

# Enhanced Organizational Ambidexterity in Electronics Manufacturing through the Automation of Production-Related Processes

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**Abstract—** The current discussion about the industrial Internet of Things (IoT) focuses in particular on diverse technologies and their possible applications in companies. However, the actual potential benefits and objectives of the fourth industrial revolution for companies are often neglected. The challenges posed by the increasing number of variants and decreasing batch sizes up to batch size one require special adaptability and flexibility. The aim is not only to offer customized products, but also to produce them with the efficiency of a mass production. This affects numerous business sectors. Whereas in the past the search for efficiency potentials was focused on the production process, it is now essential to consider strategic and operational corporate areas beyond production – the so-called overhead processes. The required flexibility of companies to produce mass-customized goods leads to an increased complexity of internal processes and a high proportion of additional overhead activities for the management of resources. In this paper, we provide an approach to automate repetitive, non-creative activities in all value added processes and to connect overhead processes with the production so that a fast, automated response to unplanned events in production is facilitated. Hence, an economical production can be realized in the context of mass customization.

**Keywords—** *Industrial internet; Automation; Efficiency potentials; Potential benefits; Value-added processes; Electronics manufacturing*

## I. INTRODUCTION

Before delving into a closer examination of the fourth industrial revolution, it is appropriate to first look at the recent three industrial revolutions and to analyze what happened in these different phases and how they are related to each other. The first industrial revolution was characterized by mechanization. For the first time, human operators were supported by production facilities [1]. This machinery was powered by external energy like steam or water power [2]. Hence, the time required to carry out various work could be significantly reduced and productivity increased. [3]

The second industrial revolution was the beginning of electrification and the mass production base on the division of labor. The use of electrical energy and assembly lines led to a significant rationalization of the production process. The work process could be broken down to many individual steps, employees were specialized for certain jobs, and production costs dramatically reduced. The second industrial revolution was impacted by Ford, a pioneer of the assembly line methods, and Taylor, who established the basis scientific management principles. [4] [5]

The third revolution consists in the application of electronic and information technology for the control and automation of production lines. The most important enabling technology in this context are programmable logic controllers. In contrast to the mechanization which displaces physical labor, the automation is able to replace mental work and human decision making. This allows both a higher production flexibility, as well as a further reduction of production costs and cycle times. [6] [2]

Basically, the first three industrial revolutions reflect two clear tendencies: On the one hand, the products and the necessary production processes become more complex and therefore require an increased abstraction ability of all persons involved to control this complexity. On the other hand, the production processes become more efficient. That means, with the help of new technological solutions, the capacity (process-bound steps per time unit) of production systems is increased. Due to this increased efficiency in task fulfillment new technologies, such as the programmable logic controllers in the third industrial revolution, can find acceptance despite their enhanced complexity. [7]

Even in the age of the fourth industrial revolution a whole new level of complexity is reached in the area of production systems by the use of cyber-physical systems (CPS). These are embedded systems which combine software components with electrical and mechanical parts and which are closely networked with each other [6]. This networking is achieved by the internet, which consists of an open and global information network. For this reason the network is also called the Internet of Things. However, the question arises how further significant increase in efficiency of production can be reached through these complex systems in context of the fourth industrial revolution. Most discussions about the fourth industrial revolution only focus on technologies and technical solution concepts like CPS, cloud computing or big data projects. From this purely technological

point of view, however, the value proposition of these technologies remains unclear [8]. This paper focuses on this issue. Therefore the major challenges for manufacturing companies are considered below to subsequently identify and develop possible potential benefits.

## II. CHALLENGES IN THE MANUFACTURING INDUSTRY

Manufacturing companies especially in high-wage countries face the challenge of protecting their leading role in the global competition for the long term by an economical production in spite of fluctuating demand and a rising number of variants [9]. This provides companies with new challenges. The increasing number of variants in combination with a decreasing batch size down to lot size 1 requires special adaptability and flexibility [10]. This calls for a fundamental transformation among manufacturing companies. One of the strengths of the German small and medium enterprises are already the engineer-to-order processes and the resulting individualized customer solutions. However, the aim is not only to offer customized products but to produce them with the efficiency comparable to a mass production process and to offer them at standard prices. This requires organizational ambidexterity meaning the capability to provide efficiency and flexibility at the same time. This new challenges in course of mass customization have an impact on numerous business sectors. *TABLE I* shows that a major part of the impacts of additional variants refers to business sectors which only have an indirect share of the value added.

TABLE I. IMPACT AREAS OF INCREASING VARIANT DIVERSITY

Business sector	Impacts on
Research and development	<ul style="list-style-type: none"> <li>▪ Preparation of product-specific requirements documents</li> <li>▪ CAD construction</li> <li>▪ Generation of part lists</li> <li>▪ Coordination between departments and domains</li> </ul>
Production planning	<ul style="list-style-type: none"> <li>▪ Compilation of scheduled work plans</li> <li>▪ Generation of NC programmes</li> <li>▪ Number of required resources</li> </ul>
Logistics	<ul style="list-style-type: none"> <li>▪ Planning effort</li> <li>▪ Definition of material flow</li> <li>▪ Space requirements and inventories</li> </ul>
Purchasing	<ul style="list-style-type: none"> <li>▪ Purchasing of smaller quantities</li> <li>▪ Information search and negotiations</li> <li>▪ Management of additional suppliers and parts</li> </ul>
Production	<ul style="list-style-type: none"> <li>▪ Work preparation</li> <li>▪ Sequencing of assembly lines</li> <li>▪ Required manufacturing area and area for temporary storage of parts</li> <li>▪ Number of tool changes</li> <li>▪ Training of workers</li> </ul>

It can be seen that an increasing variant diversity affects many areas of a manufacturing company outside the production process, ranging from the increasing effort in product development over the increasing complexity of production planning through to the difficult management of the resulting supply chain. These are strategic or even operation business sectors that are beyond the production process and mainly cause overhead costs [10]. Hence, these sectors are also called overhead sectors. On average 50 percent of all employees in manufacturing companies work in overhead sectors. Moreover, some companies achieve peak values of up to 90 percent which is accompanied by a corresponding high proportion of overhead costs. A look at the current trends and challenges of the manufacturing industry even shows an increase in this tendency [10].

## III. PROBLEM DEFINITION

Historically, the overhead sectors have not been in focus of the search for efficiency potentials so far [11]. The first three industrial revolutions mainly concentrated on production process as the area of direct value added and achieved a significant increase in efficiency on the shop floor. Numerous overhead processes are originated from the requirements of previous industrial revolutions, such as the work preparation for the planning of the production based on the division of labor.

However, enhancing the flexibility of companies in the course of mass customization leads to an ever-growing complexity of internal processes and a high proportion of additional overhead activities for the management of resources within the companies [12]. The cause is the increasing individualization of products and services that results in a growing number of projects in the companies. These need to be handled [13]. Productivity losses due to an enormous adaptation effort in production through

the creation of new work schedules, NC programs, logistics concepts and automation systems arise. Furthermore, the resilience in manufacturing, for example during material shortages, short-term prioritization of tasks, machine failures or quantity fluctuations become significantly more difficult.

This requires new forms of organization, as many companies already see the control of complexity due to the increasing individualization of products as the primary bottleneck. An organizational structure needs to be created, which refers to the management of the ongoing projects in a company and their networking. Only in this way companies are able to cope with the future challenges and thus to make an essential contribution to increase efficiency. [14]

For this reason, the current challenges at manufacturing companies, the overhead processes, have to set in the focus of the search for efficiency potentials of the fourth industrial revolution. Thus, it can be ensured that the existing technologies can develop their full potential benefits.

#### IV. AUTOMATION OF PRODUCTION-RELATED PROCESSES

Taking a closer look into the structure of production-related overhead processes makes obvious that these are still strongly characterized by manual activities in contrast to the largely automated production processes. In order to master the rising number and complexity of overhead processes, a solution to increase their automation is necessary. Thereby, the focus is mainly on the production-related overhead sectors that are listed in *TABLE I*: research & development, production planning, logistics and purchasing. As shown in *TABLE I*, there is a significant need for action in these sectors due to mass customization.

To clarify how the fourth industrial revolution can meet these challenges by automating the production-related overhead processes, it is necessary to answer three key questions:

- Which automation approaches does the fourth industrial revolution provide for the automation of non-creative and production-related overhead processes?
- What potential benefits do these approaches offer?
- Which technological enablers of the fourth industrial revolution do represent the basis for realizing this automation approaches?

##### A. Investigation using the method of qualitative content analysis

Basis for answering these questions is a study based on 40 scientific publications in the form of journals, studies, white papers and conference papers that deal with technological enablers, solutions and possible potential benefits of the fourth industrial revolution. The method of qualitative content analysis of Mayring is used to extract the necessary information from the existing data base. Through the definition of clear rules for the implementation of the text analysis and the systematic approach comprehensible and reliable results are gained [15]. The central point of this analysis technique is the establishment of a category system that serves as the essential tool of the analysis. This category system is normally derived inductively in course of the analysis. In the present case this category system is predefined by the questions mentioned above. This is called a structured qualitative content analysis with a deductive category formation [16]. Based on this, the collected content that is defined as the object of scientific publications is best assigned to the predefined categories at the best. [17]

##### B. Results and interpretation of the investigation

Result of the content analysis are structured answers to the questions regarding the automation approaches, potential benefits and technological enablers for an increase in efficiency of industrial overhead processes by automating them. The results are shown in *TABLE II*.

TABLE II. SELECTED AUTOMATION APPROACHES, POTENTIAL BENEFITS AND TECHNOLOGICAL ENABLERS OF THE FOURTH INDUSTRIAL REVOLUTION

Category	Content Elements
Automation approaches	<ul style="list-style-type: none"> <li>▪ Automatic derivation of NC programs from design data</li> <li>▪ Automatic generation of production plans</li> <li>▪ Automated worker guidance</li> <li>▪ Automated logistics planning</li> <li>▪ Flexible logistic systems</li> <li>▪ Automated procurement</li> <li>▪ Networking, communication and data exchange</li> </ul>
Potential benefints	<ul style="list-style-type: none"> <li>▪ Autonomous response to unplanned events in production</li> <li>▪ Autonomous prioritization of production orders</li> </ul>

Category	Content Elements
	<ul style="list-style-type: none"> <li>▪ Automatic selection of alternative production techniques</li> <li>▪ Autonomous optimization of production processes</li> <li>▪ Short-term response to volume fluctuations</li> <li>▪ High variant flexibility</li> </ul>
Technological enablers	<ul style="list-style-type: none"> <li>▪ Cyber-physical systems that create decentralized intelligence at all involved entities</li> <li>▪ Cloud services and service oriented architectures for processing of large amounts of data</li> <li>▪ Semantic communication standards for data exchange between various entities</li> <li>▪ Continuous digital representation of products from the development to the operation</li> </ul>

This content categorization serves as a starting point for the theoretical development of the efficiency potential of the fourth industrial revolution. The technological enablers are the basis on which efficiency potentials can be gained. For sure there are some more technological drivers than the ones that are listed in *TABLE II*, such as mobility or human-machine interaction, that play a major role in the fourth industrial revolution. In the course of the analysis, only technological enablers which are able to make a significant contribution to the automation of non-creative processes were exposed. The most important technological enabler are certainly cyber-physical systems. Through the networking of all entities a comprehensive network of sensors and actuators is provided, which both also allow a holistic detection of the environment as well as an intervention in real time in production activities. Cyber-physical systems offer an interface between the production process and the overhead processes within the value chain. Semantic communication standards, however, are the necessary prerequisite for communication with and within cyber-physical systems. There are two additional technological enablers which are indispensable for the automation of tasks within the overhead processes. On the one hand these are cloud services that provide access to data, computing capacity and software tools at all times and everywhere. On the other hand this is the continuous digital representation of products and their continuous engineering process. Only if there are clearly defined interfaces and file formats as well as harmonized and compatible tools, an automation of different tasks within a process becomes possible.

Through the analysis of these technological enablers a holistic picture of the potential impact of the fourth industrial revolution is created. Many professional contributions are often restricted to individual technological solutions and their potential. With the help of the qualitative content analysis and the categorization, it is possible to show the overall effect of various technologies represented by several solution approaches. Based on the answers to the three central questions, it can be clearly deduced that there is potential for an enormous increase in efficiency of the manufacturing companies by an appropriate technological alignment. Therefore, there has to be a consistent focus on the automation of industrial overhead processes as the common denominator of all activities. This is the only way to meet the current and future challenges for manufacturing companies, particularly in high-wage countries. With automated overhead processes, companies are able to concentrate on the actual value-adding activities in future and thus achieve a further increase in efficiency. Thus, not only the opportunity to realize an economic mass customization is created, but also the general opportunity to develop more efficient production technologies, new products based on creative technical solutions and a short-term realization of customer requests.

Fig. 1 shows the principle of an efficient, effective, flexible and fault resistant order processing which is gained by the automation of production-related overhead processes. It illustrates the interaction of direct service provision (production processes) and the indirect provision of services (overhead processes). A short-term change in the production process such as the acceptance of a lucrative order that, however, needs to be prioritized, or an interruption, for example in form of the failure of a bottleneck machine, is accompanied by expensive overhead activities in different planning areas of the company. The design of production systems that can meet these requirements, calls for a high degree of automation of the production-related planning processes in order to enable a flexible adaptation of the production process. That means, an automated response to unplanned events in production is necessary to implement an efficient, effective, flexible and fault resistant factory. Only then an economical production can be ensured in the context of mass customization.

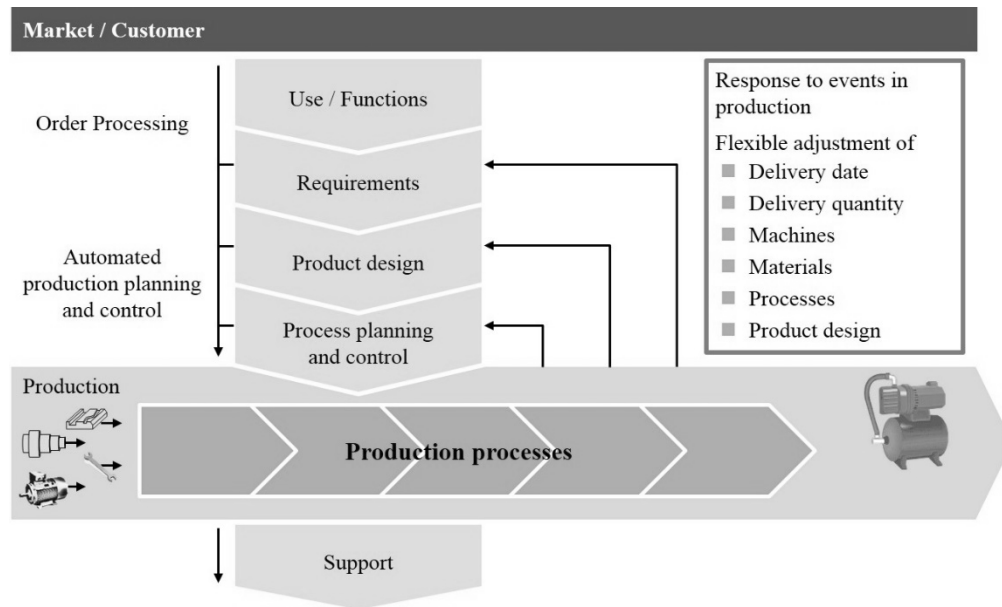


Fig. 1: Automated response to events in production

At this point it is important to mention that not all processes are suitable for automation. There will always be tasks which are not likely to be substituted by machines. These are in particular entrepreneurial skills, the control of machines and especially creativity. Non-creative activities in contrast must be carried out automatically in value-added processes. This implementation can be done in a first step by the provision of tools for manual processes such as software tools for testing processes. These software tools can help human testers to do their jobs more efficiently by automating repetitive tasks like test data creation, problem detection and defect logging [18]. This leads to a partial automation of non-creative activities [19]. A complete automation of these activities can be achieved in the long-term through the targeted use of information that are mainly gained from the production processes by cyber-physical systems and data mining processes and the resulting knowledge.

## V. EXEMPLARY NEED AND APPROACHES FOR AUTOMATION IN ELECTRONICS PRODUCTION

In conclusion and in order to give a vision on the potential benefits of organizational ambidexterity through the automation of production-related processes, a case study shall be given. The industry of electronics manufacturing is very well suited to serve as an example because of its high degree of automation that is already achieved in the field of electronics manufacturing. This refers not only to the production process but also to the product design and production planning.

In the product design of printed circuit boards (PCB), it is necessary to design an electric circuit diagram showing an abstracted view of the functions of individual components and their electrical wiring. According to the circuit diagram, a manual or automatic placement of components on the predetermined shape of the circuit board is conducted. After that, the routing process of the PCB is realized. This includes the automatic intersection-free connection of the components, which are specified in the circuit diagram, by means of software. Finally, the designed layout is automatically checked for the compliance with all specified design rules. If the layout is free of error, the information for production planning, such as the placement program, can be derived from the CAD layout data. Furthermore, the material requirements are calculated and the material availability is checked. The production order is then dispatched to the production lines according to the available capacity.

Despite the previous production planning, unplanned events in the largely automated production of printed circuit boards may occur. A major goal of many manufacturing companies is to reduce inventory and the related capital commitment, while ensuring the greatest possible security for delivery and suppl. This allows for a high adaptation potential for changes in demand, but is also associated with the risk of supply shortages. An unplanned event in this context could be a missing component due to a supply shortage or inadequate quality of the delivered components. It is then necessary to respond as quickly as possible and to find a solution in order to avoid a delayed delivery date. A simple example is the lack of a ten ohm resistor, which needs to be placed on the PCB. Theoretically, it is very easy to replace this ten ohm resistor by two five ohm resistors that are on stock and meet the same technical specifications. This, however, needs an adjustment of the PCB layout which must be done in the product design. Therefore, the necessary information must be reported to product design. This process can be automated by using technologies of the fourth industrial revolution to save time and costs. By using suitable sensor systems the fault of the missing resistor can be detected, the information is analyzed and is transferred to the product design by appropriate

communication standards in near real time. The production order has to run through the automated process of product design and production planning again. The new manufacturing information are provided at the shortest possible time to the production line. So the production order can ideally be completed on schedule with the adapted PCB layout. This process is illustrated in Fig. 2. This approach, however, is only feasible if a high enough flexibility is designed into the PCB-Layout from the beginning on. Solder pads may need to be added, e. g. by digital printing solutions such as the Aerosol-Jet-Printing-Technologies and additional solder depots need to be dispensed.

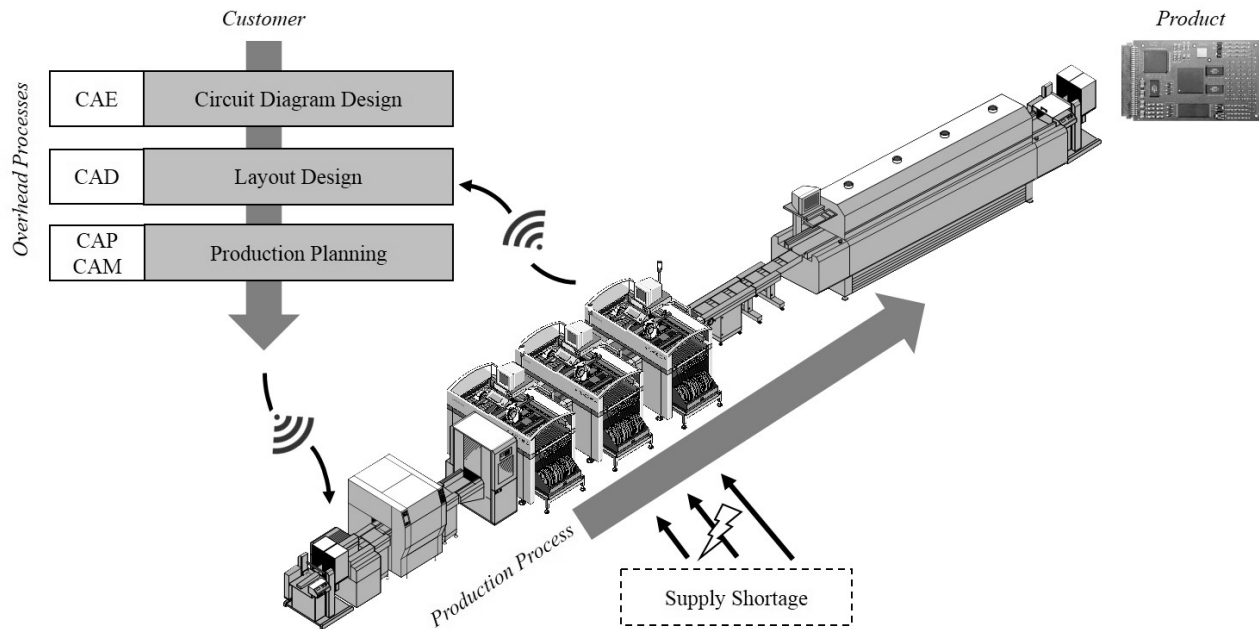


Fig. 2: Automated response to supply shortage in electronics manufacturing

## VI. CONCLUSION

The approach outlined above requires an automated product design and production planning as well as a continuous reliable monitoring of the production process and the networking of all relevant entities by means of interoperable and real-time capable communication standards. These correspond to the technological enablers are offered by the fourth industrial revolution (see TABLE II). Therefore, the simple application example should demonstrate the potential benefits that can be gained from the targeted use of technological enablers and a corresponding automation of overhead processes efficiency similar to the efficiency gains in production provided by the last three industrial revolutions.

## BIOGRAPHY

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