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INDUSTRY 4.0: COMPLEX, DISRUPTIVE, BUT INEVITABLE

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Abstract
Low cost manufacturing of quality products remains an essential part of present economy and technological advances made it possible. Advances and amalgamation of information technology bring the production systems at newer level. Industry 4.0, factory for future, smart factory, digital manufacturing, and industrial automation are the new buzz words of industry stalwarts and academicians. These new technological revolutions bound to change not only the complete manufacturing scenarios but many other sectors of the society. In this paper an attempt has been made to capture the essence of Industry 4.0 by redefining it in simple words, further its complex, disruptive nature and inevitability along with technologies backing it has been discussed. Its enabling role in manufacturing philosophies like Lean Manufacturing, and Flexible Manufacturing are also reported. At last the challenges its adoption and future research areas are proposed.

Keywords
Smart manufacturing, government initiatives, technologies backing, disruptive and inevitable, challenges in adoption Industry 4.0.

Introduction

Mankind is always looking for low cost quality products, while the benchmark for low cost and quality may vary from time to time and become more and more stringent with the time. The progression of manufacturing can be divided in four different ages from Industry 1.0 to Industry 4.0 each of them is driven by a major technological breakthrough at that time. First industrial revolution or Industry 1.0 was driven by mechanisation, water and steam power, followed by the use of electricity which was the driving force behind the second industrial revolution or Industry 2.0. The availability of computer and information technology (IT) led the society into the era of Industry 3.0. The advent of cyber physical systems (CPS), and real time applications of technologies placed the society on the verge of fourth industrial revolutions i.e. Industry 4.0 [1]. The changing way of manufacturing under these four major breakthroughs is compared in table no. 1 [2–4]. The introduction, and collaboration of the digital technologies like big data, internet of things (IoT), cyber physical system (CPS), etc into the manufacturing system are instrumental in transforming the traditional manufacturing system into the sought after manufacturing system of future. These revolutionary digital technologies are capable to handle, communicate and use the real time data in every aspect of production system from conceptualizing to designing, prototyping to manufacturing, and selling to servicing. The similar concepts were originated from different countries with different names. An attempt to collect such popular initiatives is made in table no. 2. Among all such initiatives Industry 4.0 is the most adopted and talked about initiative.

Industry 4.0 is an integration of various modern technologies especially IT and robotics to automate and control the manufacturing. A little difference of smart control and automation is observed by Wang and Wang [17] between digital manufacturing and smart manufacturing.

Table 1
Comparison among various industrial phases.

Variant	Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0
Product variety	Very high	Very small and limited	Mediocre	High
Productivity	Very low	Very high	High	High
Type of customization	Customized/ Craft products	Hardly any customization, mass production	Mass customization of products	• High personalization of mass products • Consumer as a co-producer
Unit Cost	High	Low	Mediocre	Low
Customer involvement	High	Low	Mediocre	High
Market type	Market of one	Market of masses	Market of many	Market of one
Time period (approx)	After 1770	After 1926	After late 1980s	Verge of time (after 2011, near future)
Driving technology	Mechanization, water and steam power	Electricity (standardization, transfer lines)	Computer and IT (CNC, PLC)	CPS and real time technologies, their integration and AI
Type of market	Simple demand driven market	Stable market	Volatile market	Unknown and uncertain
Dimension of market	One dimension: volume (only one-product)	Two dimension: volume and variety	Three dimension: volume, variety, and delivery time	Mass personalization at low cost within no time may be one more dimension

Table 2
Industry 4.0 and other similar terms.

S. No.	Term	Country/Government	Other Relevant Details
1	Industrie 4.0	Germany [5, 6]	Announced in Hannover Messse in 2011 [2, 7]
2	MOTIE: Manufacturing Innovation 3.0 or Smart Factory	South Korea [8]	MOTIE: Manufacturing innovation 3.0 from Korea in 2014 Ubiquitous Manufacturing [2, 9]
3	• Nouvelle France Industrielle • Industrie Du Futur	France	Focused on re-industrialization, leading French companies in adoption of new technologies and in the changing of business models
4	Smart Industry	Dutch	It is an action agenda aiming to make more competitive industry through faster and never before utilization of information and communication technology (ICT) [10]
5	• Fabbrica Intelligente • Industria 4.0	Italy	For development of a strategy which to It could transform the product, processes, and production system of Italian industry which leads them to a competitive advantage based on innovation and research [10]
6	Made in China 2025 [11]	China	To transform traditional manufacturing companies to adopt the new digital technologies
7	• Catapult • Smart factory [12]	United Kingdom (UK)	To strengthen the UK manufacturing companies by adopting innovation [10]
8	• Industrial Value Chain (IVI) • Connected Manufacturing • e-factory [12]	Japan	Actively discuss how to change human centric manufacturing with IoT with an objective to build a mutually connected system architecture based on collaboration among companies [10]
9	Produktion 2030	Sweden	To strengthen the manufacturing competitiveness of Swedish firms with embracement of new technology, new knowledge and good partnerships [10]
10	Industria Conectada 4.0	Spain	To promote multi-disciplinary collaboration and implementation of the Industry 4.0 technologies [10]
11	Prumsyl 4.0	Chzech Republic	It is an incentive plan for companies investing in digital transformation [10]
12	Advanced Manufacturing Partnership or Advanced Manufacturing 2.0	United State of America (USA)	To increase the competitiveness of USA through creation of high valuable jobs and securing its leadership in adoption of new technologies [10]
13	Digital Manufacturing	No link to any particular government plan is found	Similar to Industry 4.0

Table 2
[Cont.]

S. No.	Term	Country/Government	Other Relevant Details
14	Intelligent Manufacturing systems	Switzerland, Europian Union [2]	• Used as a synonym to Industry 4.0. • Industry 2025 [12]
15	Smart Manufacturing Smart factory: word first appeared in literature in 2010 [13]	No link to any particular government plan [10]	Generally used as a synonym to Industry 4.0 [10] similar to Industry 4.0 [9, 13] and originated in the USA [14]
16	Factory of future	–	Similar terms/concepts similar to Industry 4.0
17	Future of manufacturing	Norwey [2]	Similar terms/concepts similar to Industry 4.0 specific to Norwey
18	Samarth Udyog/Samarth Udyog Bharat 4.0	India	Facilitation and creation of an ecosystem for propagation of set of technologies of Industry 4.0 in every Indian manufacturing facility by 2025
19	Initiatives for Polish Industry 4.0-Future Industry Platform (Morawiecki Plan)	Poland	Comprehensive regional development through re-industrialisation, new partnerships, export oriented support measures with integration of all stakeholders concerned to Industry 4.0 and accelerated digital transformation of Polish industry [15]
20	Pramonė 4.0	Lithuania	To increase and to strengthen the competitiveness and productivity of Lithuanian industry with the integration of digital solutions with new technology [16]

Evolution of Industry 4.0

The prime objective behind the evolution of concept of Industry 4.0 is to compete with the uprising countries like India and China and to prevent the flow of wealth from developed countries like European Union and USA [6]. The major reason behind this flow of wealth is the reducing work force in developed countries [1] and availability of large pool of cheap labour in developing countries mainly India and China. The term Industry 4.0 is still evolving and shifting the paradigm of manufacturing by facilitating the real time communication among the different kinds of devices by inter-connecting them [18].

No clear and well accepted definition of concept and understanding of Industry 4.0 are yet established and published [7]. The paper aims to build an understanding of Industry 4.0. In order to develop it, an extant review of relevant literature and brainstorming with industry experts and academicians are carried out. Moeuf et al [19] reported over 100 different definitions of Industry 4.0 in the literature. Darth and Horch [20] noticed the claim of some authors that industry 4.0 is not bringing anything new rather it is merely integrating the existing technologies under the catchy names. It has novelty in amalgamation of highly sophisticated technologies in production systems. Further, all the technologies used in industry 4.0 are well established in their own work domain. The concept of industry 4.0 is integration of these technologies in automating the manufacturing systems and communicating with it. Therefore, the integration of these technologies with manufacturing system and allied areas seems in the natural progression of the technological advancement.

Industry 4.0 Defined

Though it is tough to capture and summarize the essence of Industry 4.0 into a formal definition, still an attempt has been made to define it in simple words given below:

"Industry 4.0 is a generic term used for highly complex and automated manufacturing systems, services, and business processes where devices are aware about self, communicate among themselves and humans both, further, they can be accessed remotely, and able to take remedial actions and apt decisions instantly according to situation with the use of artificial intelligence, prior experience and data available in the network and cloud."

The brief outline of rest of the paper is as follows: Technologies backing Industry 4.0 are presented in Sec. 2 with the help of a diagram. Its complexities, and disruptive nature, are elaborated in Subsec. 2.1 and 2.2 respectively. Its enabling role in achieving various Manufacturing Philosophies are discussed in Subsec. 2.3, while reasoning about it's inevitability is made Subsec. 2.4. Section 3 is devoted to the challenges ahead in adoption of it. Conclusions are drawn in section 4 and lastly scope for future work is proposed in Subsec. 4.1.

Technologies backing Industry 4.0

The Integration of number of technologies and real time communication are the essence of Industry 4.0. The number of advanced technologies founding their role in Industry 4.0 is growing and a set of such major technologies [18, 19] is represented in Fig. 1. Some authors categorised these technologies as pillars [21] of Industry 4.0. A vast literature is already available on the details of these well-known technologies. This is the reason for not going into further details of these technologies.

Complexity of Industry 4.0

As defined above Industry 4.0 is an integration of number of technologies ranging from simple mechanical manufacturing to highly advanced mechatronic systems. It deploys advanced computing, electronic control, collaborative robotics, real time communication, augmented reality, and IT with manufacturing systems. Merely the names of these technologies are enough to give an idea about their complexity. On one hand the integration and real time application of these technologies along with manufacturing and business processes manifold increases complexity while on the other hand newer and sophisticated technologies are finding their role in it. Which further adds to its complexity.

The exchange of information will take place not only among humans but among every possible pair between humans, and machines [22]. This will produce the unprecedented volume of data. Such communication not only adds in its complexity but also raises the issues of data analysis and cyber security. This is further strengthening its highly complex nature.

Disruptive nature of Industry 4.0

At present, Industry 4.0 is in its starting and developing phase. A very large volume of growing literature is available about it, its advances and role of different technologies in its era. A very few literature is available on its disruptive nature or better to say the change or disruption it may bring into the society.

The implementation of these new technologies will bring the skill shortage [10] among the existing workforce. This will compel the industry to invest re-skilling their existing employees or acquire these skills from outside or to recruit new workforce skilled on these technologies from job market. The situation will increase the demand for higher qualification as well as higher skills in qualified work force [23, 24], therefore it will elevate the demand of higher qualification. Further, the gap between highly qualified and lower qualified workforce will further be considerably widen [23]. The room for "job polarization" is also observed by Trotta and Garengo [10]. Identification, recruitment, raining, re-training, and retention of desired and dynamic workforce will be the challenge for human resource managers of smart organizations [25] of future.

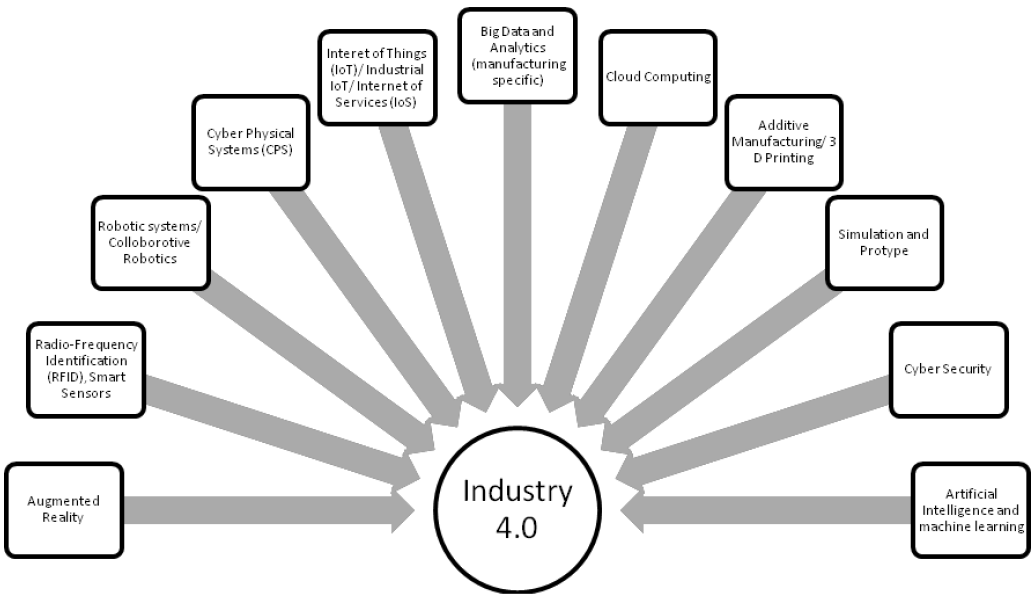

Fig. 1. Major Technologies backing Industry 4.0.

Osborne and Strokosh [26] estimated that 47% of total US employment is on risk due to computerization. Nagy et al. [25] reported that people are frightened due to possible job losses due to digitization and robotics. The ratio of vulnerability to new jobs for Germany is 7:6 as analyses by Arntz et al. [27]. In November 2017, McKinesy, a consulting firm pointed that almost 800 million jobs are at risk due to adoption and implementation of new technologies and push for the automation [10]. Loss of jobs will also be the reason for people migration from one place to other. Findings of study of German Manufacturing Small and Medium Enterprises (SME) by Sommer [28] revealed that smaller SMEs may be the victims of this revolution rather being the beneficiary.

The boundaries of traditional engineering disciplines are disappearing, and sooner will completely be vanished with adoption of this industrial revolution academia has the responsibility to produce the industry ready man-power. Academic institutions which are following traditional disciplines from centuries will no longer be able to follow the same practices. They have to change themselves to introduce the interdisciplinary as well as multi-disciplinary courses which suits to this industrial era and make students not only able to handle these technologies but also apply them in real industrial situations. In order to introduce the courses able to match with the skill demand of trainees, academia has to train and to skill their faculty and trainers in tune with the changing pace of industry with a futuristic vision and adaptability.

The risk of cyber security, crime, and unethical use of these advanced technologies are there. New regulatory frame work for adoption of artificial intelligence and other set of other technologies under the umbrella of Industry 4.0 will be required. Effective and strict laws to deal with will be the need of hour.

In the light of above discussions it will not be appropriate to say that it will create a disruption among the present ecosystem as well as will bring the new opportunities in it.

Manufacturing philosophies & Industry 4.0

Lean Manufacturing, Agile Manufacturing, and Flexible Manufacturing are remained few most sought after terms for manufacturing industry around the globe during last century, event at present adoption of these manufacturing philosophies proposed during industry 3.0 era are the distant dream for some. Large numbers of industries are still using the practices of Industry 2.0 era [28].

Sanders et al. [30] reported that the concepts of lean manufacturing can be implemented successfully through the technologies of Industry 4.0. Buer et al. [7] rightly remarked that Industry 4.0 supports lean manufacturing. Companies adopting automation be benefitted from the methods of lean manufacturing. Flexibility is the key of success to a manufacturing system and number of flexibility dimensions [31, 32] are required to be a true flexible manufacturing system, these dimensions of flexibility can be realized by adopting advance technologies of Industry 4.0. Industry 4.0 is the solution for implementation of complete flexible manufacturing system [33]. It can be said that the manufacturing philosophies like lean manufacturing, agile manufacturing, flexible manufacturing, just in time, etc conceptualised during the time 3^{rd} industrial revolution can be achieved at their full potential by using the enabling technologies of fourth industrial revolutions. It is a set of advanced technologies facilitating in implementation and adaption of above mentioned manufacturing philosophies. It has the ability to realize the factory of dream into a reality in near future. It infers that Industry 4.0 is a natural technological progression of manufacturing.

Inevitability of Industry 4.0

At present, customer behaves like a king but in near future customer behaviour will be like a dictator. High personalization at low cost within no time will be the reality. Quality of service and response will be the differentiating factor. The firms have to serve the customer within no time, not only to excel but to survive in the market. This will be achieved only with the help of technological advancement as envisioned in Industry 4.0. In addition to Industry 4.0 initiatives mentioned in table no. 2, other countries like Hungary, COSME (Turkey, Iceland, Serbia) countries, Austria, Slovenia, Luxembourg, Latvia, Slovakia, The Netherlands, Portugal, Czech Republic, Belgium, Denmark, etc are also started their national initiatives to adopt these digital technologies. In India, industrial bodies like FICCI, CII, and ASSOCHAM are taking initiatives and conducting awareness programmes for Industry 4.0. The quantum and promptness of government and industrial initiatives to adopt and implement these technologies in manufacturing and services itself is an evidence to establish importance and inevitability of Industry 4.0 practices.

Challenges in adoption of Industry 4.0

Change is the core element of nature. Every change brings some disruption in one or more aspect of life, Industry 4.0 is not an exception of it. Though, it has a great potential to change practices

and economics of our society positively [34] but it has it's own challenges. The fourth industrial revolution will not only bring technological change but it will affect the society in many aspects including socio-economic, cultural, ecological [34], social, and economical. It will impact the current practices of manufacturing, healthcare, education, hospitality, services, and almost all other business practices in many aspects. Some major potential challenges and issues ahead in adoption of Industry 4.0 [3, 21, 34–37] are represented by a self explanatory Fig. 2. Some authors [3, 21, 34–37] have elaborated and named as challenges in adoption to Industry 4.0 while others [37–39] have discussed and called them as barriers. In addition to the challenges mentioned in the Fig. 2, unknown environmental side effects may be a general issue as the implementation of these new technologies in an integrated manner [35].

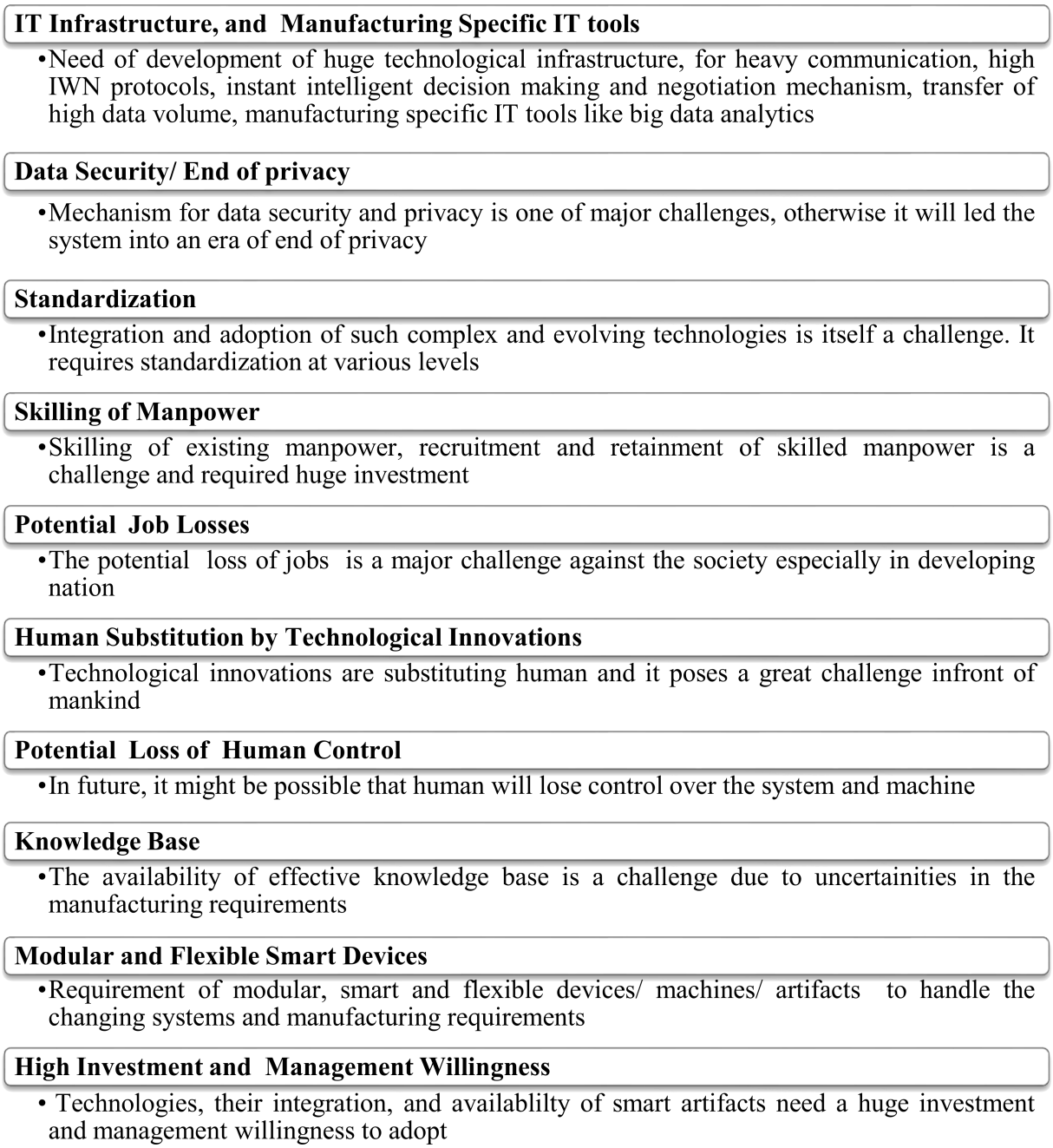

Fig. 2. Challenges ahead in implementation of Industry 4.0.

Conclusion

The paper presents a comprehensive study about industrial revolution on the horizon [3] named Industry 4.0 and attempts to capture its essence in simplest words. In near future after adoption of Industry 4.0, everyone is on a level platform the advantage of cheap labour will be no more in the favour of developing countries. In order to sustain in forthcoming manufacturing era the industries had to develop the capabilities to design and manufacture the innovative and personalised products as per the varying customer taste and demand within in no time, economically and efficiently. This will redefine the complete manufacturing landscape, requirement of skill set, educational practices, and services etc. Though, Industry 4.0 is complex, disruptive but it is inevitable, still no country of world can isolate itself form adoption of it, Sooner or later every country and every industry has to adopt it. Major industrial countries already started taking steps towards its implementation. Some of Industries like Amazon, Boing, Nokia, etc have already started practicing the concept and tools of Industry 4.0 in their day to day operations and others have to follow. It would be appropriate to remark that it should be taken as "Opportunity 4.0".

Scope for future work

Further studies may be carried out in real implementation, opportunities, enablers and barriers of Industry 4.0. Studies establishing the prominance and inter-relationships of barriers and enablers would be beneficial for further implementations. Some empirical studies of industry readiness for implementation of Industry 4.0, will be beneficial in developing a Industry 4.0 framework for smooth transition from present industrial scenario especially in small, medium and micro enterprises to smart manufacturing with a futuristic vision.

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