



A Review of Industry 4.0: The Fourth Industrial Revolution in Manufacturing Industries

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Abstract: Industry 4.0 is the development of a smart factory concept that requires the traditional philosophy of manufacturing systems to change. The smart factory presents new factors and elements of traditional manufacturing systems and incorporates the current requirements of smart systems so that it can compete in the future. The Fourth Industrial Revolution is a way of a combination of advances in robotics, the Internet of Things (IoT), artificial intelligence, genetic engineering, and other technologies. The revolution also describes the exponential changes to the way humans living relating to the cyber technology. This paper is intended to review and summarize the fourth industrial revolution in manufacturing industries as in today's competitive and demanding market increasing challenges are inevitable in manufacturing industries.

Keywords: Industrial Revolution (IR4.0), manufacturing, industries, flexible manufacturing, agile manufacturing

1.0 INTRODUCTION

The Fourth Industrial Revolution (IR 4.0) is predicted to change humans' way of life, work-related, and communication systems. IR4.0 can be defined as the changes in industrial processes via automation and digitization through robotics and emerging technologies which include cyber-physical systems, the internet of things, cloud computing and cognitive computing (Zainal Abidin et al., 2018). In near future, the thing we value and the way we value them is also likely to change. Nowadays, the changing phase in business models and employment trends in manufacturing industries is already awoken by the beginning of information and communication technology (Sharif Ullah, 2019). Estimated 65% of kids enrolling in primary education today will end up working in jobs that have not been created yet according to The World Economic Forum.

Automation and artificial intelligence are the change agents in IR4.0 that will make certain groups of employees jobless, replacing them with new workers with the needed skills or with machines that can make the job cheaper (Maskuriy et al., 2019). Hence, changing the factory process into automation is the only way to reduce costs whereas maintaining the quality. In these present days, there are no certainties that students go to college or university to study for a degree that will set them up with a job for life. Thus, the fourth industrial revolution are driven by digital transformation, enhances human-machine relationships and offers flexible, high-productivity, resource-friendly manufacturing. Additive manufacturing improves healthcare and sustainability, while flexible and agile systems boost operational efficiency and responsiveness to demand.

2.0 BACKGROUND

Manufacturing industries has been through radical changes as a result of globalization abruptly increasing competition. Manufacturing competitiveness is extremely dependent on the ability to rapidly and efficiently adapt to major external changes which are changes in market

trend and continuous advance in processing technology. The Internet of Things (IOT), wearable technologies, robotics and Artificial Intelligence (AI) are some of the technologies transforming traditional factories into part of IR 4.0. Thus, this will enable companies to optimize their resources and having high efficiency in producing higher-quality goods.

The start of smart factory technologies will also speed up production and help manufacturers respond more quickly to the market needs changing. In today's world, it is demanding for a company to get high return at lower batch numbers and over shorter product life cycles and have the ability to rapidly swap production to new products as needed because traditionally, factories are set up for long and high-volume production runs. Automation and digitalization provide an answer to many of manufacturing's big question if the industry can retain workers and enable them to switch to more skilled roles, overseeing the use of AI, robots and additive production methods. A new generation of manufacturing workers requires technical skills, expertise and knowledge so it can continue to innovate and reinvent itself. Thus, this will be the challenge for manufacturing industries over the next decade.

The transition to the digitization of manufacturing is so convincing and that it is being called Industry 4.0 to represent the fourth revolution that has occurred in manufacturing industries. Back in 2011, an association consist of representatives from business, politics, and academia promoted a method to strengthen the competitiveness of German manufacturing industry; that is when the term "Industry 4.0" became an outburst (Bahrin et al., 2016). From the first industrial revolution i.e. mechanization through water and steam power at the 18th century, to the mass production and assembly lines along with the commercialization of electricity in the second revolutionary phase in the early 19th ; the fourth industrial revolution will take what was started in the third with the adoption of computers and automation and enhance it with smart and autonomous systems driven by data and machine learning (Carvalho et al., 2018; Kim et al., 2016). The history time frame of industrial revolution as per portray in figure 1. Shifts are truly happening in manufacturing industries that already catches the world attention, even though rumours say Industry 4.0 as merely a marketing catchword.

New technology started to arise when computers were introduced in Industry 3.0; and presently submerge into the future as Industry 4.0 reveals, computers are connected and communicate with one another to ultimately make decisions without human intervention. A combination of cyber-physical systems, the Internet of Things and the Internet of Systems make Industry 4.0 possible and the smart factory a reality (Lidong & Guanghui, 2016). As a result of the support of smart machines that keep getting smarter as they get access to more data and technology convergence and various elements over societies, humans, and environment, the factories will have high return in productivity, quality, delivery, and flexibility (H.S. Kang et. al., 2016). Eventually, it's the network of these machines that are digitally connected and create and share information that results in the true power of Industry 4.0.

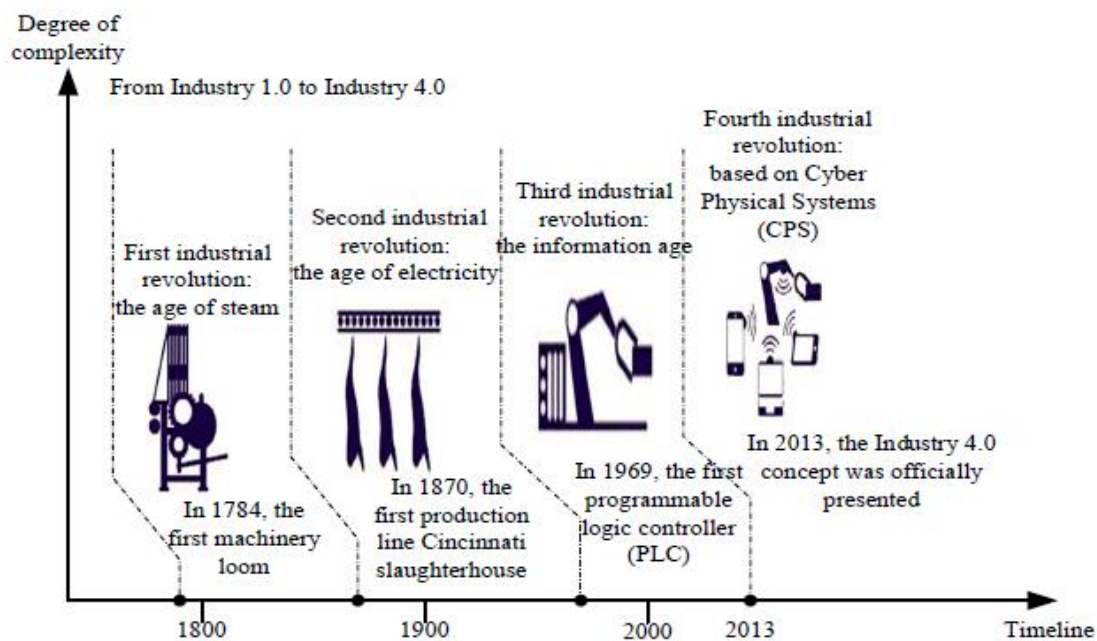


Figure 1: The four industrial revolution history (Zhou et al., 2016).

As for 3D printing, or additive technology, it becomes another critical point in gradual innovation in manufacturing. It is expensive and inefficient to produce prototypes of new products or parts with typical manufacturing techniques. However, additive technology bear lower cost to move a design from the drawing board to the real world in a short time. As 3D printing evolves, additive technology will also increasingly replace traditional production methods such as casting. Across the Mitsubishi Heavy Industries Group, for example, 3D printing is already used to produce components for turbines, turbochargers and aviation technologies, and has been critical in improving fuel efficiencies in these products

There are several others technological areas that can be adopt to strengthen the Industry 4.0, which are horizontal and vertical system integration, the internet of things, cybersecurity, the cloud, big data analytics, simulation, additive manufacturing (3d printing), augmented reality, and robot (Bahrin et al., 2016). Figure 2 shows the technologies related to Industry 4.0. These are the major areas involved in implementing changes in today's world and also preparing for a future where smart machines improve their performance and efficiency. Globalization has intensified competition in manufacturing, necessitating rapid adaptation to market trends and technological advancements. IR 4.0 technologies like IoT and AI enhance efficiency and quality, while smart factories accelerate production. The industry's challenge lies in upskilling workers to manage advanced technologies and drive continuous innovation. This paper will further discuss on the digital transformation in the manufacturing industries, Additive Manufacturing, Flexible Manufacturing System and Agile Manufacturing System.

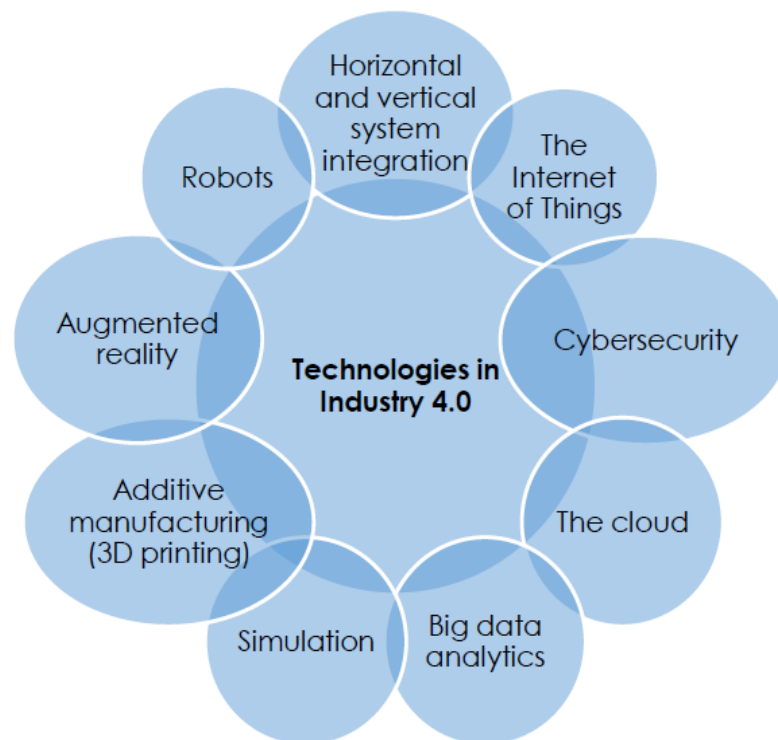


Figure 2:Technologies Related to Industry 4.0 (Bahrin et al., 2016).

3.0 DIGITAL TRANSFORMATION

IR 4.0 is about automation and data exchange through digital transformation. In a manufacturing context, this would mean introducing robotics and sensors to replace human labour for tasks that could be automated as far as the cost concern. The collection and complete evaluation of data from many different sources such as production equipment and systems as well as enterprise and customer management system will support real time decision making (M.Rüßmann, M. Lorenz, 2015). The digital transformation also extends to other areas such as finance where an automated system would be able to generate invoices or sales reports through the help of online tools; without having to bother the human for an overdue report. One of the many elements of IR 4.0 is connected devices which came in wide range of products from motion sensors and Bluetooth-enabled trackers to surveillance cameras.

The generated data from connected devices and systems also can be used to analyse business trends or to forecast changes to the business operations such as how often an asset breaks down to the number of medical leave an employee takes over the course of his employment. These data would then help entrepreneurs to make informed decisions on how to proceed with their business. An entrepreneur needs to know internally the objectives of the organisation in order to decide whether to embark on the digital journey upfront or, depending on capital, whether to start with a mix of solutions. The time frame for the digital route implementation is up to six month comprises the time needed to train staff before going on

hand. Thus, the digital transformation within manufacturing industries can be a powerful tool in today's world.

Hamidi et.al., 2018 has studied the revolution of industry that leads to the current industry 4.0 through digital transformation which aimed to have a high-flexibility, high-productivity, and become resource friendly that may provide a new level of human-machine relationship. The research is aimed in understanding the readiness of the Small Medium Enterprise (SME) in Malaysia towards digital transformation of Industry 4.0. Figure 3 below shows the readiness of Malaysian SMEs towards Industry 4.0 according to predefined dimension.

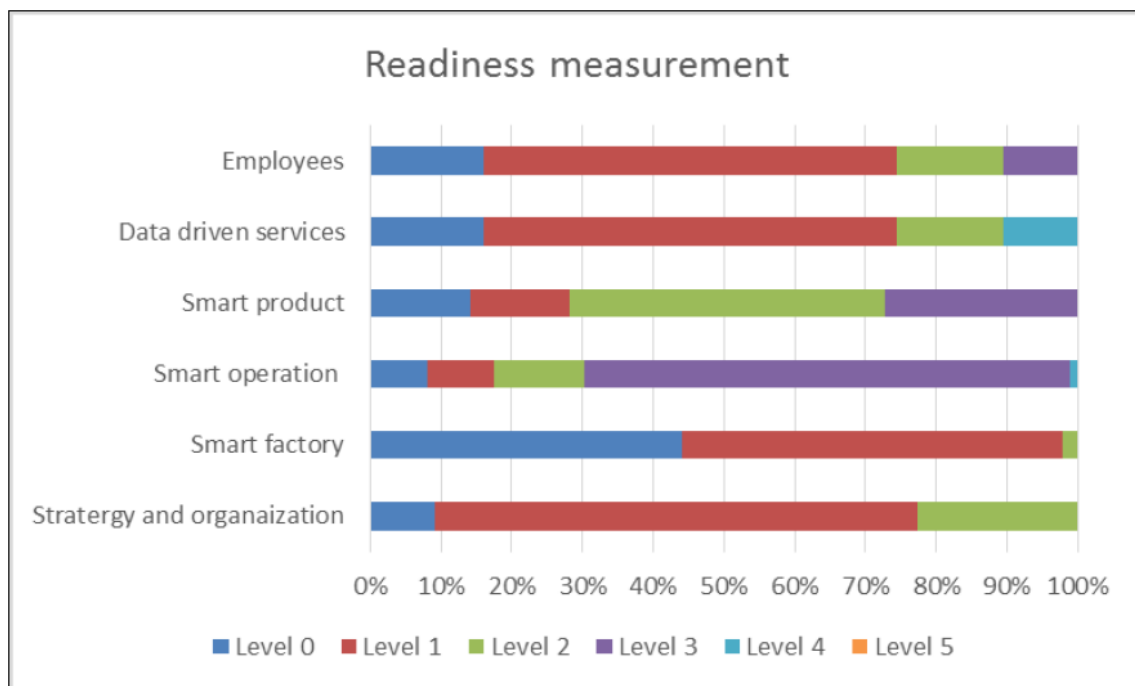


Figure 3: Readiness Measurement for Malaysian SMEs (Hamidi et al., 2018).

4.0 ADDITIVE MANUFACTURING

Additive Manufacturing (AM) is defined as the process of joining materials to make objects from 3D model data, layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining. Rapid Prototyping (RP) is additive manufacturing technologies that automatically construct physical models (Maskuriy et al., 2019). One way to classify RP systems is by raw material used to build the prototype referring to figure 4. RP systems can be categorized into liquid-based such as Stereo lithography (STL), solid-based such as Fused Deposition Modelling (FDM) and Laminated Object Manufacturing (LOM), and powder based such as Selective Laser Sintering (SLS), Three-Dimensional Printing (3DP), and Electron Beam Melting (EBM). The steps involved in product development using general rapid prototyping can save a lot of time and there is the possibility of testing more models.

There are many positive impacts of AM such as customized healthcare products to improve population health and quality of life, reduced environmental impact for manufacturing sustainability and simplified supply chain to increase efficiency and responsiveness in demand

fulfillment (Huang et al., 2013). Prioritize continuous training programs to equip workers with technical skills needed for IR 4.0 technologies like AI and robotics. In addition, Bikas et. al. 2016, indicate that AM able to manufacture complex form and redesign conventional assemblies into one complex shape with tiny waste at low volume in an economical way.

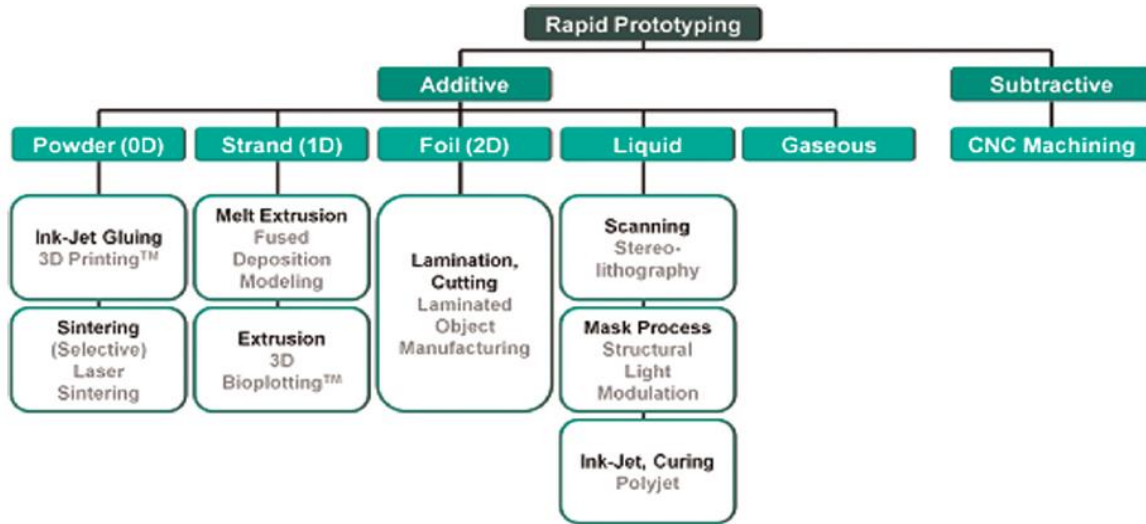


Figure 4: Category of RP process based on the principle of layer solidification and raw material (Gebhardt & Hotter, 2016)

4.1 Three-Dimensional Printing (3D printing)

3D Printing often used to create prototypes with additive layer manufacturing technologies or the process of joining materials layer by layer to make objects from three-dimensional (3D) model data. 3D printing technologies provides a cost-effective and time-efficient way to produce low-volume, customized products with complicated geometries and advanced material properties and functionality compared to the conventional material removal method (Huang et al., 2013). Alternative word found in the literature include additive processes, additive techniques, additive layer manufacturing, layered manufacturing, and freeform fabrication (Mellor et al., 2013). It allows for the creation of printed parts, not just models. This 3D printing process able to reduce the time and cost and also human interaction as well as product development cycle, and it allowed the possibility to generate almost any difficult shape that could be very hard to machine by conventional machine (Wong & Hernandez, 2012).

Nowadays, this 3D printing technologies often used in medical field as per discussed by several researches (Cheng et al., 2018; Pang et al., 2018; Pucci et al., 2017; Wang et al., 2018) . For example, the usage of 3D printing allowing physician to use 3D physical model for teaching purpose, patient education, device evaluation, and procedural planning (Zhou et al., 2016)(M.Rüßmann, M. Lorenz, 2015). As these technologies continue growing in clinical field, (Pucci et. al. 2017), sketch out three specific 3D printers, models and computer-aided design (CAD) software for 3D printing in neurosurgery as well as its applications and the boundaries for common practice. While Cheng et.al. 2018, indicate the 3D printing technology

is accurate, fast, and economical; and helpful to the medical field as it will reduce the operation time by reducing exposure time to general anaesthesia, and wound exposure time, and blood loss as well as enhancing preoperational evaluation and simplifying the surgical procedure.

5.0 FLEXIBLE MANUFACTURING SYSTEM (FMS)

A flexible manufacturing system (FMS) is a group of mathematically controlled machine tools, interconnected by a central control system. The various machining cells are interconnected, via loading and unloading stations, by an automated transport system. It has been described as an automated job shop and as a miniature automated factory. Operational flexibility is enhanced by the ability to execute all manufacturing tasks on numerous product designs in small quantities and with faster delivery. Simply stated, it is an automated production system that yields one or more families of parts flexibly. Today, this prospect of automation and flexibility presents the opportunity of producing nonstandard parts to create a competitive advantage (Kia et al., 2012).

The idea of flexible manufacturing systems developed during the 1960s when programmable controllers, robots and computerized numerical controls carried a controlled environment to the factory floor in the form of numerically controlled and direct numerically controlled machines. For the most part, FMS is limited to organizations involved in job shop environments or small lot productions. Usually, small lot manufacturers have two kinds of equipment from which to choose, un-automated or dedicated machinery, general purpose tools. Dedicated machinery outcomes in cost savings but lacks flexibility. General purpose machines such as milling machines, lathes or drill presses are all expensive, and may not reach complete capacity. Flexible manufacturing systems provide the small lot manufacturer with another option one that can make small lot manufacturing just as efficient and productive as mass production.

5.1 Varieties of FMS

5.1.1 Machine Flexibility

It is the ability to adapt a given machine in the system to a wide-ranging of production operations and part styles. The bigger the range of operations and part styles the bigger will be the machine flexibility (Z.M Mohamed, et. al., 2001). The several factors on which machine flexibility hinges on as below:

- Setup or changeover time.
- Ease with which part-programs can be downloaded to machines.
- Skill and adaptability of workers in the systems Production Flexibility.
- Tool storage capacity of machines.

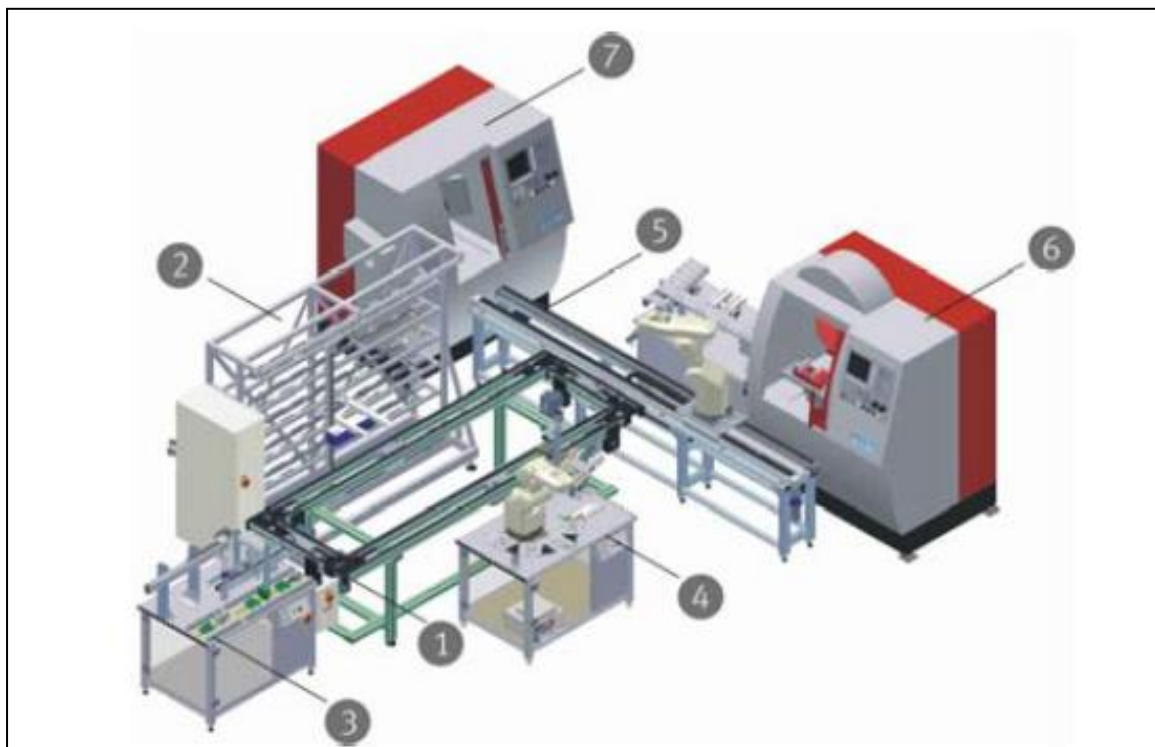


Figure 5: Flexible Manufacturing System (P. Kostal, K. Velisek, 2011)

1 – Conveyor, 2 – Storage, 3 – Pallet Handling and Quality Station, 4 – Robot Vision and Assembly Station, 5 – Robot Feeder of Machine Tools, 6 – CNC Lathe, 7 – CNC Milling Machine

5.2.2 Product Flexibility

It is the array of part styles that can be produced on the systems. The kind of part styles that can be produced by a manufacturing system at reasonable cost and time is determined by the process envelope (M. Hallgren, J. Olhager, 2009). It depends on following factors as below:

- Machine flexibility of individual stations.
- Range of machine flexibilities of all stations in the system.
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5.2.3 Mix Flexibility

It is defined as the capability to change the product mixture while preserving the same total production quantity that is, producing the same parts only in different proportions (F. Salvador, et. al., 2007). It is also known as process flexibility. Mix flexibility provides security against market variability by accommodating changes in product mix due to the use of shared resources. However, high mix variations may result in requirements for a bigger number of fixtures, tools and other resources. Mixed flexibility depends on factors such as below:

- Match/parallel of parts in the mix.
- Relative work content times of parts made.
- Machine flexibility.

5.2.4 Volume Flexibility

The system can differentiate the production volumes of different products to accommodate changes in demand while maintaining profit (M. Hallgren, J. Olhager, 2009). It can also be named as capacity flexibility. Factors affecting the volume flexibility are as below:

- Level of manual labour carrying out production.
- Amount invested in capital equipment.

5.2.5 Routing Flexibility

It can describe as capacity to yield parts on alternative workstation in case of equipment tool failure, breakdowns and other interruptions at any specific station (G. Nomdem, D. J Van Der Zee, 2008). It aids in increasing throughput, in the presence of external changes such as engineering changes, product mix or new product introductions. Following are the factors which decide routing flexibility:

- Similarity of parts in the mix.
- Common tooling.
- Similarity of workstations.

5.2.6 Expansion Flexibility

It is described as the effortlessness with which the system can be extended to foster total production volume (N. Julka et. al., 2007). Expansion flexibility depends on following factors as below:

- Cost incurred in adding new workstations and trained workers.
- Category of part handling system used.
- Effortlessness in expansion of layout.

6.0 AGILE MANUFACTURING SYSTEM (AMS)

Agile Manufacturing (AM) is a comparatively fresh operations concept that is projected to improve the competitiveness of organizations. Manufacturing/service processes based on AM are categorized by customer-supplier integrated processes for manufacturing, product design, marketing, and support services. Agile manufacturing necessitates elevating of the customer; organizing to manage change, cooperating with competitors, uncertainty and complexity and leveraging people and information. In current years, several research papers have been published in the area of AM (L.M Sanchezy, R. Nagiyet, 2001). The term 'agile' was invented in 1991. However, there are still some stern concerns that prevent companies from taking an entirely different direction from AM. Considering the possible importance of agile manufacturing in 21st century manufacturing competitiveness, an attempt has been made in this paper to re-examine the scope, strategies and definitions of AM. In addition, agile manufacturing strategies is developed to accommodate shorter product life cycles and fluctuating market demands effectively.

6.1 Agile Manufacturing Characteristics

Figure 6 shows the new model for enlightening the agile manufacturing model. The model takes into account the infrastructure, characteristics of the market, technologies and strategies. It determines to highlight the new dimension of the definition of the agile manufacturing model (A. Gunasekaran, Y. Y. Yusuf, 2002).

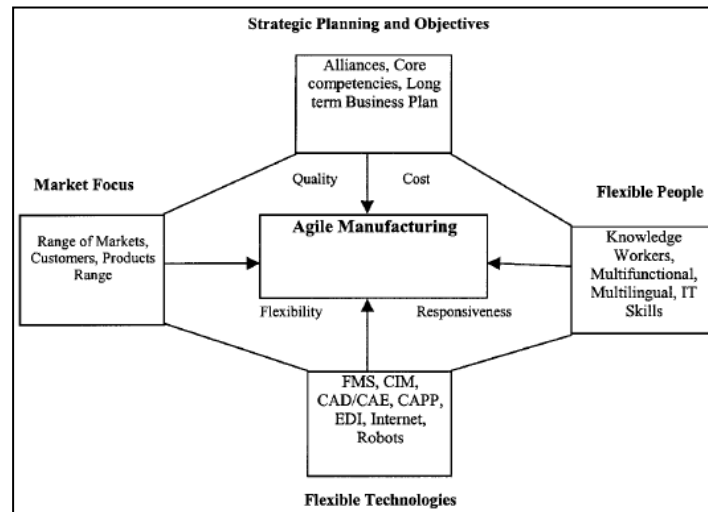


Figure 6 : Agile Manufacturing Paradigms/Model (A. Gunasekaran, Y. Y. Yusuf, 2002).

6.2 Agile Manufacturing Strategies and Technologies

Analysing the overall characteristics of strategies and technologies (A. Gunasekaran, Y. Y. Yusuf, 2002), the literature available on AM can be grouped under the following themes: (i) strategic planning, (ii) product design, (iii) virtual enterprise, and (iv) automation and Information Technology (IT). The details of the classification are illustrated in Figure 7.

6.2.1. Strategic planning

Strategic planning of performance improvement is gaining attention in all areas of manufacturing. The reason for this is that it takes into account the long-term interest of the company in determining suitable business and operational policies. To achieve agility in manufacturing, several sub-strategies are needed, including virtual enterprise, rapid-partnership formation, rapid prototyping, and temporary alliances based on core competencies (R.A. Abair, 1997).

6.2.2. Product design

The agile manufacturing system should be able to produce a variety of components at low cost and in a short time period. The design rule reduces manufacturing lead times in consecutive changes of product models (G.H Lee, 1998). Along with changes of product models, machines are relocated considering the overall costs of material handling and reconfiguration.

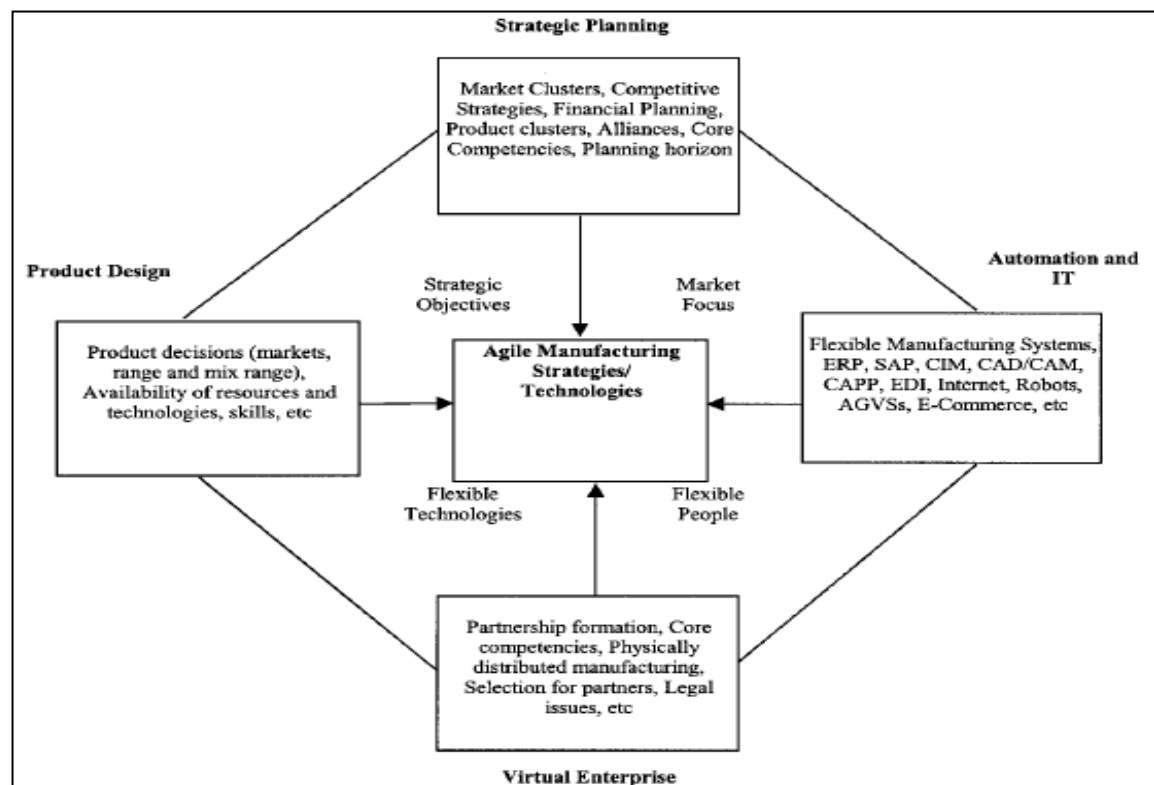


Figure 7 : Agile manufacturing strategies/techniques (A. Gunasekaran, Y. Y. Yusuf, 2002).

6.2.3 Virtual enterprise

A virtual organization is the integration of complementary core competencies distributed among several carefully chosen, but real organizations all with similar supply chains focusing on speed to market, cost reduction and quality (R.A. Abair, 1995). Appropriate strategies and methodology, which will involve communication, training and education, and goal deployment, must be adopted for an effective coordination and integration of participating firms at different levels of cooperation (A. Gunasekaran 1999).

6.2.4 Automation and Information Technology

Agile manufacturing needs intelligent sensing and decision-making systems capable of automatically performing many tasks traditionally executed by human beings. Visual inspection is one such task and hence there is a need for effective automated visual inspection systems in AM environments (D. Enke, Dagli, 1997). Agile manufacturing requires agile-enabling technologies such as virtual machine tools, flexible fixturing, and agile design alternatives.

7.0 CONCLUSION

In conclusion, the fourth industrial revolution takes place for changes for better as the new technologies can be powerful agents for good. In digital transformation revolution, meant to have a high-flexibility, high-productivity, and become resource friendly which provide a new level of human-machine relationship. Additive manufacturing has contributed in healthcare products to improve population health and quality of life, reduced environmental impact for manufacturing sustainability and simplified supply chain to increase efficiency and responsiveness in demand fulfillment. Flexible manufacturing system is a revolution in the field of manufacturing technology in industries, whereby the operational flexibility is enhanced by the ability to execute all manufacturing tasks on numerous product designs in small quantities and with faster delivery. Last but not least, Agile manufacturing system, is a new form of manufacturing system which enables manufacturers to build the best consumer-based product while also keeping up with a varying demand.

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