*The Nucleus* **55**, *No. 4 (2018)* 182-192

www.thenucleuspak.org.pk

**The Nucleus**
ISSN 0029-5698 (Print)
ISSN 2306-6539 (Online)

# Pattern of Industrial Growth and Revolutions

T. Hussain[1*] and M.H. Aziz[2]

[1]*Department of Industrial Engineering, University of Engineering and Technology, Taxila, Pakistan*

[2]*System Science and Industrial Engineering Department, Binghamton University, New York, USA*

ARTICLE INFO

*Article history*:
*Received : 25 January, 2018*
*Accepted : 29 November, 2018*
*Published : 20 December, 2018*

*Keywords*:
*GDP*
*Meso*
*Innovation*
*Disruption*
*Sustaining*
*Kondratief*
*Juglar Cycle.*

ABSTRACT

*The world begun industrial development in eighteenth century and experienced four industrial revolutions which made a huge impact on economic growth. Those countries rose as an economic power which adopted and worked on advance technology in each industrial revolution. Advent of technology could be attributed to chance, choice or crises that could be either disruptive or sustaining in nature. Two theories are used to discuss the growth pattern of economy named as: Theory of long waves and Theory of production revolutions. Kondratieff and Juglar cycles have applied to map each revolutions along with its elements that have prevailed the economy. There is a link between industrial growth patterns and GDP. Further, these revolutions have three phases (pre, during and post revolution) which effect the micro, meso and macro level in both positive and negative way. However, as far as overall industrial development cycle is concerned, theory of production revolution proposes that we are now in the intermediate phase of industrial growth and most probably its falling phase will start in 2070. Moreover, theory of long waves suggest that fourth revolution is now in rising phase and will reach to peak in coming 50-60 years in the form of decentralized self-regulating system. Circumstances suggest that increase of autonomous system and bio-technology will raise unemployment along with life expectancy. As a result, world might face safety, security, health, food and accommodation issues. Industries will tend towards micro-economy and they may face reliability, data security, employee loyalty and flexibility problems. According to corresponding relationship of industrial growth and revolution, we expect that next industrial revolution would be crises based and bio-technology would concentrate on control of human's emotions. Scientific progress and research will enhance due to the rise of Quantum Informatics.*

## 1. Introduction

World has experienced four industrial revolutions. The term "industrial revolution" was constituted by Britain in early nineteenth century where it established the basic framework of investigation and research used by large enterprises. It played an important role in Britain economy and then spread into other parts of the world [1]. Prior to that, it was a family based system till the middle ages. They raised their own food, made clothes, put up houses and met other needs from their own resources. Then came the handicrafts system and the main characteristic of that system was specialization of some particular work. At third stage, handicraft system was being replaced by domestic system in which the workers were having their own tools with them but the input raw materials were supplied by the intermediators and the output products produced were sold to the consumer by the intermediators. With the passage of time, factory system developed satisfying the economic needs of individuals, communities and countries by manufacturing products/goods in factories by utilization of men, materials, machines and methods to meet the market demands [2].

In product and manufacturing system (see Fig. 1), the first industrial revolution began in Britain in the late 18th century which replaced hand working with machines in textile industry. This revolution began with the born of factory system [3]. The second revolution was a period of rapid industrial development mostly in Britain, Germany, United States, France, Italy and Japan and characterized by the build out of railroads, large-scale iron and steel production, widespread use of machinery in manufacturing, greatly increased use of steam power [4] and telegraph, use of petroleum and the beginning of electrification. It also was the period during which modern organizational methods for operating large scale businesses came into existence. The third revolution came in the form of digital manufacturing system [5]. 3D printer, additive manufacturing, clever software, automation system and robotics have introduced in that era [6, 7]. Industry revolution 4.0 also called "smart factory", is the current popular trend of automation and data exchange in manufacturing technologies which includes cyber-physical systems, the internet of things and cloud computing [8, 9]. Fig. 1 provides a comprehensive summary of industrial revolution and their progress elements. Mechanization had started the development process with its element of steam engine which boost up the researchers to discover the electrification in second revolution [10]. Working with machines and electricity demanded a quick communication process as it losses the time resources. As a result, information technology and electronics came up which provide grounds for automation and internet of things for fourth revolution (Fig. 1).

* *Corresponding author :* *tajamalhussain53@yahoo.com*

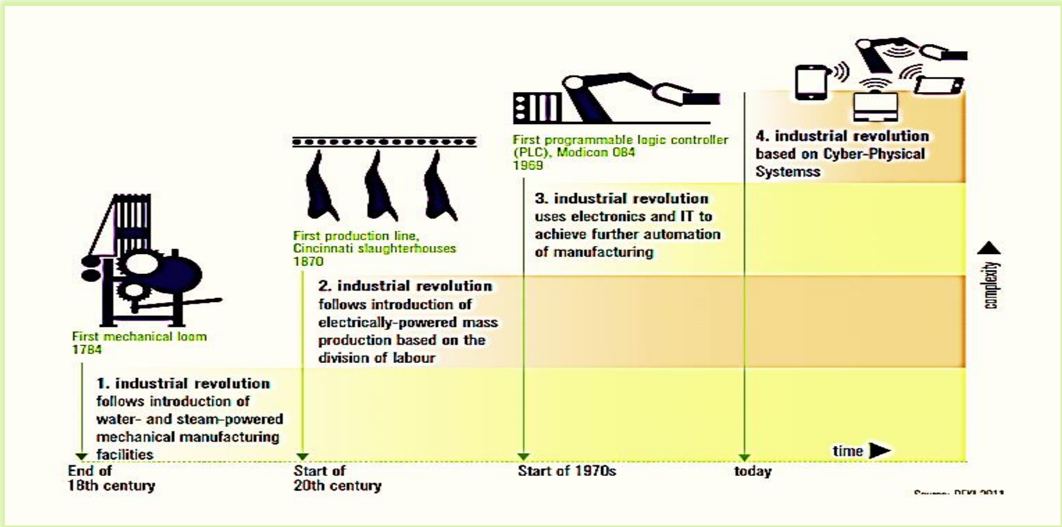


Fig. 1: Four industrial revolutions discussed by Veza et al. [10].

Revolutions have brought advance technology of manufacturing. At present, several manufacturing terms are used by researchers such as Direct Digital Manufacturing, Smart manufacturing, Cloud manufacturing (CMfg), Advance Manufacturing Technology (AMT) and Industry 4.0.

There are two types of technology change: it could be disruptive or sustaining [11]. Disruptive innovation disrupts an existing market and replaces with new market as Wikipedia disrupted the traditional encyclopedia. Whereas, sustaining technology incrementally improves the existing technology. Further, sustaining technology could be evolutionary or revolutionary [12]. Evolutionary changes bring about gradual and progressive development [13] for instance carburetors were displaced by fuel injection for gasoline. On the other hand, revolutionary changes appear unexpectedly but remain unable to make an impact on existing technology such as the first automobile appeared surprisingly but very few were actually sold.

Technology change follows a specific roadmap or pattern. New technology develops after creation of unmet need which is necessary to be accomplished. Researchers present their ideas which are screened, identified and after selection of the best idea, it takes long time to be developed and implemented. Although, new technology has associated high risks but once deployed in the market, it achieves a much faster penetration and higher degree of impact than the existing technology [14]. Technology change effects the established internal and external environment. If disruptive innovation comes, the already existing technology gets vanished and established a complete new market [15]. This new technology then starts a journey of incremental improvements until the investment in it remains beneficial. At the peak point, industrial environment reaches the leverage limit and does not value the enhancement [16]. Then a new need arises and provides opportunity for new technology to appear and, the old one to vanish and this cycle repeats again. One example of this cycle is the modern research directions that led to basic changes in the design of cellular networks towards fifth generation (5G) [17]. It is also found that large national level firms have played the major role in the advent of technology and small firms are more involved in commercializing the technology. Small firms need to upgrade so that they can participate in developing disruptive technologies [18]. Hence there is a need to discuss that how industrial revolutions came and provide ground for industrial growth. Although various approaches are available but long-wave theory best fit on it. Kondratieff cycle period is 40 to 60 years and each revolution came almost under this period. On the other hand, Juglar cycle period is 7 to 12 years which means that each Kondratieff cycle consist of 4 to 5 Juglar cycles which depicts the progress of revolution. In this way, each Kondratieff and Juglar cycle provide input for next cycle until we reach the present revolution. Previous researchers discussed the various reasons of revolutions but in a general broad way, it can be classified into three ways as by chance, choice and crises. Other reasons can be categorized under these broad conditions. Moreover, theory of production revolution is a concept which describe very large qualitative stages of development of the world productive forces in the historical process; whereas, every new production surpasses the previous one in a fundamental way. It designates the whole progress pattern of revolutions. In this paper we have discussed the following:

1. Review of four industrial revolution using Long waves and Juglar cycles.
2. Casual attribution of industrial revolution as by chance or by choice or by crisis (3Cs).
3. Categorize each revolution as disruptive or sustaining and tagged their hosting regions/countries.

4. Further explored the phases of an industrial revolution as pre, during and post.
5. Discussion of economic rise and fall due to revolutions.
6. Comparison of four revolutions with overall industrial growth and forecasting the future trends.

## 2. Review of Industrial Revolutions

Before industrial revolution, artisans did innovation but without systematic knowledge. Economic activities were slow paced, almost in stagnant position and then all of a sudden, growth of coal, mining, cotton industry and pig-iron integrated with the steam engine to many-fold the economic growth. In seventeenth century, iron works mostly depended on utilization of charcoal but it was available in little amount with high process. Also it required more powerful air pumps due to which John Smeaton introduced the first piston driven air pumps but after few years in 1776, Wilkinson invented steam engine overshadowed by James Watt's condensation steam engine in 1779 that proved to be a great breakthrough in that era [19]. All pre-conditions developed one after another by chance resulted into mechanization of the industry.

People began to study and apply natural processes to industrial process due to which industrial knowledge started to enhance and systemized day by day. Those prescribed and propositional knowledge were functions of innovative systems that became the base of economy change and produced effective innovations [20]. Division of knowledge and specialization begin in eighteenth century which provided easy access to the related best knowledge.

American innovators then started innovation on the basis of systematized knowledge to provide ground for second industrial breakthrough. A society in which rapid growth became the norm after gathering of all prescribed useful information [21, 22]. Electric light, telephones, internal combustion engines and engineering industries (chemical and sewing industries mostly) emerged. Besides, a rapid growth occurred in the manufacturing of electrical equipment and utilities. Second revolution was a choice in pursuit of American dream; at one side freed slavery, at other side division of labor and mass customization.

This division of labor, though freed, resulted into mass inequality and later world witnessed two world wars and residual cold war. The third industrial revolution was the result of crises and the effort to diminish the effect of it. Rate of major innovations began to slow down after 1950 as an actual decline occur in domestic petroleum production and steel output. All energy-intensive and material-intensive products of second revolution reached to a point of saturation in US and Europe. At that critical limit, the impacts of fossil fuels threatened the environment and further development of economy. These challenges came along with opportunities and an impressive potential for innovation [23, 24]. To save space and energy and time and computation; demand for small cars, rise of Toyota production system, mass customization, huge research and development (R & D) investment in computers, vision for automatic factory brought the industry towards Industry revolution 4.0.

The concept of Industry 4.0 or fourth industrial revolution came with the step forward by Germany. Mechanization, electrification and digitalization have been integrated in it to produce a Cyber Physical System (CPS) and the Internet of Things (IoT) and Services. Smart networking, mobility, flexibility, integration of customers and new innovative business models are the basic characteristics of Industry 4.0 [25]. As this revolution came due to entrepreneurial work of Germany, along with US and EU, China also emerged on the industrial scale with proper working and research, hence we attribute fourth revolution by choice.

Coal and iron provided the fundamental base for steam engine in the first revolution and it disrupted the old working methods [26]. Oil, electricity and mass production brought revolution due to which first revolution faded into second. Sustainable development always emerge as a global strategic vision that we should address to overcome the economic, social, environmental and technological challenges [27]. Third revolution had attempted to make a contribution for those challenges. Nowadays, 3-D printing [28], IoT, cloud manufacturing and electronics automation have disrupted the old production methods. Table 1 summarizes the reason, type and hosting region of revolutions.

Schumpeter's theory of long waves described the technological revolutions underlying the 'Kondratieff cycles' of economic development from 1780 to 2000 [29-31]. In 1920, Nikolai Kondratieff observed the historical record of some economic indicators available to him which indicate a cyclic regularity of phases of gradual increases in

Table 1: Reasons, types and corresponding cycles of revolutions.

| Revolution | Kondratieff cycle years | Juglar cycle numbers | Reason | Type of revolution | Host countries |
|---|---|---|---|---|---|
| First | 1780-1840 | 4 | Chance | Disruptive | Britain [33] |
| Second | 1890-1950 | 4 | Choice | Disruptive | USA, Japan, Germany [34, 35] |
| Third | 1970-2010 | 3 | Crises | Sustaining | USA, China, Japan [24, 36] |
| Fourth | 2011-Today | 3 | Choice | Disruptive | Germany, China [37, 38] |

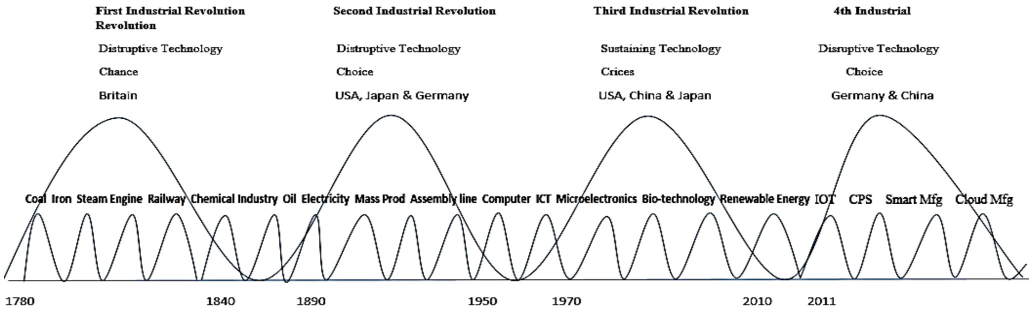


Fig. 2: Kondratieff cycle depicts revolution and Juglar cycle its components as used [32].

values of respective indicators. It is followed by phases of decline the period of these apparent oscillations seemed to him to be around 50 years. This pattern was found by him with respect to such indicators as prices, interest rates, foreign trade, coal and pig iron production (as well as some other production indicators) for some major Western economies (first of all England, France and the United States), whereas the long waves in pig iron and coal production were claimed to be detected since the 1870s for the world level as well. In 2009, Reijnders [32] used the 'Kondratieff cycles' to explain the rise and fall of GDP from 1800 to 1913. Economic theory explains the following cyclical components:

a. 'Kitchin' cycles with an average interval of 3–5 years.

b. 'Juglar' cycles with an average interval of 7–12 years.

c. 'Kuznets' cycles with an average interval of 15–25 years.

d. 'Kondratieff' cycles with an average interval of 40–60 years.

Previous researchers have applied different cycles to describe economic rise and fall but in this paper, we have integrated Kondratieff and Juglar cycles to map industrial patterns as these are best fit according to period difference of revolutions and its elements. Although, previous researchers have explained the revolutions and growth but they did not discuss 3C's, disruption and sustaining factors with proper orientation. In this paper, we compare the four revolution cycles with overall industrial growth in terms of theories. Every revolution provided input for the next and we are now confronting with the fourth revolution (see Fig. 2). Future develops out of the past and present as certain patterns have a wide range of applications. We can use our knowledge of the trends of past and present to forecast the future developments. Some predictive theories are quite helpful in this regard [39]. In this paper we have discussed the theory of long cycles and the theory of production revolutions. Theory of long waves allowed us to discuss the revolutions one by one with each revolution and its elements are inputs for the next one (see Fig. 2). This projection describes the present position of the fourth revolution. Juglar cycle further depicts the innovative components of revolution. Theory of production revolution has been used to study overall growth pattern of industries.

Pattern of any revolution can be understood by taking determinants of all three phases (pre, during and post) of industrial revolution.

## 3. Phases of Industrial Revolution

### *3.1. Pre-Industrial Revolution Stage*

Various determinants on different scales make significant impacts and provide ground for advance technology to come into existence. According to Taalbi [40], there are four forces that drive the innovation: (1) institutional research, (2) problematic research, (3) market opportunities and (4) technological opportunities. These factors provide an environment to assume that future technology will come through chance, choice or crises. If research done by routinized research and development towards the direction of innovation and made impact on social and economic level, it is called institutional search and came by choice. Innovation can be due to market opportunities done due to customer requirement or unexploited market niche. Technological opportunity search is practiced when there is a forecasting of upcoming new technology. Both market and technology opportunities are backbone of innovation that came by chance. Problematic research is usually crises based which includes the imbalance and dissatisfaction with current situation of affairs. Five categories of problems drive the innovation regarding all three levels:

*Economic problems* due to change in factor prices, profits or obstacles.

*Environmental problems* may be due to negative effects of industrial products that effect the peoples other than producer and consumer.

*Organizational problems* due to occupational noise. Toxic welding gas is harmful primarily for organization but it may negatively affect the environment as well.

*Technological bottlenecks* such as insufficient performance of technological components.

*Miscellaneous barriers* due to firm specific problems like medical technical problems [41]. Medium-high industries usually do problematic research while technological opportunities dominate in high technical industries [41]. Invention and innovation aggregates and results into useful technology generally led by strong educated leadership or entrepreneur [42]. Often macro-economic conditions get poor and government top leadership decides to encourage entrepreneur for innovation. Higher educational institutes like universities, research institutes, national laboratories, academies, startup and large customer firms are fundamental actors of innovation [43]. Sometimes government policies establish an environment for industrial sector and due to which inward transaction of technology with outward make plan for innovation [44]. However, technology strategy and aggressiveness are main determinants.

According to modern endogenous growth theory; human capital, R & D, physical capital and economies play an important role in innovation. Sometimes, selfish consideration of advancement, natural human drives of greed and ambition are motivational factor for innovation. In 4th revolution, crises do not drive the innovation. By using the prescribed and propositional knowledge, there comes vast variety of choices for innovators. Hence, there is a competition of investment on R & D for technology boom in modern days.

Culture plays a vital role in industrial revolutions as people rely on individual and collective culture in adopting the new technology [45]. There is always a choice at micro, meso and macro level to grow specific culture. Government leadership and meso level top management play a serious role in it. There are three types of cultures:

1. Inter-organizational culture prevails in the organization.
2. Organizational culture that exist between different industrial organizations.
3. Outside organizational culture which effect and interact with organizational culture and national or international culture.

At meso level, top management, employees, customers, R & D, organizational environment, organizational strategy, production orientation, human resource management, firm size, its market position and adopted technology, all constitute a culture which favors or rejects something. Top management has a choice to create any kind of working environment. Usually, anything imposed by top management becomes the part of that culture. Top management, organizational strategy and HRM lead to create a specific culture in the organization [46-48]. Culture between different organizations include monopoly, competition, customer choice and market trends while determinants of outside organizational culture are global environment, government policies, government leadership, country economic growth and its position at international level.

In developed countries, institutions focus on incremental and continuous modification tending towards maturity while developing countries in contrast, have been focused to build institutions, disruption of institutions and interactions of informal and formal institutions [49]. Often, institutional change in developing countries come discontinuously due to unstable institutional environment.

### *3.2 Industrial Revolution Stage*

Industrial shift underwent a transition in industrial economy and massive structural changes took place where innovation became the domain of in-house R & D of established firms. In advance industrial economic countries, manufacturing firms undertake expensive in-house R & D which cannot be supported in countries that have developing economy. In this way, economies go through specific life cycle from initial backwardness to industrial maturity. Firms that successfully implement the innovation create short time monopoly, produce profitable intermediate goods and set up in-house R & D facilities to produce a continuous flow of low cost innovations [50, 51]. A relationship of economic development between meso and macro level is such that the size of market increases with the number of firms at macro level is called specialization effect but reduction of their market share is called fragmentation effect. It eventually reaches at equilibrium; at that point, each firm setup R & D facilities and growth becomes self-sustaining.

At macro level, usually legitimacy has been considered as the most critical issue [52]. Other factors can be countries economic position, latent demand for products, competitive pressures from related industries, skills of new venture owners and works that may affect the implementation of innovation. For abrupt growth in economy, government should not abide entrepreneurs to implement the new technology. Assembling resources, identifying opportunities, recruiting and training of employees are all

Table 2: Relationship between revolutions and growth. Values of GDP per capita and time to show full effects.

| Revolution number | Time to show full effects | Economic GDP per Capita growth | Revolution due to |
|---|---|---|---|
| First (1780-1840) | 150 years | $ 3,450 | Chance |
| Second (1890-1950) | 100 years | $ 6,350 | Choice |
| Third (1970-2010) | 47 years | $32,000 | Crises |
| Fourth (2011- ) | Continue phase | $57,466.79 | Choice |

savior challenges for entrepreneurs and all these activities require the cooperation and strategic interaction of individuals and groups [53]. After top leadership of government, top management of firms are reluctant to trust on new technology [54]. Hence, trust and perceived risk are major first level determinants of success.

### *3.3 Post-Industrial Revolution Stage*

Revolutions make vast impact on micro, meso and macro level in both positive and negative ways. Innovations replace old methods and processes with composition of systems get change. This leads to structural change and economic development [55]. Industrial sector follow a specific life cycle in wide range of circumstances. Revolution in manufacturing technology and its implementation successfully in organizations results in economic development which in turn give rise to new sector of products [56]. Each new sector has some entry and exit point. An adjustment gap created after innovation and new sector has the potential ability to enter in the market with the availability of finance. However, it creates temporary monopoly of new sector before imitation begins and raised the intensity of competition within the sector [57]. Initially, the market is empty and neither the production capacity nor a structured demand exists for new product. After imitation, market gets saturated and large adjustment gap starts to decrease and eventually reaches to zero. Adjustment gap means difference between demand at new sector and demand when production imitation reaches its maximum. Hence, each new industrial sector (meso level) follows a circular life cycle with number of firms enter and reach at its maximum, composition of technology structure changes, an equilibrium establishes between supply and demand and finally falling down towards an exit.

## 4. Comparison of Revolutions with Economy

History depicts that there was no significant economic growth before 1750, suggesting that the quick progress made over the past 250 years happened due to the advent of industrial revolutions with GDP values [58] mentioned and summarized in Table 2. The economic development established by the U.K. before 1750, gradually began to grow more rapidly after first revolution, reached to its fastest growth rate in the middle of the 20th century and slowed down since. In first revolution, U.K. became the most influential region due to its development of coal, iron, steam, machine tools, cotton industry and inauguration of factory system that played an important role in fundamental drive of subsequent economic growth. Although second revolution begin in 1890 but leadership of economic development shifted to US in 1906. However, both the first two revolutions required more than 100 years to show their full effects through the economy. The follow-up relationship between revolutions and growth is presented in Table 2. Values of GDP per capita and time to show full effects have been taken from [58].

Implementation process was much faster for third revolution. Taking the inventions and their adoption together, many of these processes could happen only once. After 1970, productivity growth slowed down significantly due to fossil fuel crises and the main ideas of second revolution had been implemented by then. Certainly, economic development enhanced again for some years after that crises.

In fourth revolution, increase of economic growth is certainly slow and we expect that future rise of growth will be even slower and sustaining. In U.K, it took five centuries to triple the GDP from 1300 to 1800 ($1,150-$3,450) and almost a century to double ($6,350) in 1906. At that time, economic growth power shifted from U.K to USA as second revolution made a vast impact on economic growth in America. First revolution as it came by chance, took a long time to show its effects but second revolution came by the choice of American innovators in USA, so it prevailed more quickly than the first one. Before third revolution, crises appeared due to toxic products (fossil fuels) of chemical industry and unemployment. It resulted into slowness of GDP but with the reach of third revolution, again its pace got up till 2007 [59]. In 78 years from 1929 to 2007, GDP rose from $6,350 to $32000. After 2007, the pace of rise has gone down and we expect that it will be sustaining as more unknown crises are expected in the coming 50-60 years.

The industrial revolution was basically a technological revolution and its evolution can be understood by focusing on the reasons of invention. This subject, if discussed in the social context will sharpen our understanding by concentrating on the incentives faced by inventors and the context in which they worked. This approach specifies that the reason of industrial revolution in Britain was not because of luck or culture or British genius or the rise of science. Rather it was Britain’s success in the international economy that set a roadmap for Britain’s entrepreneurs with unique and highly remunerative possibilities. The industrial shift was a response to the opportunity. The commercial success for Britain was to create a structure of wages and prices that differentiated Britain from other Continents. In Britain, wages were remarkably high and energy cheap. Underlying the technological breakthroughs of the industrial revolution was Britain’s commercial and imperial expansion of the seventeenth and eighteenth centuries, which was the cause of the peculiar wage and price pattern. The state policies that mattered most were mercantilism and imperialism. This wage and price history was a fundamental reason for the technological breakthroughs of the eighteenth century whose object was to substitute capital and energy for labour [60]. There were, however, important features of British popular culture that distinguished the country from much of the continents and those features (greater literacy and numeracy) underpinned the technological achievements of the eighteenth century. They were not autonomous movers, but were themselves consequences of the economic development that preceded the industrial revolution and that produced the high wage and cheap energy [61]. Hence self-motivation and strong will power to get the discrimination play an important part for Britain to get succeeded.

The technological developments in first industrial revolution had little or no scientific base. It created a chemical industry with no chemistry, an iron industry without metallurgy, power machinery without thermodynamics. Engineering, medical technology and agriculture until 1850 were practical bodies of applied knowledge in which things were known to work, but hardly understood why they worked. When science verified that such ambitions were impossible, research altered its direction. Things were known to work, even then they tended to be inflexible and slow to progress. The inventions after 1870 (second revolution) were different from the ones that preceded it. In this era, useful knowledge that mapped into new technology was a certain driver of innovation. The second industrial revolution enhanced the mutual feedbacks between two forms of knowledge that was a science and technology. Even before 1870, some natural processes were sufficiently understood to provide some guidance as to how to make technology more effective. The persistence and acceleration of technological progress in the last third of the nineteenth century was due increasingly to the steady accumulation of useful knowledge. Some of this knowledge was what we could call today a science but a lot was based on less formal forms of experience and information. Inventors like Edison and Felix Hoffman relied on some of the findings of formal science, but a lot more was involved. As a result, the second industrial revolution extended the rather limited and localized successes of the first to a much broader range of activities and products. Living standards and the purchasing power of money increased rapidly, as the new technologies reached like never before into the daily lives of the middle and working classes [34]. The other aspect of revolution worth stressing is the changing nature of the organization of production. It witnessed the growth in some industries of huge economies of scale and a throughput.

The 2nd world war 1939–1945 transformed the structure of R&D throughout the industrial economies. Leadership of global scientific development shifted from Western Europe to the Unites States. Industries based on innovations in ICT and biomedical science began to develop rapidly after the 1950s. After 1914–1945 period of war and depression global trade and investment flows revived. International flows of technology also expanded and economies such as Japan, South Korea and Taiwan had emerged as sources of industrial innovation in between 1980s and 1990s [36]. These economic regions became a more important peacetime actor in the "national innovation system" through procurement of the products of knowledge-intensive industries. At that time, the structure of the US R&D system resembled those of other leading industrial economies of the era like U.K., Germany and France. But the postwar US R&D system differed from those of other industrial economies in at least three aspects: (i) US antitrust policy during the postwar era was unexpectedly inflexible, (ii) small new firms played a significant role in the commercialization of innovative technologies and (iii) defense-related R&D funding and procurement applied a prevalent influence in the high-technology sectors of the US economy.

Global history has analyzed for a long time on the comparative economic successes and failures of different parts of the world, especially European versus Asian regions. However, balance changed in the latter part of the eighteenth century when a transformation began in continental Europe and England that revolutionized the power relations of the world and brought an end to the supremacy of agrarian civilization. Comparative studies of the industrial revolution have given major importance to waterborne transport. Adam Smith (1776), in his Wealth of nations, acknowledged that industrial development is heavily depended on the water transport infrastructure. In the initial decisive phases of the industrial revolution, waterborne transport was emphasized by the fact that most goods in pre-modern economies travelled by land, or on boats in coastal transport [62]. Road transport was generally preferred as it was more reliable than water transport. On the other hand, travelling on roads often become impossible due to rain [63]. However, England had more facilities of road transport available while in Asia (China and India) the monsoon rains made large parts of the road network unusable, even for small-scale commerce and transport of light goods. An influential view holds that Europe exceptionally well-functioning markets supported with a certain set of institutions provided the incentives to make investments needed to industrialize which created difference between Europe and Asia.

## 5. Position of Fourth Revolution

Industry 4.0 has disrupted the exiting manufacturing paradigms by introducing Cyber-Physical Systems, CPS (a fusion of the physical and the virtual worlds), the Internet of Things and the Internet of Services [9, 67]. Manufactured products in these decades are smart products based on CPS and they will be self-management in future [68, 69]. Industrial revolutions have centralized the production management from handicrafts to factory system which further developed through information technology and tending towards automation in this era. According to many researchers, this centralized system will further automate in coming years.

This revolution is tending towards self-regulating systems and is expected that history will revert to decentralized system in the form of micro-industry [70]. People will establish consumer production in their homes and sale through online purchasing mechanism. But as far as large multinational companies are concerned, employees control their work remotely by sitting in their homes through interconnected micro-industry system [71].

Autonomous and self-regulating systems may arise numerous crises and concerns for society, industry, national and international level. Unemployment is a big problem for many developing countries and it could prevail quickly as soon as industry would shift towards self-regulating system [72]. This may produce hindrance in implementation of micro-industry but competition will enforce the developing regions to implement it. Secondly, life expectancy is increasing with the advancement of bio-technology and 60-70 percent average population of old age will increase that will produce concerns regarding health, safety, security, poverty and accommodation. At industrial level, decentralized and distributed micro-industry will reach to its peak that arise concerns for company related to reliability, data security, flexibility and loyalty of employees [25, 73, 74]. Ethical and social issues can arise that will demand to redefine them according to modern conditions [75]. These all social, national and international issues will lead humans towards increase of depression, unhappiness and mental stress. Hence we can expect that next revolution will be crises based, disruptive and it may end the industrial era. Bio-technology will be the leading paradigms after next K-wave and fourth revolution may die out at the end of this century with rise of these crises.

## 6. Phases of Industrial Revolutions

History depicts the three main production revolutions: the agrarian revolution, the industrial revolution and the modern production revolution [76]. According to theory of the production revolution, every revolution constitutes three phases: initial innovative phase (emergence of a new revolutionizing sector), intermediate modernization phase (diffusion, synthesis and improvement of new technologies) and final innovative phase (when new technologies acquire their mature characteristics) as shown in Fig. 3. Initial phase of industrial growth begin in late eighteenth century (1780-1900) in which development started from micro industrial level. Factory system was the primary modernization era of growth in which decentralized system had transformed to centralized system. Electrification, mass production and chemical industry was the period of initial maturity in growth. Information and communication technology further matured and expanded the technology. Autonomous systems introduced by fourth revolution have led to absolute domination of technology. Its initial growing phase has been completed in 1950. We expect that now we are in its modernization phase (see Table 3).

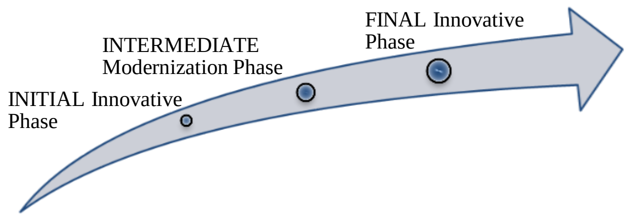


Fig. 3: Theory of production revolution [39].

Intermediate phase is the distribution, diffusion and improvement of initial phase. Social and technological conditions are going in favour of technological breakthrough. It is expected firmly that final phase will begin in next 50 to 60 years as we are tending towards self-regulating system in which disintegrated production will happen. Taking K & J waves in comparison with theory of production revolution, we have developed a correlation of fourth revolution with overall industrial growth as depicted in Table 3 and Fig. 4. Certainly, there is no direct link between K & J waves with phases of industrial growth due to different growth of industrial production principle phases. On average, first two K waves of industrial revolution represent the early period of industrial growth and third wave corresponds to expansion of maturity of growth which will reach on its ultimate peak in next 50 to 60 years. After stagnation stage, industrial era will fall up to remotely controlled micro-industry. However, it is expected that new K wave will start in 2060-2070. Juglar wave represent the sustainable development of innovation, hence probably we can expect 5 or 6 next Juglar cycles of fourth revolution.

Table 3: Relationship between industrial growth and revolutions.

| Phases of Industrial Growth | Years | Revolution Position | Kondratieff cycle |
|---|---|---|---|
| Initial Innovative Phase | 1780-1840 | First Revolution | 1st cycle complete & starting phase of 2nd cycle |
| Initial Rising Phase | 1840-1890 | First Revolution | |
| Maturity Phase | 1890-1950 | Second Revolution | 2nd cycle completed |
| Maturity Expansion | 1950-2010 | Third Revolution | 3rd |
| Modernization Phase | 2011-2040 | Fourth Revolution | 4th |
| Peak Phase | 2040-2070 | Fourth Revolution | Final phase of industrial growth |
| Falling Phase | 2070-2100 | End of Industrial Era | - |

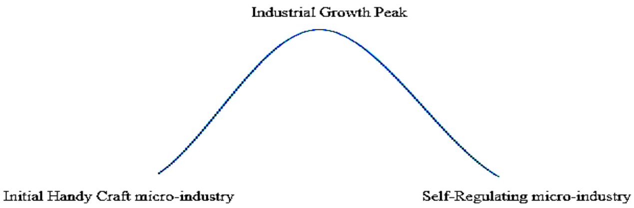


Fig. 4: Overall industrial growth pattern (estimation through literature).

However, research on quantum computer is a very active subject in the field of quantum informatics in these modern days. Compared with classic computer, the algorithm quantum computers use is the quantum algorithm. According to modern research, we believe that quantum computer will affect people’s life with a large extent. It will improve the conditions of scientific research and speed up the process of scientific progress in the future.

## 7. Emergence of Quantum Informatics

Quantum informatics is an emerging field developed by the combination of information science, quantum mechanics and computer science in the 1980s. The progress and development of quantum information science has broad importance in science and technology. The application of quantum information technology has become the usual trend of people's efforts in these days. The quantum coding and decoding, purification and regulation, preparation, storage and transmission of quantum state have become the hotspot of technicians and scientists [64]. It has intense impact on the defense technology, national economy and the people's livelihood.

Quantum informatics generally consists of quantum computation and quantum communication. Quantum information is based on the basic principles of quantum mechanics to deal with the information. The classic information is expanded to quantum information and micro-system quantum state is used to express information [65]. Quantum information science have many advantages which classical information does not possess, like ultra-fast computing and large capacity storage, absolute security and confidential communication. Information theory, quantum mechanics and computer science have experienced a long and complicated process from the initial parallel development to cross fusion. The birth of quantum mechanics dates back to the energy quantization proposed by Planck's epoch-making essay "On the law of distribution of energy in the normal spectrum" in 1900. It results due to the efforts of physicists such as Einstein, Born and Dirac which provide foundations of official quantum mechanics theory. As the representative of the two sides, Einstein and Bohr had severe debate on the basic issues of quantum mechanics which resulted into huge promotion in the development of quantum mechanics [66]. Quantum mechanics has become a significant part of science which quickly applied to basic particles and other different physical systems and achieved great success.

## 8. Conclusions

This paper examined the pattern, causes and effects of industrial growth and revolutions. Three causes can be attributed for industrial innovation: chance, choice or crises. Innovation can be disruptive or sustaining. Besides, disruptive technology also gradually converts into sustainable technology. Kondratieff and Juglar cycles are used as a tool to describe each revolution inputs, outputs and the hosting regions. Further, determinants of revolutions explained by dividing it into three parts as: pre-revolution stage, during revolution stage and post-revolution stage. These revolutions influenced the micro, meso and macro level for industrial transformation. Economy of U.K. GDP per capita increases to triple in five centuries (1300-1800) and its pace picked up after that. Economic development shifted to the US after second revolution, therefore continued to increase consistently and eventually slowed down before third revolution. This revolution insured a more positive impact on US economy and made it slow progressing after fourth revolution which expectedly remained as sustaining in next 30 to 40 years. Theory of production revolution suggests that industrial growth that begin in 1780 and after facing certain rising phase, now reached at its modernization innovation phase. Its final phase will start in next 50-60 years. Hence, there is a strong correlation between industrial growth and revolutions as suggested by theory of long waves and theory of production revolution. Fourth revolution will reach to its ultimate peak in next coming decades and industrial growth will fall from innovative modernization phase to final innovative phase. Self-regulating system may be the last era of industrial sector as both fourth revolution and industrial growth will reach to ultimate falling position. Nevertheless, pattern of growth suggest that society, industry, national and international levels will face serious crises. Advent of micro-industry will bring problems related to data security, safety, flexibility and loyalty of employees. Life expectancy will enhance due to bio technology and automation systems will give rise to peak of unemployment. Rise of social economic pressure on people needs a way to control their emotions and depressions due to which bio technology may arise abruptly. Hence, we can expect that next revolution would be crises based, disruptive and bio-technology will be the leading sector. Countries at all level (micro, meso and macro) should develop a strong policies and framework to sustain their development for coming half century. Quantum computation field is on emerging path in these days. It is expected that this field will play a vital role in quick scientific research and development in next paradigm. It may facilitate the fourth revolution to reach its peak with quick pace.

Although, many researchers have discussed these revolutions and industrial growth but this paper has provided (1) a comprehensive view (2) their past, present and future impact at micro, meso and macro level, (3) economic development due to revolutions and (4) correlation between industrial growth and revolution. Industrial sector should focus on 3C's factors and development of strong relationship with micro-innovation level to adopt new technology as soon as it get launch and (5) a light discussion on emerging field of quantum informatics. Limitations of this paper is given as:

- Different types of cycles, view point chart tool, closed loop analysis and strategic management maturity model have been studied but best options which cover all aspects of revolutions include only Kondratieff & Juglar cycle. We do not found theory other than production revolution for industrial innovative growth that has explained it comprehensively.
- There is a need to correlate bio-technology and industrial growth to forecast dimensions of human based crises.
- Paper didn't consider the different countries development and their relationship with revolutions.
- Comprehensive discussion on relationship between fourth revolution and quantum informatics need to be done.

## References

[1] K. Bruland and K. Smith, "Assessing the role of steam power in the first industrial revolution: The early work of Nick von Tunzelmann", Research Policy, vol. 42, pp. 1716-1723, 2013.

[2] J. Mokyr, "The Rise and fall of the factory system: Technology, firms, and households since the industrial revolution", Carnegie-Rochester Conference Series on Public Policy, pp. 1-45, 2001.

[3] C. Bekar and R.G. Lipsey, "Science, institutions, and the industrial revolution", Journal of European Economic History, vol. 33, pp. 709-753, 2004.

[4] A. Nuvolari, B. Verspagen and N. Von Tunzelmann, "The early diffusion of the steam engine in Britain, 1700–1800: A Reappraisal", Cliometrica, vol. 5, pp. 291-321, 2011.

[5] A. Riel and M. Flatscher, "A design process approach to strategic production planning for industry 4.0", European Conference on Software Process Improvement, pp. 323-333, 2017.

[6] M.J.a.K. Jacob, "A Third Industrial Revolution? Solutions to the Crisis of Resource-Intensive Growth", Social Science Research Network, 2009.

[7] P. Hawken, A.B. Lovins and L.H. Lovins, "Natural capitalism: The Next Industrial Revolution", New York, USA: Routledge, 2013.

[8] H. Lasi, P. Fettke, H.-G. Kemper, T. Feld and M. Hoffmann, "Industry 4.0", Business & Information Systems Engineering, vol. 6, pp. 239-242, 2014.

[9] R. Drath and A. Horch, "Industrie 4.0: Hit or hype? [Industry Forum]", IEEE Industrial Electronics Magazine, vol. 8, pp. 56-58, 2014.

[10] I. Veza, M. Mladineo and I. Peko, "Analysis of the current state of Croatian manufacturing industry with regard to industry 4.0", Vodice, Croatia: Croatian Association of Production Engineering, 2015.

[11] R.N. Kostoff, R. Boylan and G.R. Simons, "Disruptive technology roadmaps", Technological Forecasting and Social Change, vol. 71, pp. 141-159, 2004.

[12] D. Yu and C. C. Hang, "A reflective review of disruptive innovation theory", Int. J. Manage. Reviews, vol. 12, pp. 435-452, 2010.

[13] B. Esmaeilian, S. Behdad and B. Wang, "The evolution and future of manufacturing: A review", J. Manufacturing Systems, vol. 39, pp. 79-100, 2016.

[14] C.M. Christensen, "The ongoing process of building a theory of disruption", J. Product Innovation Management, vol. 23, pp. 39-55, 2006.

[15] R. Adner, "When are technologies disruptive? A demand-based view of the emergence of competition", Strategic Management Journal, vol. 23, pp. 667-688, 2002.

[16] J.M. Utterback and H.J. Acee, "Disruptive technologies: An expanded view", Int. J. Innov. Manage., vol. 9, pp. 1-17, 2005.

[17] F. Boccardi, R.W. Heath, A. Lozano, T.L. Marzetta and P. Popovski, "Five disruptive technology directions for 5G", IEEE Communications Magazine, vol. 52, pp. 74-80, 2014.

[18] S.K. Kassicieh, B.A. Kirchhoff, S.T. Walsh and P.J. McWhorter, "The role of small firms in the transfer of disruptive technologies", Technovation, vol. 22, pp. 667-674, 2002.

[19] R.U. Ayres, "Technological transformations and long waves", 1989.

[20] M.P. Hekkert and S.O. Negro, "Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims", Technological Forecasting and Social Change, vol. 76, pp. 584-594, 2009.

[21] J. Mokyr, "The contribution of economic history to the study of innovation and technical change: 1750-1914", Handbook of the Economics of Innovation, vol. 1, pp. 11-50, 2010.

[22] J. Komlos and S. Nefedov, "A compact macromodel of pre-industrial population growth", Historical Methods: A Journal of Quantitative and Interdisciplinary History, vol. 35, pp. 92-94, 2002.

[23] M. Jänicke and K. Jacob, "A Third Industrial Revolution? Solutions to the crisis of resource-intensive growth", 2009.

[24] M.C. Jensen, "The modern industrial revolution, exit, and the failure of internal control systems", The Journal of Finance, vol. 48, pp. 831-880, 1993.

[25] N. Jazdi, "Cyber physical systems in the context of Industry 4.0", IEEE International Conference on Automation, Quality and Testing, Robotics, pp. 1-4, 2014.

[26] J. Mokyr and J.V. Nye, "Distributional coalitions, the Industrial Revolution and the origins of economic growth in Britain", Southern Economic Journal, pp. 50-70, 2007.

[27] F. Jovane, H. Yoshikawa, L. Alting, C. Boër, E. Westkamper, D. Williams, M. Tseng, G. Seliger, A.M. Paci, "The incoming global technological and industrial revolution towards competitive sustainable manufacturing", CIRP Annals-Manufacturing Technology, vol. 57, pp. 641-659, 2008.

[28] B. Berman, "3-D printing: The new industrial revolution", Business Horizons, vol. 55, pp. 155-162, 2012.

[29] J. Wonglimpiyarat, "The nano-revolution of Schumpeter's Kondratieff cycle", Technovation, vol. 25, pp. 1349-1354, 2005.

[30] O.-P. Hilmola, "Stock market performance and manufacturing capability of the fifth long-cycle industries", Futures, vol. 39, pp. 393-407, 2007.

[31] T. Modis, "A hard-science approach to Kondratieff's economic cycle", Technological Forecasting and Social Change, 2017.

[32] J.P.G Reijnders, "Trend movements and inverted Kondratieff waves in the Dutch economy, 1800–1913", Structural Change and Economic Dynamics, vol. 20, pp. 90-113, 2009.

[33] R.C. Allen, "The British industrial revolution in global perspective", New York, 2009.

[34] J. Mokyr, "The second industrial revolution, 1870-1914", Storia dell'economia Mondiale, pp. 219-45, 1998.

[35] A.S. Blinder, "Offshoring: the next industrial revolution?", Foreign Affairs, pp. 113-128, 2006.

[36] D.C. Mowery, "Plus ca change: Industrial R&D in the "third industrial revolution", Industrial and Corporate Change, vol. 18, pp. 1-50, 2009.

[37] K. Zhou, T. Liu and L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges", Fuzzy Systems and Knowledge Discovery (FSKD), 12th International Conference, pp. 2147-2152, 2015.

[38] H. Kagermann, "Change through digitization—Value creation in the age of Industry 4.0", Management of permanent change, ed: Springer, pp. 23-45, 2015.

[39] L.E. Grinin, A.L. Grinin, and A. Korotayev, "Forthcoming Kondratieff wave, Cybernetic Revolution, and global ageing", Technological Forecasting and Social Change, vol. 115, pp. 52-68, 2017.

[40] J. Taalbi, "What drives innovation? Evidence from economic history", Research Policy, 2017.

[41] M. Rüßmann, M. Lorenz, P. Gerbert, M. Waldner, J. Justus, P. Engel and M. Harnisch, "Industry 4.0: The future of productivity and growth in manufacturing industries", Boston Consulting Group, vol. 9, 2015.

[42] T. S. Robertson and H. Gatignon, "Technology development mode: a transaction cost conceptualization", Strategic Management Journal, pp. 515-531, 1998.

[43] K. Hoffman, M. Parejo, J. Bessant, and L. Perren, "Small firms, R&D, technology and innovation in the UK: a literature review," Technovation, vol. 18, pp. 39-55, 1998.

[44] U. Lichtenthaler and H. Ernst, "Opening up the innovation process: the role of technology aggressiveness", R & D Management, vol. 39, pp. 38-54, 2009.

[45] S.-G. Lee, S. Trimi, and C. Kim, "The impact of cultural differences on technology adoption", Journal of World Business, vol. 48, pp. 20-29, 2013.

[46] F. Mavondo and M. Farrell, "Cultural orientation: its relationship with market orientation, innovation and organisational performance", Management Decision, vol. 41, pp. 241-249, 2003.

[47] F. Rauner and D. Salari, "Cultural determinants of technology transfer-a case study in human resources planning for steel production", AI & SOCIETY, vol. 17, pp. 266-277, 2003.

[48] D.G. Sirmon and P. J. Lane, "A model of cultural differences and international alliance performance",Journal of International Business Studies, vol. 35, pp. 306-319, 2004.

[49] M. Karaulova, O. Shackleton, W. Liu, A. Gök, and P. Shapira, "Institutional change and innovation system transformation: A tale of two academies", Technological Forecasting and Social Change, vol. 116, pp. 196-207, 2017.

[50] J. Paap and R. Katz, "Anticipating disruptive innovation", Research-Technology Management, vol. 47, pp. 13-22, 2004.

[51] P. F. Peretto, "Industrial development, technological change and long-run growth", Journal of Development Economics, vol. 59, pp. 389-417, 1999.

[52] H. E. Aldrich and C. M. Fiol, "Fools rush in? the institutional context of industry creation", Entrepreneurship, ed: Springer, pp. 105-127 2007.

[53] H. E. Aldrich and C. M. Fiol, "Fools rush in? The institutional context of industry creation",Academy of management review, vol. 19, pp. 645-670, 1994.

[54] J. K. Choi and Y. G. Ji, "Investigating the importance of trust on adopting an autonomous vehicle", Int. J. Human-Computer Interaction, vol. 31, pp. 692-702, 2015.

[55] M. Bar and O. Leukhina, "Demographic transition and industrial revolution: A macroeconomic investigation", Review of Economic Dynamics, vol. 13, pp. 424-451, 2010.

[56] P. P. Saviotti and A. Pyka, "Product variety, competition and economic growth", J. Evolutionary Economics, vol. 18, p. 323, 2008.

[57] P. P. Saviotti and A. Pyka, "Economic development, qualitative change and employment creation", Structural Change and Economic Dynamics, vol. 15, pp. 265-287, 2004.

[58] R. J. Gordon, "Is US economic growth over? Faltering innovation confronts the six headwinds", National Bureau of Economic Research, 2012.

[59] S. B. Carter, S. S. Gartner, M. R. Haines, A. L. Olmstead, R. Sutch and G. Wright, Historical statistics of the United States: Millennial edn. vol. 3, Cambridge University Press, 2006.

[60] R.C. Allen, "The British industrial revolution in global perspective: how commerce created the industrial revolution and modern economic growth", Unpublished, Nuffield College, Oxford, 2006.

[61] R.C. Allen, "The industrial revolution in miniature: The spinning jenny in Britain, France and India", The Journal of Economic History, vol. 69, pp. 901-927, 2009.

[62] T. Tvedt, "Why England and not China and India? Water systems and the history of the Industrial Revolution", J. Global History, vol. 5, pp. 29-50, 2010.

[63] C.H. Shiue and W. Keller, "Markets in China and Europe on the eve of the industrial revolution", American Economic Review, vol. 97, pp. 1189-1216, 2007.

[64] Y. Zhao, "Research progress on quantum informatics and quantum computation", IOP Conference Series: Earth and Environmental Science, p. 012103, 2018.

[65] Y. Zhang, "Principles of quantum information physics", Science Press, Beijing, 2005.

[66] M.A. Nielsen and I. Chuang, "Quantum computation and quantum information", ed: AAPT, 2002.

[67] F. Almada-Lobo, "The Industry 4.0 revolution and the future of manufacturing execution systems (MES)", J. Innov. Manage., vol. 3, pp. 16-21, 2016.

[68] J. Posada, C. Toro, I. Barandiaran, D. Oyarzun, D. Stricker, R. de Amicis, E.B. Pinto, P. Eisert, J. Döllner and I. Vallarino, "Visual computing as a key enabling technology for industrie 4.0 and industrial internet", IEEE Computer Graphics and Applications, vol. 35, pp. 26-40, 2015.

[69] D. Romero, J. Stahre, T. Wuest, O. Noran, P. Bernus, Å. Fast-Berglund and D. Gorecky, "Towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies", Proc. of Int. Conf. on Computers and Industrial Engineering, 2016.

[70] J. Wan, S. Tang, Z. Shu, D. Li, S. Wang, M. Imran and A.V. Vasilakos, "Software-defined industrial internet of things in the context of industry 4.0", IEEE Sensors Journal, vol. 16, pp. 7373-7380, 2016.

[71] J. Lee, B. Bagheri and H.-A. Kao, "Recent advances and trends of cyber-physical systems and big data analytics in industrial informatics", Proc. of Int. Conference on Industrial Informatics, pp. 1-6, 2014.

[72] M. Wilenius, "Leadership in the sixth wave—excursions into the new paradigm of the Kondratieff cycle 2010–2050", European Journal of Futures Research, vol. 2, p. 36, 2014.

[73] A.-R. Sadeghi, C. Wachsmann and M. Waidner, "Security and privacy challenges in industrial internet of things", Design Automation Conference (DAC), 52nd ACM/EDAC/IEEE, pp. 1-6, 2015.

[74] M. Waidner and M. Kasper, "Security in industrie 4.0: challenges and solutions for the fourth industrial revolution", Proc. of Conference on Design, Automation & Test in Europe, pp. 1303-1308, 2016.

[75] M. Hermann, T. Pentek and B. Otto, "Design principles for industries 4.0 scenarios", 49th Hawaii International Conference on System Sciences, pp. 3928-3937, 2016.

[76] D. Scaron, "Waves of technological innovations and the end of the information revolution", J. Economics and International Finance, vol. 2, pp. 58-67, 2010.