Chapter

Revolution of Production System for the Industry 4.0

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Abstract

Nowadays, good coordination of production and logistics at a production operational level is required to handle rapidly evolving technology, frequently changing customer demand and satisfaction, and remain competitive. Accelerated by exponentially growing technologies in information and communication technology, production industries are in the throes of a digital transformation, which is referred to as the fourth industrial revolution or Industry 4.0. The shorter product life cycles due to market-demand variables and volatile developments in the production system have forced manufacturing company to work flexibly in order to adapt to changing customer needs. These environments cannot be managed through traditional production systems such as job shops and dedicated production lines. Reconfigurable manufacturing system, which combines the versatility and capability to re-configure of job shops and the dedicated production lines, has been seen as a potential solution in such situations. As the main component of production systems, a new concept of material handling, a reconfigurable conveyor system is introduced.

Keywords: production system, Industry 4.0, reconfigurable, revolution

1. Introduction

Production industries are one of the important industries, which produce and manufacture various products. This industry makes a large influence in the country's economic growth and quality of life for its citizens because production creates lasting wealth while also distributes wealth through high-paying jobs.

The impact of globalization has created a new challenge for production industries. The possibility for greater integration within the world economy through movements of goods and services, capital, technology, and labor has been leading to a market situation that is difficult to predict. A rose only by 3.6% in the world manufacturing value-added in 2018, slightly lower than the 3.8% recorded in the previous year, has proved that production industries nowadays cannot depend on steady market demands any longer [1].

Production companies have been confronted with a dynamic and changing environment for a long time. The fast transfer of information and global open markets have increased the change frequency [2]. This has raised the pressure of time and costs.

Today's changing market climate has broadened up the horizon of competition for many companies. Dealing with a short innovation cycle of global competitors and a wide range of individualized product demands from customers all over the world, companies will need to provide quality and reliable products within the international competition needs. Only enterprises that react on changing markets and customer preferences quickly and cost-effectively are able to stay competitive in this environment [3]. On the other hand, the competition has opened up and provides an endless challenge to the researcher to provide a better solution.

As forecasting and planning become less and less reliable, the support for continuous changes is helpful. Short response times and high changeability in layout and in processes for the production and logistics systems are strongly required [2].

2. Production system

A production system, as a value creation module (**Figure 1**) is a system that transforms input in the form of material, energy, information, and monetary means, into value-created output such as a fabricated or assembled product [4]. This is achieved through the synergy of value creation factors: product, process, equipment, organization, and human [5]. The value creation of a product involves several processes, which require organization procedures to manage their execution. The processes consist of technical operations, which can be categorized as machining, assembly, testing, handling, conveying, storing, collecting, distributing, sorting, and packaging [6]. The operations are performed or supported by humans and equipment. Linking all the operations involved in the production, processing, and distribution of goods within specified areas is defined as a material flow [7]. It covers all forms of work objects' (e.g., substances, parts, and carriers) movement in the production system either by manual or using automation.

In order to sustain competitiveness in dynamic markets, new designs of production systems are required. Since its development two centuries ago, the production

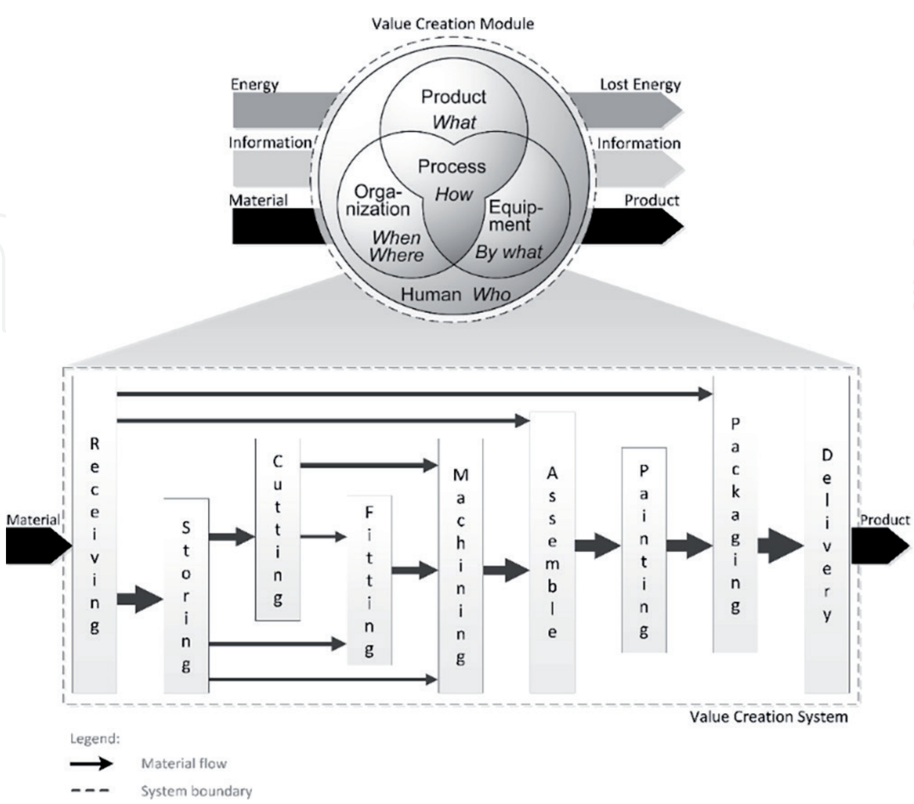

Figure 1.
Production systems as a value creation module.

industry has revolved through several paradigms [8]. The first paradigm was Craft Production, which created the product the customer requested at a high cost. There were no production systems associated with this paradigm. Most of the production industries during this year used manual processes by handmade. In addition, the providers of craft products were confined to localized geographical regions, hence such production was not scalable.

After a certain century, a new moving assembly line was introduced in the 1913s. This year is the beginning of mass production, which provided low-cost products through large-scale production. However, the number of varieties offered by such production was very limited. The year 1955 shows the peak of mass production due to the highest rate of production. The production system during this era is called dedicated production line.

In the late 1980s, global competition and consumer demands for high-product variety led to the development of mass customization [3]. Manufacturers designed the basic product architecture and options while customers are allowed to select the assembly combination that they prefer the most. Dedicated production line is not able to cope with the product variations of product family. An invention of computer numerical control (CNC) technology was introduced in the year 1980s to support the high-frequency changes in customer's requirements. This production system can be called as flexible manufacturing system (FMS). Planning of the product family enabled manufacturers to share certain common components across the products in the family so that the economy of scale is achieved at the component level.

However, the process of manufacture and development of new products has become more challenging yet complicated [9]. While there are many changes and variations in customer requirements, the high flexibility of the system to produce a variety of products on a similar system is also required at the same time. In the 2000s, the production industry needs to face unpredictable, high-frequency market changes, and other challenges due to globalization in this twenty-first century [10].

Nowadays, customers' desire to influence and participate in the design of products is the key driver leading to the new emerging production paradigm, which we call personalization or personalized production. Therefore, a new type of production system is required in order to make the competition between companies in the production industry to make it become more responsive to all the market changes [11]. The concept of reconfigurability is introduced in production to support high-frequency market changes [10]. The revolution of production systems based on production paradigms is illustrated in **Figure 2** using a product volume-product variety relationship.

2.1 Dedicated production lines

Producing large quantities of standardized products known as mass production is the American system of production. This production strategy began with the launch of the Henry Ford Moving Assembly Line, which culminated in a high product demand following World War II. In this production era, dedicated production lines represented a key paradigm in production industries. Dedicated production lines produced large quantities for a single part type and very profitable when demand for this part is high [12]. **Figure 3** shows an example of dedicated production lines for the manufacture of cars. The dedicated production lines are cost-effective as long as they can operate at full capacity. However, market pressure from global competition and over-capacity worldwide is increasing. In order to maintain the varieties of products, many dedicated production lines are required [13]. This increases the overall factory cost significantly.

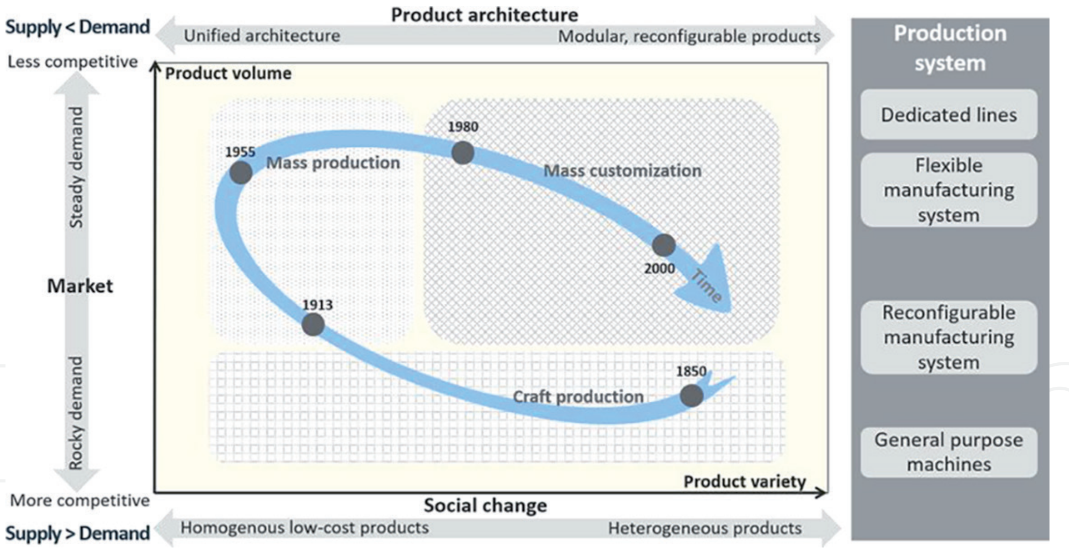

Figure 2.
The revolution of production systems.

Figure 3.
Dedicated production lines for the manufacture of cars.

Dedicated production lines also have its disadvantages. According to Delorme et al. [14], a dedicated production line requires a large investment and needs to be used for a long time to be competitive. The dedicated line is very complicated to change, and if necessary, it will require a high cost and effort to reconfigure. In addition, breakdowns of the system are also a crucial issue. This is attributed to the interrelatedness of each station in the line where the entire line has to be halted if one of the stations fails. FMS was introduced to overcome these problems.

2.2 Flexible manufacturing systems

The demand for product variety rose in the late 1980s, which leads to the paradigm of mass customization [15]. Since then, there has been a major increase in the number of product variations offered by product manufacturers. This has been proven by the increment in numbers of different car models in the United States of America from 44 in 1969 to 165 in 2006 [16]; due to many choices of components and accessories combinations offered for each car model. The segmenting of product markets and international competition both led to the development of highly diversified and customized products that required FMS as their production system.

The FMS concept allows production companies to predefine a range of production processes within the context of the system capabilities (**Figure 4**). In a single system configuration, FMS enables production companies to quickly and easily activate a range of product models on request, thus improving their competitiveness and profitability through a highly efficient system design [17]. Companies can effectively manufacture a number of product types in the same system. However, when an unexpected production requirement arises, the adaptability of FMS is constrained by limitations and synchronization problems [18]. FMS are not designed for structural changes and therefore cannot respond to abrupt market fluctuations, such as varying user requirements and major equipment failures [19]. Similarly, a study by Koren and Shpitalni [11] showed that there is a growing need for FMS to be reconfigured and reused more efficiently in order to maximize return on investment.

2.3 Reconfigurable manufacturing system

The pervasive internet presence, computational and analysis software, and the introduction of modern responsive production systems, such as 3D printing, pose an opportunity for a new product development paradigm: personalizing products according to individual needs and preferences. Through collaboration with production companies and other consumers, customers are able to design and realize their innovative products. This co-development process enables customers to engage in design, product modeling and simulation, fabrication, and assembly processes that respond quickly to the needs and preferences of customers, by means of the open-product architecture [20], the on-demand production systems, and adaptive cyber-physical system.

The heterogeneity of consumer demands has forced enterprises to offer a higher number of product variants, produced in smaller batch sizes. A huge increase in product varieties in different product ranges and sectors can be noticed [21], and this trend will continue [22].

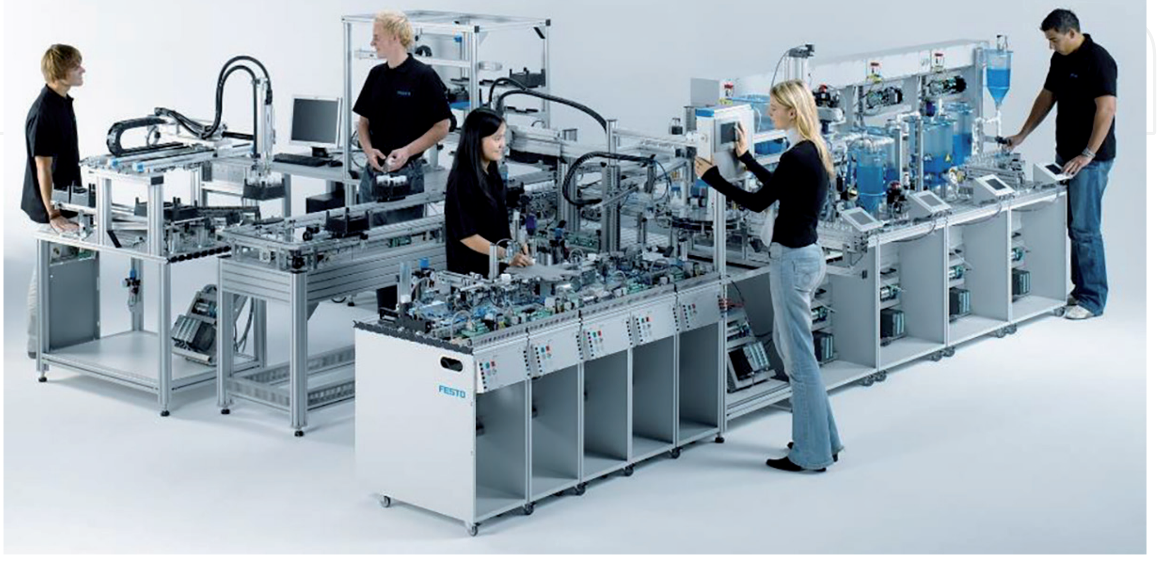

Figure 4.
An example of an FMS developed by FESTO group.

As a result of the high cost of reconfiguring the FMS, reconfigurable manufacturing system (RMS) concept has been introduced to tackle the issues in FMS. In earlier definitions of the RMS, [23] RMS is differentiated from dedicated production line and FMS by their adjustable system structure adaptability and the scalability to varying demands. The structural adjustment can occur at the system level, machine level, or both levels. RMS is a cost-effective production system paradigm when adapting frequent changes is required [24]. It reduces system costs by designing a production system for the whole part family and provides the necessary custom flexibility to produce all the components in the part family. It, therefore, has the ability to produce a broad range of components at varying levels of production and in high-economic-performance environments. An example of an RMS is shown in **Figure 5**.

Koren and Shpitalni [11] said that reconfigurable is designed at the outset for ability changes in software and hardware to a new circumference to response to a sudden change in market requirements. RMS has been proposed extensively in different industries and companies to produce modularized, customized, flexible, and scalable products.

Reconfigurability implies a responsive production engineering technology that is able to respond quickly to changes in the product market by designing production machines and systems that are cost-effective and quick to reconfigure. In the absence of reconfigurability design, the process to reconfigure the system and its machine shall be both long and ineffectual. There are three basic elements in designing the process for RMS, which are the control system, material handling system design, and layout design. **Table 1** shows the details about each of the elements.

Figure 6 shows the type of configuration and reconfiguration system. Two different kinds of reconfigurable systems can be differentiated according to Pritschow et al. [26]. In type 1, machine modules are predefined in system architecture, while in type 2, machine modules are not designed within the architecture of the system. The type 2 reconfigurable system cannot be immediately or automatically reconfigured.

There are numerous aspects that can be definable in order to fully understand the reconfigurable material handling system: convertibility (functionality shift purpose), scalability (capacity change plan), modularity (modular elements), integrability (quick integration interfaces), customization (part family flexibility), and diagnosability (easy diagnostic design) [27]. Customization, scalability, and

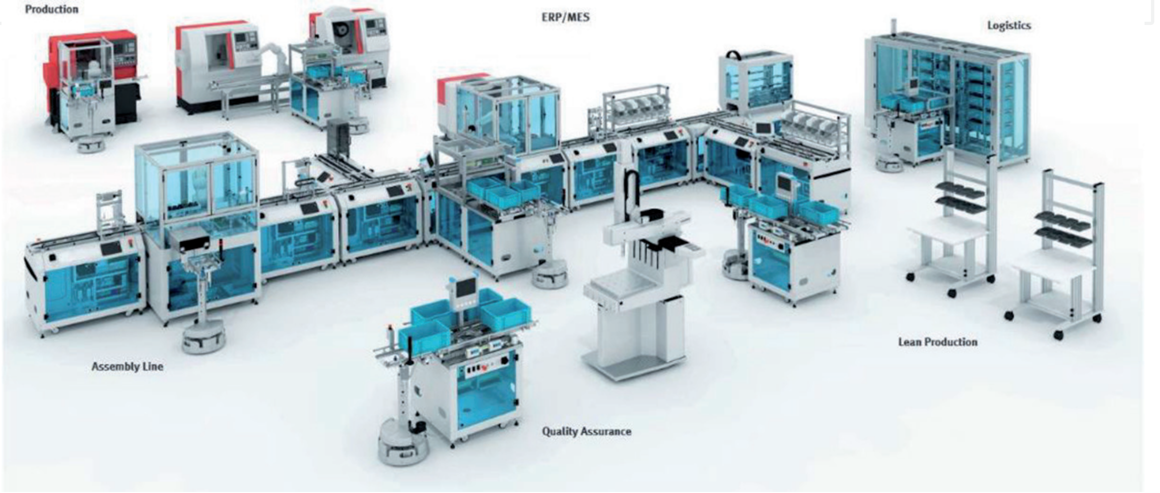

Figure 5.
An RMS system developed by FESTO group.

convertibility are critical reconfiguration characteristics, while modularity, integrability, and diagnosability allow rapid reconfiguration [25]. The detailed characteristics of reconfigurable material handling are shown in **Table 2**.

Element	Details
Control system	The specification of the controller to form an automated material handling system
Material handling system	The selection of material transport equipment that relates to the movement of the parts
Layout design	The choice of the physical arrangement of production facilities such as machines, tools, and plant layout

Table 1.
The basic elements in design processes for RMS [25].

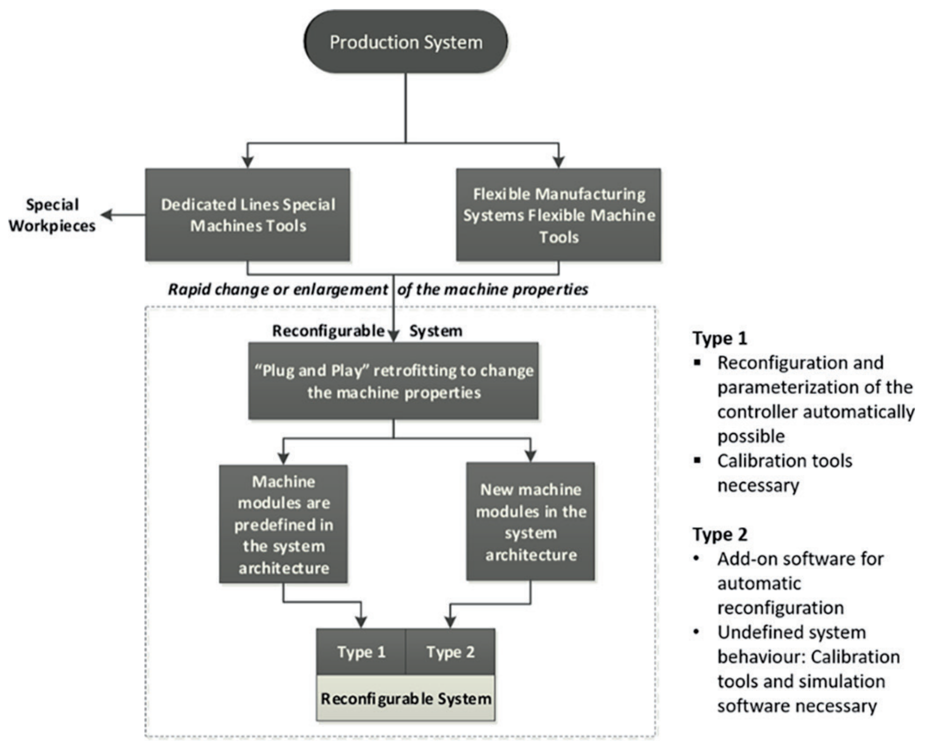

Figure 6.
The type of configuration and reconfiguration system [26].

Elements	Details
Convertibility	The ability to transform the functionality from the existing system to new production requirements easily
Scalability	The ability to modify production capacity by adding or subtracting component of the system easily
Modularity	The ability to manipulate between alternate production scheme for the optimal arrangement
Integrability	The ability to integrate module rapidly and precisely by a set of mechanical, informational, and control interface
Customization	The ability to produce a particular product based on the customer's requirement
Diagnosability	The ability to automatically read the current state of a system and quickly correct operational defects

Table 2.
The characteristics of reconfigurability [27].

3. Reconfigurable conveyor system

A production system consists of material handling equipment, production machines and tooling, computer control system, and others that promote the efficient use of energy, material, resources, and equipment. As the main component of production systems, material-handling systems can be defined by the movement, storage, protection, and control of products and materials throughout the processes of manufacturing, disposal, distribution, and consumption of all related materials and goods [28]. In possessing a new production system, a new concept of material handling should be proposed. Since conveyor is the most commonly used material handling equipment in production industries, research was conducted in developing a concept of reconfigurable conveyor system that supports changeability in production.

3.1 Reconfiguration in automated conveyor system life cycle

The development of a conventional and centralized controlled conveyor system lies in a range of activities, which are different from technology and personnel requirements set by the system manufacturer. Current approaches for developing the system, while well-established and using well-proven methods, still follow a rigid sequential model and use an ad hoc collection of poorly integrated tools to translate requirements into the desired system (**Figure 7**) [29]. The planning and design of the system, fabrication of the mechanical structures, construction of electrical components, formation of control systems, and validation of the systems take place sequentially. In such an engineering process, the creation of the control system can only be carried out after all the electrical and mechanical units have been integrated.

In the operational phase, the conveyor system is utilized as it is intended. An operator of the system can monitor the operating status, identify malfunctions, and fix minor problems. In case of major problems, the help of the system provider is needed. Depending on the problem complexity, the system provider will help through a hotline, remote maintenance, or onsite maintenance.

After several years of operations or, in certain cases, changing of control strategies, restructuring or exchanging individual conveyor system units, expansion or modernization of an existing system are necessary. This is normally triggered by an increase in throughput demands, storage and buffer capacity, or a change in product variants. In principle, from the perspective of the system provider, the life cycle of the system will go through again for such cases (**Figure 8**). However, the key difference in these activities is the integration of new components with the existing systems either physical hardware (physical reconfiguration) or control software technology (logical reconfiguration) [26]. Specifically, the adaptation of existing conveyor system control software requires high efforts due to the engagement of all control logic levels. The largest effort lies in reconfiguring, reprogramming, and commissioning of an adapted material-flow control system [30].

3.2 The conceptual framework

A conceptual framework of a reconfigurable conveyor system can be classified into two categories, which are physical and logical. The physical aspect is the overall design of the conveyor including the shape, size, and material used. The conceptual design is drawn in computer-aided design software to visualize the suitability of the design with the reconfigurability criteria, before their construction. For

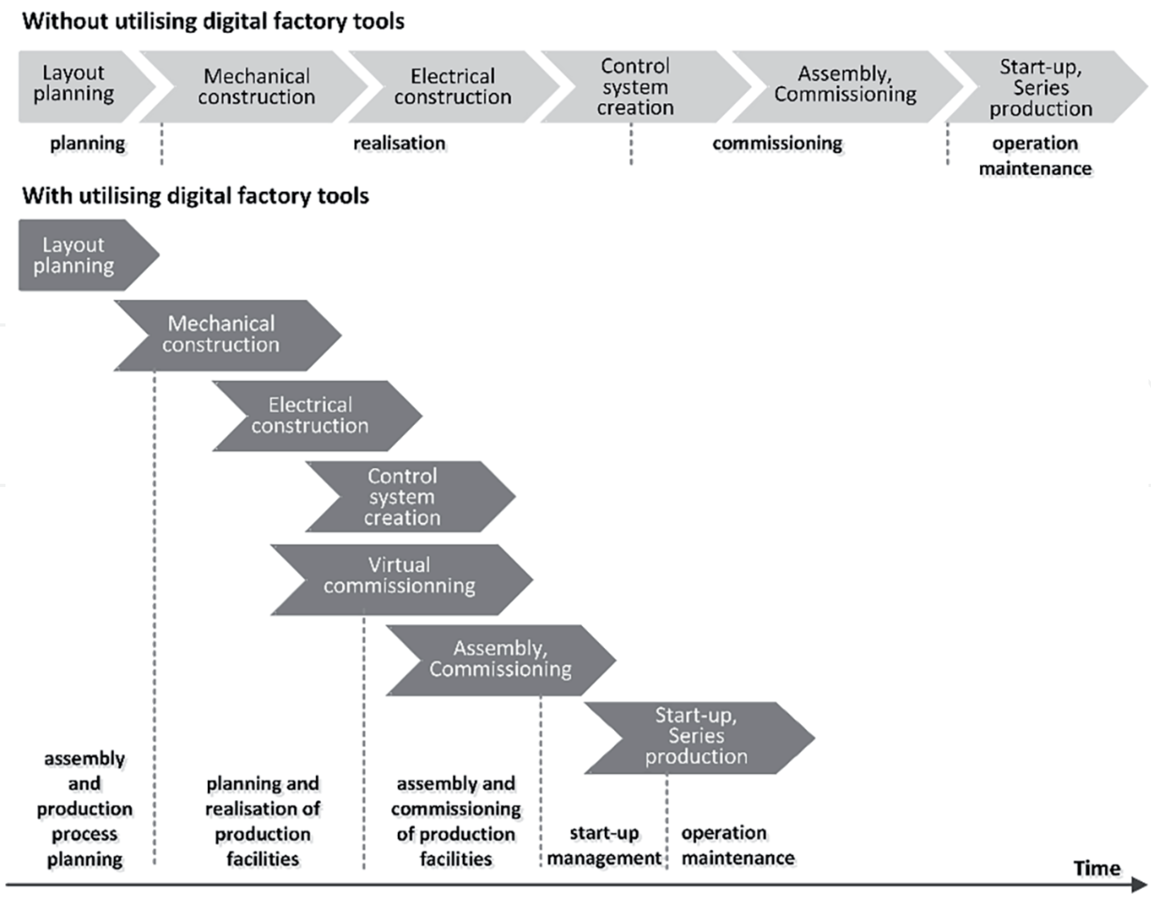

Figure 7.
The life cycle of an automated conveyor system [10].

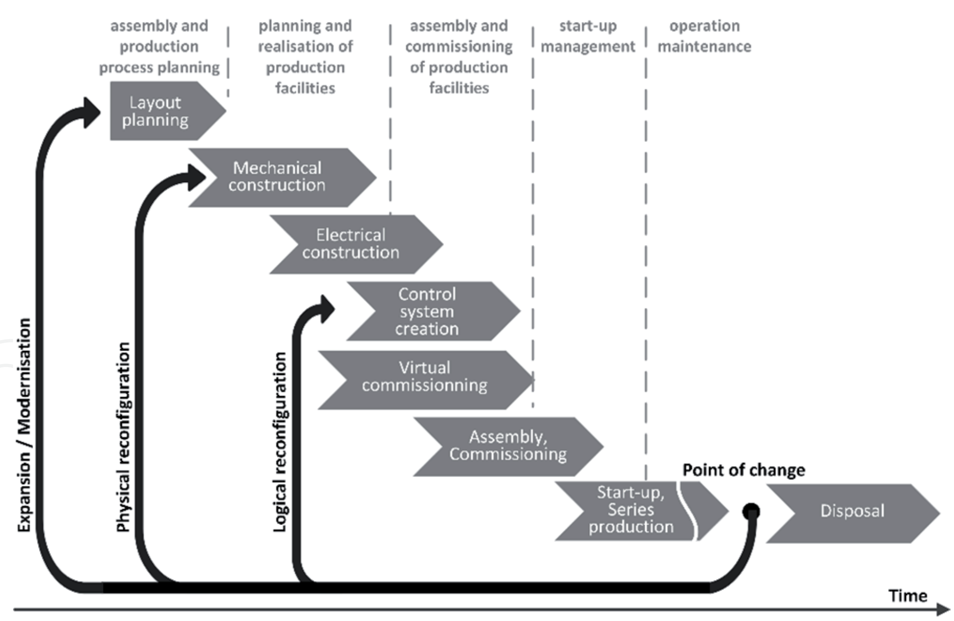

Figure 8.
Changes in the life cycle of an automated conveyor system [10].

the logical aspect, the programmable logic controller (PLC) is used as the control system since it is the most commonly used controller in production industries.

The physical reconfigurable conveyor system was designed in modules (**Figure 9**), in which each module consists of few components such as adjustable steel combine stands, adjustable wheels, pneumatic cylinders with turntable, and belt conveyor. This modular concept makes the conveyor system easier to integrate, customize, and convert when all the modules are connected in order to form a system. **Figure 9** shows the module of the reconfigurable conveyor system.

The concept for reconfigurable conveyor systems used adjustable magnetic locking systems to connect the modular components. It had replaced the fasteners with a better quick-change performance and fewer tools required. Based on its modularity, several possible layouts can be created by using the modules that had been designed. Some of the basic possible layout arrangements for the

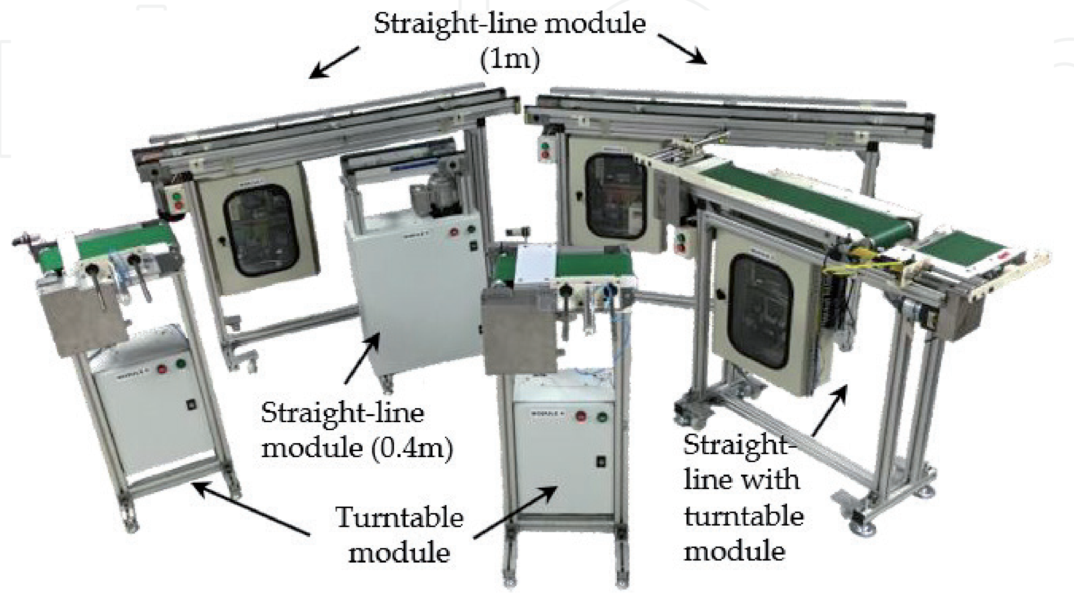

Figure 9.
Modules of the reconfigurable conveyor system.

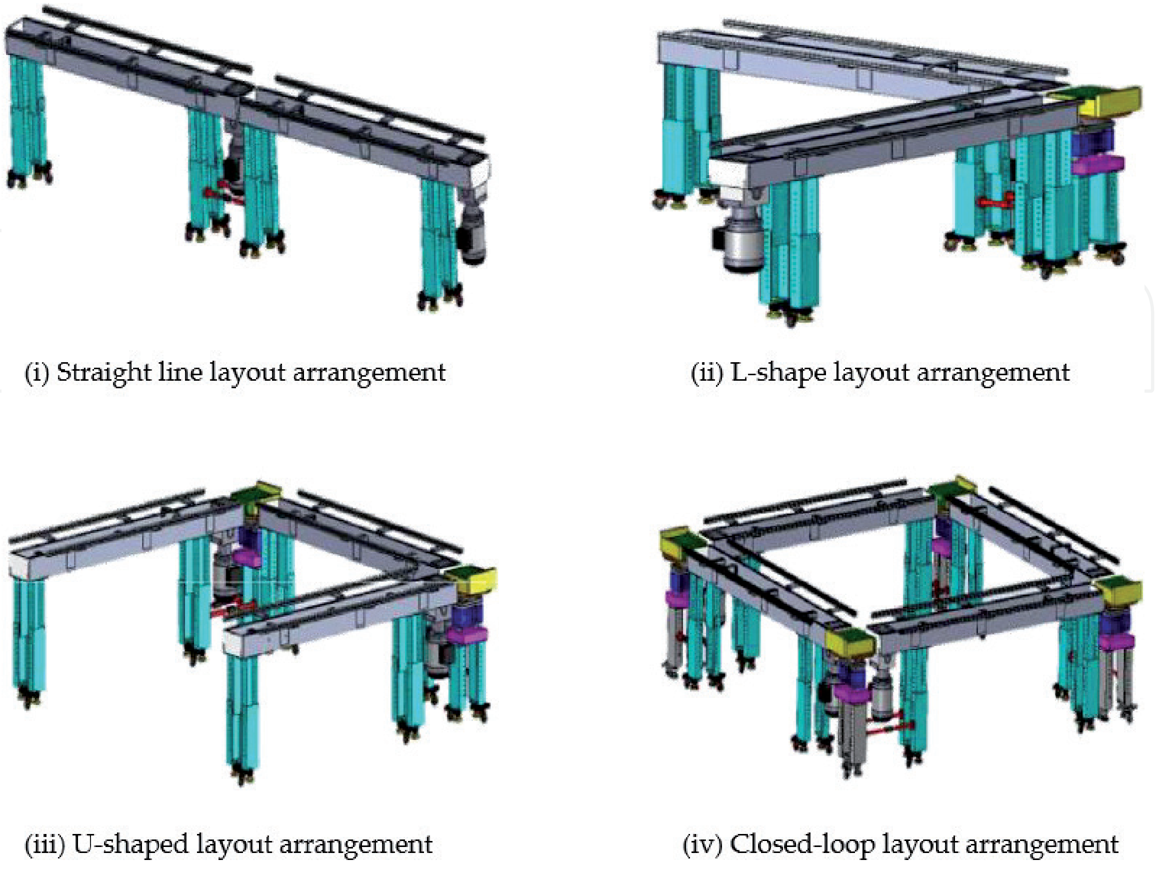

Figure 10.
Possible layout configuration.

reconfigurable conveyor system are straight-line layout arrangement, L-shape layout arrangement, U-shape layout arrangement, and closed-loop layout arrangement (**Figure 10**).

The overall changeover operations have become less complex and faster. Maynard Operation Sequence Technique (MOST) analysis is used to conduct the predetermined time system of the conveyor system. The unit used for the MOST analysis is time measurement units (TMU) where 100,000 TMUs are equivalent to 1 hour. Two sequence models will be used to analyze the setup time of the existing conveyor system and conceptual reconfigurable conveyor system. A total of five operations are needed to carry out the dedicated conveyor system, whereas only three operations are carried out by a reconfigurable conveyor system.

Table 3 shows the comparison of the total time needed to assemble the L-shape layout between a dedicated conveyor system and a reconfigurable conveyor system. The reconfigurable conveyor system only needs 39.24 min to make the L-shaped configuration compare with a dedicated conveyor system, which takes 81.72 min.

Type of conveyor	Operation	Changeover time (min)	Total time (min)
Dedicated conveyor system	Fasten 14 steel bars	33.6	81.72
	Fasten 8 support stands	20.64	
	Fasten 4 steel bars	10.32	
	Loosen 4 steel bars	10.32	
	Miscellaneous	6.84	
Reconfigurable conveyor system	Fasten 10 combine stand	12.00	39.24
	Fasten 10 bolts for 2 modules	21.00	
	Miscellaneous	6.24	

Table 3.
The MOST analysis of the reconfigurable conveyor system.

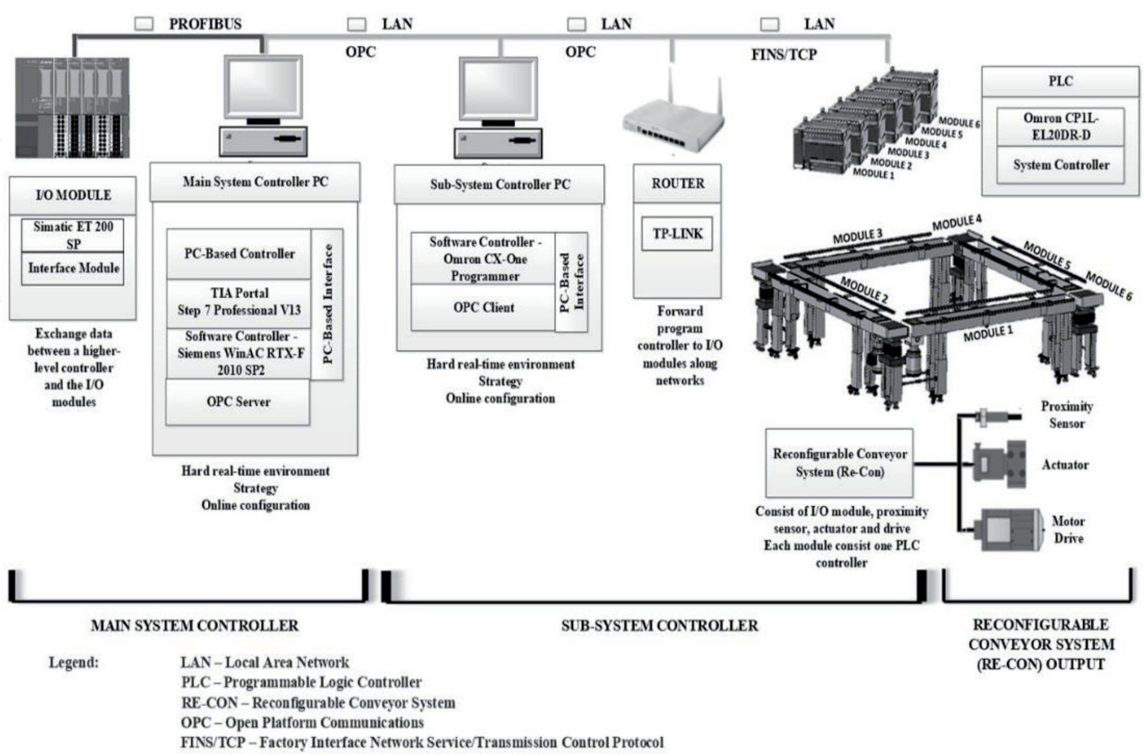

Figure 11.
The architecture of reconfigurable conveyor system.

Almost 50% of the changeover time is reduced by using a reconfigurable conveyor system.

The architecture of the reconfigurable conveyor system concept consists of two controllers, which are the main system controller and a subsystem controller (**Figure 11**). The main system controller is using a Siemens controller as its main control. An application-oriented integration of three software programs is used in a realizing concept for reconfiguration. This software includes Siemens TIA Portal, Siemens Step 7 Professional V13, and Siemens Simatic WinAC RTX-F 2010 SP2. In this research, Siemens Simatic WinAC RTX-F is used as the software controller. A PC-based controller is used as the basis for the connection. All software used must support each other to make sure the connection and program control can be transferred without any error.

Furthermore, a Profibus card reader is installed at Siemens SIMATIC ET200SP to exchange data between high-level controllers to the Inputs/Outputs (I/Os) module. After that, the control program will be transferred to the I/Os module through a TP-Link router. The control program consists of logic control programs. All the relevant I/Os need to be considered based on the program that has been

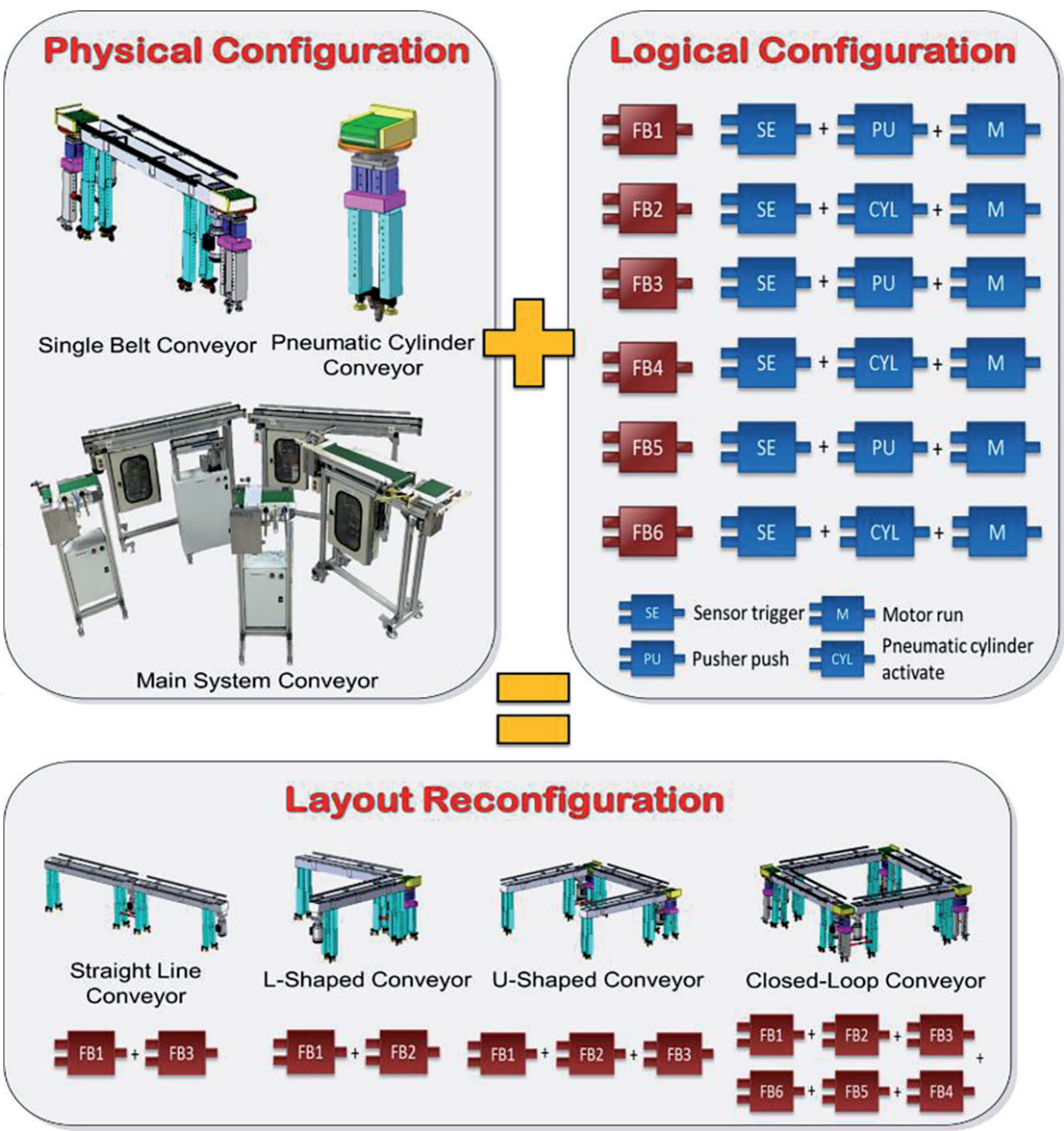

Figure 12.
The conceptual framework of the reconfigurable conveyor system.

designed according to the mechanical structure. The control logic is drawn in a ladder diagram. The control program will be transferred to six modules of Omron CP1L-EL20DR-D through the Open Platform Communications (OPC) server and the Factory Interface Network Service (FINS)/Transmission Control Protocol (TCP) network by using local area network cables. OPC is used for communication of real-time implementation between controllers that have different manufactures. Meanwhile, the FINS/TCP Ethernet network is used to connect PLCs through multiple segments at the same network to obtain an IP address. Omron CP1L-EL20DR-D comes with an Ethernet function for communication. The Ethernet is used as a communication method between each controller in this system. IP and MAC address from each controller will be considered to transfer the control program to each sequence of operation. After all, the program is transferred successfully, and the reconfigurable conveyor system outputs including sensor, actuator, and motor drive will be functioning.

Lastly, the main system controller software connected to I/Os modules will receive the signal from the physical equipment. If the condition is satisfied, the conveyor will continue to move based on the control program. But, if there are any errors, the main system controller PC will show the errors and the user can change and modify the program online directly without stopping the conveyor.

The logical (re-)configuration of the reconfigurable conveyor system is designed by using function blocks. Each function of the physical components (sensors and actuators) has its own function block, which are stored in the function block library. The program of each module consists of combinations of function blocks from different numbers of sensors, pushers, pneumatic cylinders, and motors. Depending on the layout (re-)configurations, the main control program for the reconfigurable conveyor system can be designed by combining the module's function block. **Figure 12** illustrates the overall reconfiguration concept of the system.

4. Discussion: production system for the future

The term Industry 4.0 and its reference architecture model are originated from Germany (Industry 4.0). It was first introduced in 2011. Now, the vision—and reality—of the Industry 4.0 has caught the attention of organizations across the globe. Moreover, even though Industry 4.0 originally was used only for production, it is de facto going further. We clearly see nowadays how the several parties that were involved in Industry 4.0 themselves move it to smart transportation and logistics, smart buildings, smart oil and gas plant, smart healthcare, and even smart cities.

In the fourth industrial revolution (**Figure 13**), the production industry is moving from 'just' the Internet and the client-server model to ubiquitous mobility, that integrates digital and physical environments referred to as Cyber-Physical Systems. This can be achieved through the integration of information and communication technologies (such as Internet of Things—IoT and Big Data) with operation technologies (such as collaborative robots and artificial intelligence/smart cognitive), which allows Industry 4.0 factories to automate and optimize in completely new ways and bring the smart factory up to the next level.

Research has been performed by Qin et al. [31] to analyze the current production system and comparing them with the concepts of the Industry 4.0 requirements. Based on their research outcome (**Figure 14**), it is obvious that the current implemented production system has not yet achieved the Industry 4.0 level comprehensively, although many researchers and companies are working on this topic. There is still a long way to go to improve production up to the required level to match all concepts with all dimensions.

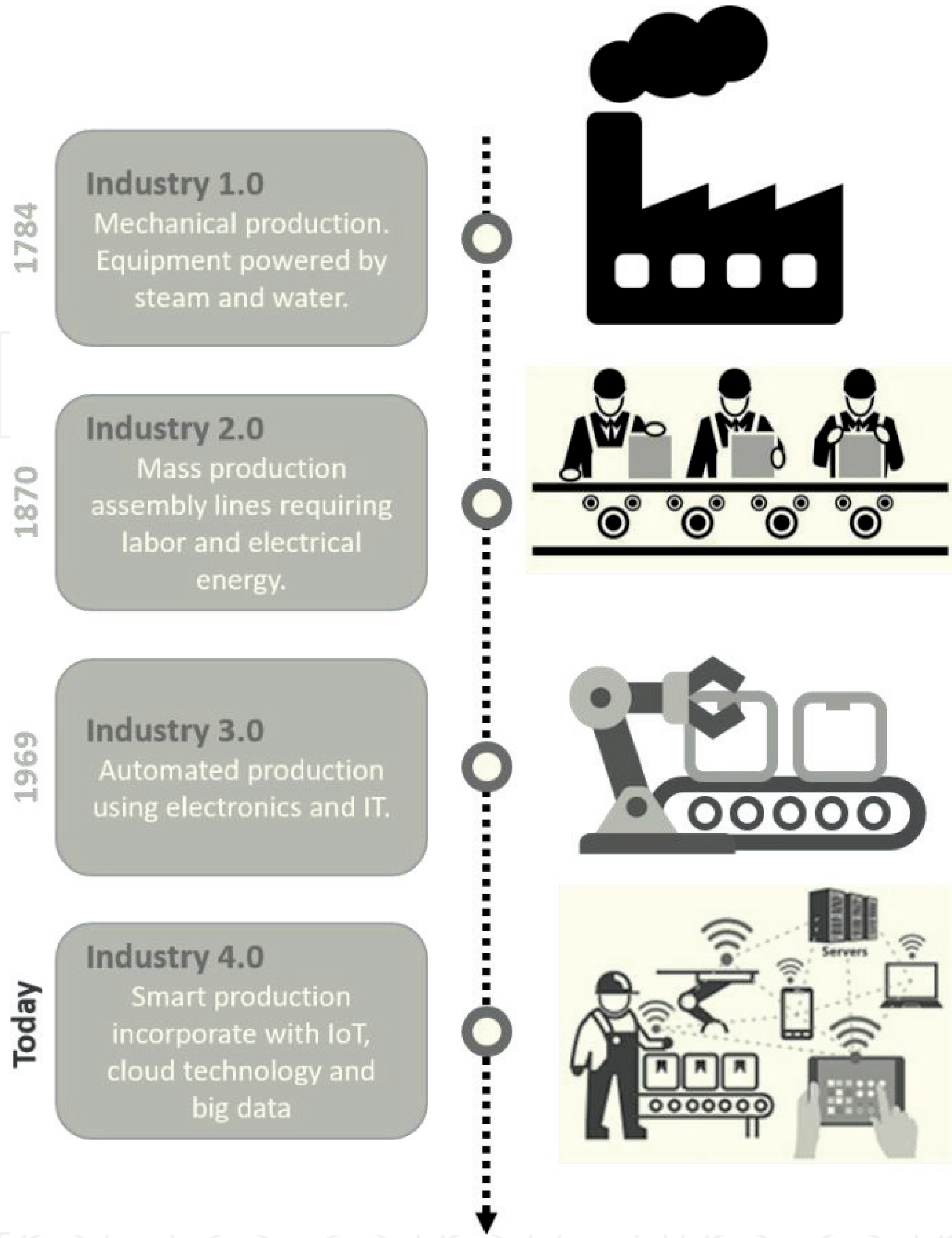

Figure 13.
The revolution of the production industry.

5. Conclusion

Production industries have shifted from one paradigm to another for the last couple of decades, starting from craft production, mass production, customization production, and personalized production. The growing later paradigm would cover the goals and strategies of a previous paradigm and will involve more reactive production systems. Fluctuating product demands and dynamic market environment in personalized production has resulted in the development of RMS, which are able to react and adapt to frequent changes while maintaining the flexibility of FMS.

The importance of changeability in production systems has been well recognized and applied for many years. Since then, several research activities have been conducted to fulfill the needs of changeability. At an operational level, a lot of activities are focused on physical and logical reconfiguration including reconfigurable

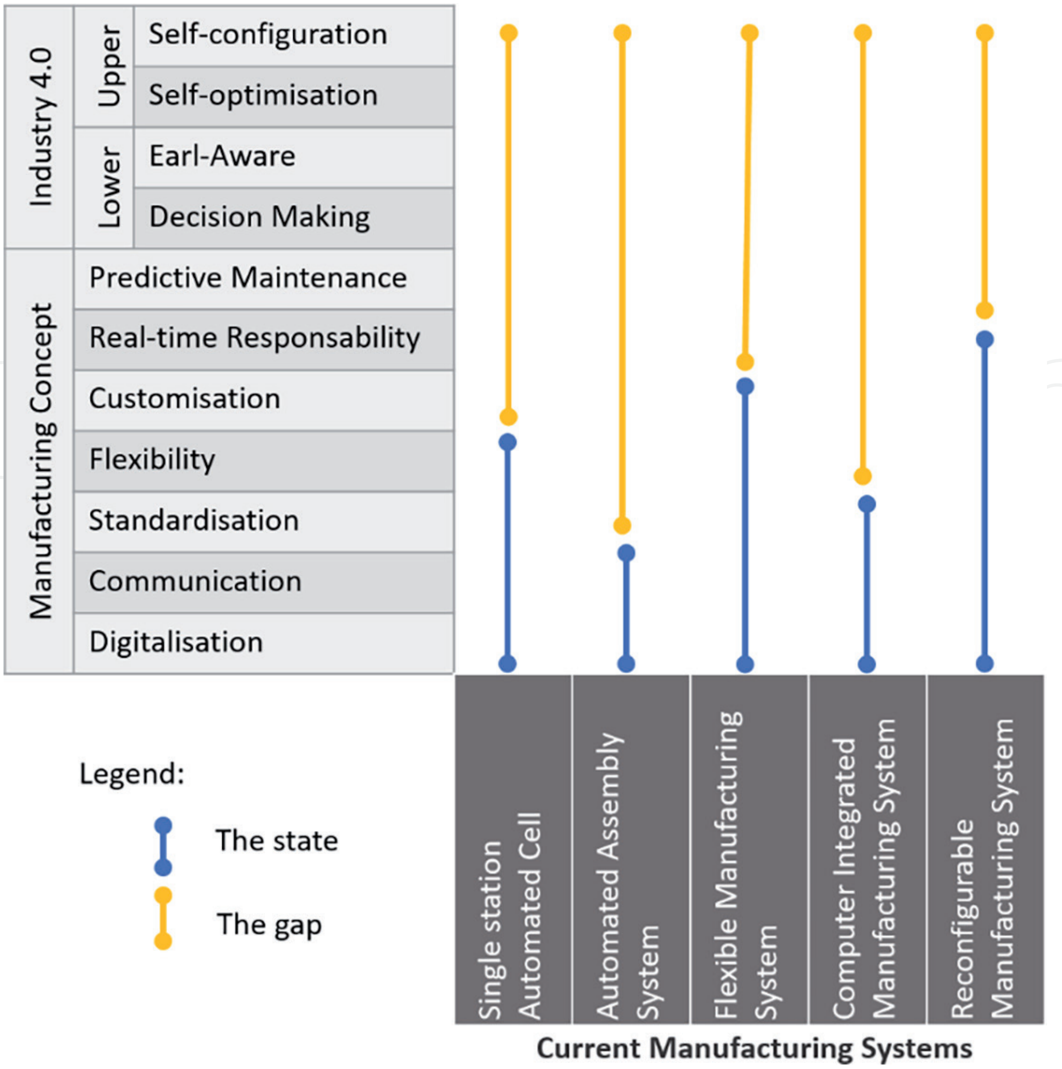

Figure 14.
The identified gap between current production systems and the Industry 4.0 concept.

material handling systems. Interfaces between mechanical structures have been studied for easy-to-use and plug-and-producible concept, and construction kits for modular material handling systems have been developed to realize the concept. A conceptual framework of reconfigurable conveyor system that supports physical and logical reconfiguration is introduced.

Future fields of research in production engineering will focus greatly on enhancing the autonomy and changeability of the production system. In line with the Industry 4.0, Artificial Intelligence and Cyber-Physical System technologies also need to be implemented for the enhancement of the conceptual framework. Strong interdisciplinary activities in this research field are, therefore, to be anticipated in the next few years.

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