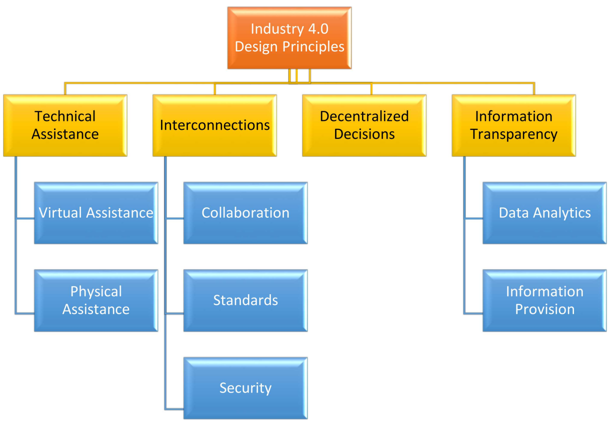

Fig. 9. Design principles for Industry 4.0.

Industry 4.0 will only be established by developing smart machines which are able to take decisions themselves such as tool change and the process selection considering different order considerations [50]. Although the tools have made a substantial influence in the planning and direction of these businesses, the full development of the potential of Industry 4.0 still requires efforts to integrate and coordinate the capabilities of each technology [51]. Application of lean techniques in combination with industry 4.0 concepts leads to great benefits for the company [17]. The authors also suggest that lean practices and Industry 4.0 could supplement each other. Industry 4.0 tools may be used to optimize lean methodologies such as total productive maintenance (TPM), kanban, just-in-time (JIT), value stream mapping, poka-yoke and heijunka. The outcome of this combined technique, known as 'Lean 4.0', can provide an integration that wants to execute a philosophy which aims towards perfection by considering the assistance from Industry 4.0 tools [52]. A hierarchical structure of KPIs allows measuring the performance under strategic, tactical and operational perspectives [53]. It acts as a necessary tool for the company to measure performance and lets them identify relationships between different KPIs.

TPM is highly crucial for autonomous maintenance. It defines a series of preventive and predictive maintenance activities that take place in the factory [54]. It greatly influences the enhancement of outcomes as well as waste material reduction, thus ensuring higher product quality. Machine learning techniques could be employed in order to predict abnormalities and process errors [55]. OEE may be used to authenticate the efficiency of the autonomous maintenance implementation by displaying the performance of equipment [56]. This indicator is widely in many businesses for validating the ratio of productive time of machinery. This allow identification of any rise in the availability of equipment [57].

IIoT has brought a wave of technological changes in logistics sectors including integrity control and transparency in supply chains [58]. Logistics improving flexibility, fast response to market change and predicting the closeness of the company to the needs of customers, is known as "smart logistics". which in turn helps in providing better service to the customer, decrease the production as well as storage expenses, and optimize the production and quality. Though smart logistics will change according to the technology used, it is highly time dependent and thus it is necessary to define the level of technology to be incorporated [59]. These systems will have a lot of implications on the procedures used for reserve sche-

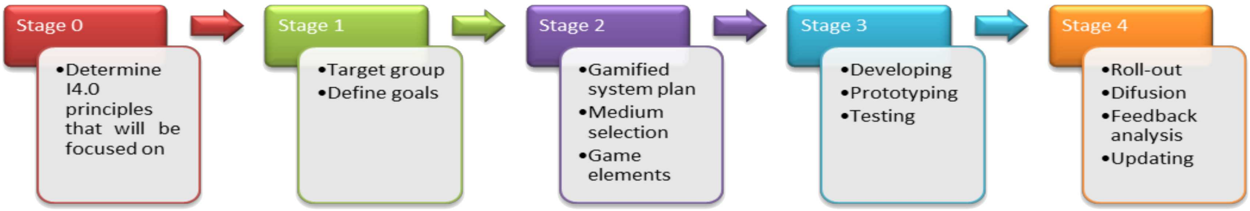

Fig. 10. Conceptual Framework of Gamified Applications for Industry 4.0.

duling [60], warehouse management systems [61] and transport management systems [62].

Cyber theft and security are one of the most concerned topics before implementing Industry 4.0 [63].

An organisation could lead to a serious loss of integrity, availability, or confidentiality if its proprietary data gets leaked. Cyber security threats can be divided into three layers [64]:
1) aware execution layer (i.e. from sensors and actuators),
2) data transport layer (i.e. from network architecture),
3) application control layer (i.e. from user data storage).

Various countermeasures must be implemented, in order to mitigate the risks generated by these cyber security threats [65]. The rudimentary countermeasures include encryption, obfuscation, fuzzing, building firewalls, antimalware, and intrusion detection systems.

Various important variations in the business models of small and medium enterprises (SMEs) are being generated due to Industry 4.0. SMEs have two pathways in front of them, i.e. user of Industry 4.0 or provider of Industry 4.0 [66]. Users are the one who primitively try and implement CPS-based solutions in various departments whereas the providers are the ones who provide these solutions to the other organizations [67]. SME response strategies can be broken down into four different types: craft manufacturers, prepress designers, Industry 4.0 users and full users [68]. Moreover, many developed business models have not considered the social aspects even though they have considered the environmental and economic aspect. In addition to an economic dimension to achieve ambidexterity in sustainability, coordination between the social and environmental dimensions is quite necessary [69]. An organisation must aim to create such a framework which implements gamification in order to tackle sustainability awareness issues [70].

Figure 10 represents a proposed conceptual framework for gamified applications for the Industry 4.0 paradigm [71].

The industries in India is still not able to adopt Industry 4.0 completely whereas the scenario in Germany is totally different, where most of the manufacturer have already started implementing the concept [72]. But due to high availability of cheap workforce in India, still the Indian manufacturers could have competitive advantage over other countries because workforce plays the most important role in attaining manufacturing competitiveness.

Issues and Challenges in Industry 4.0

Since 1980's, the introduction of different and new technologies has transformed the mechanical industries to highly automated industries. These industries are very responsive and adaptive to the customer demands [4]. While implementing the techniques of Industry 4.0, the industries may face some challenges such as [72, 73]:
- upgrading the existing machines,
- capital intensiveness,
- data processing errors [74],
- worker compatibility with the new technology,
- cyber-attack – sensitivity and susceptibility of data [63],
- due to the fresh concept of Industry 4.0, the availability of standard and benchmarked processes is very low [75],
- even after the implementation of Industry 4.0, high transmissibility of data collected from the system without any quality loss is still a major hurdle [76],
- automation is replacement of shortage of low-cost labour [77]. In a country like India where low-cost labour is available in abundance, automation takes away the job opportunities as it is more efficient and mistake proof alternative to humans,
- there can be an environmental impact. Due to automation, many energy resources are being used due to which non-renewable resources are getting depleted at a faster rate,
- with the introduction of new concepts, new business models are required and an unskilled management skill could be a greater challenge [78].

Research Outlook

The systems of Industry 4.0 are integrations between labour forces and equipment. The system is influenced by a number of factors such as 'system flexibility', 'automation level' and 'types of operations' [10]. Every manufacturing system is only able to include a few concepts of Industry 4.0, primarily interoperability [79]. The current systems are hardly standardized, making the concepts of modular factories seem like a far-fetched dream. Flexible production systems and reconfigurable production systems are the closest to Industry 4.0 systems.

Despite the continuous research being carried out in the field of Industry 4.0 by a huge number of companies, the technical roadmap of accomplishment is still unclear. Many changes need to be inculcated in the processes of quality management with respect to these newly emerging technologies as well [80].

Going deeper into this paradigm, it is clear that with a proper implementation and use of innovative tools and parameters, there will come a substantial amount of change in the economic, business and decision models of a company [81]. The performance metrics and measures as well as the customers' levels of expectations are bound to change. The standards of sophistication in practices and methods of firms will rise in order to gain a competitive advantage.

In terms of business models, the following aspects are still to be properly understood- the impacts of outsourcing and offshoring in the supply chains and logistical operations; competitive strategies that lead to pivoting and minimum viable changes for the firm; and the role played by product innovation and autonomy in the levels of quality.

There is scope for incorporating Lean production techniques as a standard approach in manufacturing systems [82]. Complementary management principles such as Just-in-time (JIT), 5S, kaizen and man-machine separation act as integrated principles. Use of value-stream mapping in improvement processes is beneficial. Developing a set of KPIs will enable the firm to obtain solutions for a certain set of problems. The user stories approach will ease the entire process as well by documenting and clustering the problems to solutions [83].

The common conclusion that can be inferred through this entire review is that there is a great need of changing the current manufacturing process and the whole paradigm is shifting towards the direction of Industry 4.0.

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