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Madsen, Erik Skov; Bilberg, Arne; Grube Hansen, David

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Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics

*Erik Skov Madsen (esm@iti.sdu.dk)
Centre for Engineering Operations Management
University of Southern Denmark
Odense M, Denmark*

*Arne Bilberg
The Mads Clausen Institute
University of Southern Denmark
Soenderborg, Demark*

*David Grube Hansen
The Mads Clausen Institute
University of Southern Denmark
Soenderborg, Demark*

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Abstract

This paper demonstrates how the industrial revolution of the future, Industry 4.0, will dramatically increase technological complexity, and how the vocational skills needed in today's Industry 2.0 and 3.0 will require significant augmentation. Based on statements from policy makers and data from empirical studies, the paper concludes that future complex manufacturing facilities will demand much greater vocational skills. Such advanced skills will be necessary for corporations to handle the complex technology related to manufacturing facilities predicted for Industry 4.0.

Keywords: Industry 4.0; Vocational skills, Vocational education

Introduction

Companies, industrial organizations, policy makers, and universities all over the world are considering advanced and flexible productions systems for the future. In Germany, the idea of the fourth industrial revolution is expected to transform traditional mass and batch manufacturing into digital and highly flexible manufacturing (Spath et al., 2013; MacDougall, 2014). The same expectations exist in the UK (Foresight, 2013) and in other countries such as China and Denmark (China G 20, 2014; Johansen et al., 2010).

The change in manufacturing from Scientific Management and Lean Manufacturing (e.g. Womack et al., 1990) towards much more flexible and adaptable technology, where

different technologies are merged, is expected, in the UK, to call for a greater focus on vocational skills and vocational educations to develop, operate, and maintain these innovative production systems (Burnett & Thrift, 2014). Because Germany already has a strong focus on vocational education, German studies are not considering the same changes as those in the UK; they do, however, anticipate bringing information and production technology closer together in the vocational education system (Spath et al., 2013).

The change towards more flexible production systems and a stronger focus on vocational education will likely put pressure on universities. Recently, universities and academic educations have been challenged by large companies like Ernst & Young who no longer require “a degree” for employment (Ernst and Young, 2016). At Google, Laszlo Bock, the head of people operations, explains that graduates of top schools often lack “intellectual humility” by not being able to work in teams or to step back and learn from failures (*New York Times*, Feb. 22nd, 2014).

In the change towards the fourth industrial revolution, much more flexible production systems and the use of cyber-physical systems may call for an increase in the number of different competencies needed since each production is expected to be made in very small numbers or batches. The tendencies from Google and Ernst & Young may therefore move into the field of operations management and create new needs for vocational and academic education. Specifically, employees who are able to collaborate in teams to solve all the technical issues related to complicated production systems will be needed.

Thus, the purpose of this paper is to research the educational challenges in operations and maintenance of the flexible productions systems within Industry 4.0. This research focuses on the shop floor and presents the following research question: *What vocational and academic skills/educations are required in operations and maintenance of the flexible and highly automated manufacturing systems developed in Industry 4.0?*

From Industry 1.0 to Industry 4.0

Before considering future industrial trends, it is important to look back and reexamine earlier trends in the industry. A short overview of industrial development is illustrated in Figure 1 below.

The first industrial era started with a revolution in the 1800s. The steam engine made it possible to drive equipment, and the first mechanically-driven looms were introduced in factories from 1760 to 1840 (Schwab, 2016); these advances enacted a huge change in manufacturing. The second industrial revolution (Industry 2.0) included the use of electricity and scientific management principles (Taylor, 1911) and covered the late 1800s to the 1920s. Work tasks, for example, were specialized at assembly lines and mass production. Elements from the second revolution can still be found today, particularly in the field of mass production.

Through the introduction of the computers and semiconductors in the 1960s, a third industrial revolution (Industry 3.0) was born (Schwab, 2016). This revolution is identified by the development of semiconductors, mainframe computing (1960s), personal computing (1970s-1980s), and the internet (1990s). In this era, Programmable Logic Controllers (PLCs), CNC tooling machines, and, later, robotics led to discussions of Computer Integrated Manufacturing (CIM) and included concepts of fully automated and unmanned factories. However, companies realized how complexity and huge

investments in Flexible Manufacturing Systems (FMS) led to extra operational costs. Other concepts emerged, such as Lean thinking, inspired by Toyota Production Systems (Womack & Jones, 1990). The lessons learned from CIM and the third industrial revolution, according to Zuehlke (2010), were to reduce complexity through modularization and lean technologies, to avoid centralized hierarchies in favor of loosely linked decentralized structures, to encourage self-organization on the system level, to allow for concurrent engineering by the decoupling process, and finally to develop technologies for the human.

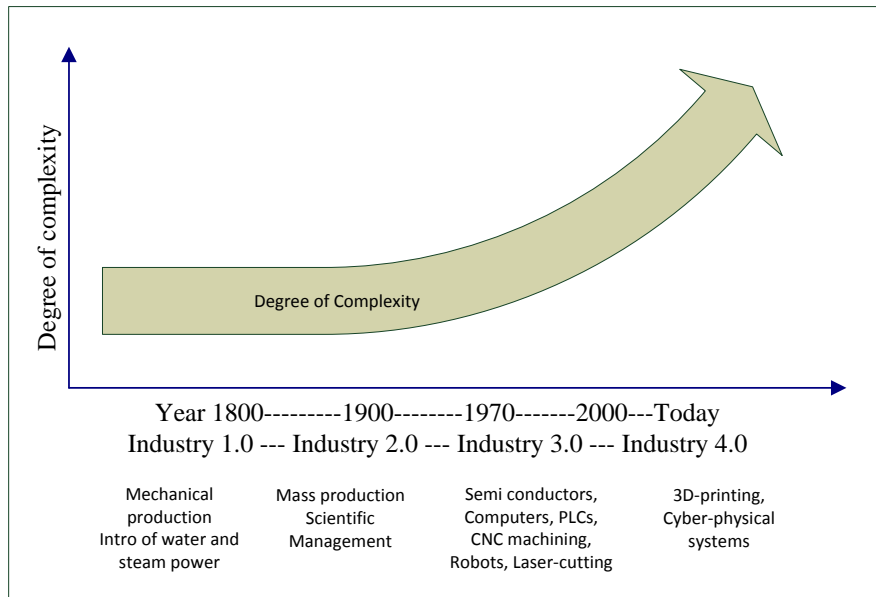


Figure 1: Increased degree of complexity from Industry 1.0 to 4.0

The world is now approaching the fourth industrial revolution (Industry 4.0) where the internet and information and communications technology (ICT) solutions are integrated into manufacturing equipment and make connectivity and communication possible as never seen before. The fourth industrial revolution is therefore expected to involve computer integration but with seamless integration through the internet of things, big data, 3D printing, autonomous vehicles, advanced robotics, new materials, and other factors not yet established (Schwab, 2016). Humans may still be expected to play a major role in decision making and operations; the discussion is not about unmanned factories but, instead, about humans and machines working in collaboration. As illustrated in the figure above, the degree of complexity through the fourth industrial revolution is expected to grow further and to call for many more skills among those who will operate the complex equipment. As Zuehlke (2010) notes, we are now in a comparable situation to where we were some 30 years ago.

Vocational education and skills in manufacturing

Different traditions for vocational education and training (VET) systems can be found in Europe. In Germany, Switzerland, Austria, and South Tyrol there has been a long tradition of focusing on vocational education and skills through a “dual system” where qualifications are based upon the successful completion of courses and through

negotiations involving both trade unions and employers (Brockmann et al., 2008). In Germany (and Denmark), the VET system has a tradition of focusing on education for occupation (*Berufliche Bildung*) (Rauner, 2006), and a Dual Study Program (*Duales Studium*, 2016) has been developed in Germany. In the Dual Study Program, students with a high school degree may attend a five-year study program and achieve both a vocational education and a BA degree. This program combines a college education with a practical apprentice experience (for example, in engineering), and the program is heavily supported by German industry. In Denmark, a similar but shorter EUX program has been established where students can obtain both a vocational education and a high school degree via a combination of five years of apprenticeship and high school study (Danish Industry, 2011).

The UK has taken a different approach. Their vocational system has proven to be strongly employer-led, an output-based approach where the focus is on direct employability for specific jobs (Leitch, 2006). However, for many years UK policy makers have highlighted the need for a greater focus on vocational education and skills training (Wolf, 2011; Jackson, 1959). According to a speech given by Michael Gove, MP, the Secretary of State for Education, the UK's education "remains weaker than most other developed nations" and "our capacity to generate growth by making things remains weaker" (Wolf, 2011, p. 4). Although literature on vocational education in the UK often highlights high tech skills, the Rolls-Royce company (jet engines) considers apprenticeships and vocational education skills as extremely important with regard to future advanced production (Wolf, 2011). Research conducted in the European Union (Cedefop, 2012) explains how a shift towards more skill-intensive jobs will require a demand for people who are highly qualified.

Surprisingly, a similar discussion of how to improve VETs is taking place in China (World Bank, 2013). From 2002 to 2014 the number of college graduates in China has increased fourfold, but many college graduates have found it difficult to achieve employment (Hairong, 2013; Barabasch et al., 2009). Research has also documented a need for the development of shop-floor competencies in China (Lai et al., 2011). In June 2014, the State Council in China issued the 'Decision to Push Ahead the Development of Modern Vocational Education' (China G20, 2014) to meet the requirements for vocational education and skills in future production scenarios in China.

When studying the need for vocational education and skills in production, it is important to consider the tasks to be carried out. Studies of production on the shop floor (Kusterer, 1978; Döös, 1997; Patriotta, 2003; Madsen, 2009) have illustrated how vocational skills and competencies are essential to achieve smooth production, particularly when malfunctions or disturbances arise. In an Italian study at FIAT typically belonging to the third industrial revolution, Patriotta (2003) found that well-developed skills among technicians were essential to keep a technological jewel of 266 robots and advanced equipment on track welding and manufacturing car bodies. Madsen (2009) reported similar findings, noting that groups of highly specialized and skilled workers were needed in modern manufacturing. However, Madsen (2009) also identified that knowledge most often was hidden and tacit in a manufacturing environment, particularly in a complex production environment where employees needed to cooperate in order to solve extremely complicated and confusing tasks such as 'bricolage' in several production systems. The development of these skills takes time. According to Gladwell

(2008), it takes roughly 10,000 hours of practice to achieve mastery in a field, often referred to as the 10,000-hour rule. Recently, Bremer (2015) has found that more advanced technologies in the future and the “Internet of Things” of the workplace will lead to clearly more complicated work tasks.

Design/methodology/approach

This study uses a case study method (Eisenhardt, 1989) and an action research approach (Coughlan & Coughlan, 2008) by involving researchers in two cases. First, a literature study was made. The literature study included a survey of the current academic literature and a number of reports from companies and organizations where their focus was on how vocational and academic education prepares employees to handle manufacturing technology challenges from the fourth industrial revolution. Some of the literature was in German or originated in Germany because this country is where the main discussion of the fourth industrial revolution is taking place.

The empirical base of the study involves two cases in organizations in Denmark, China, and Germany. Case A presents a study of a Chinese production plant with up to 800 employees where production facilities were at a generally low level of automation for manufacturing and assembling an industrial product. Throughout a longitudinal study exceeding five years, more than 400 employees were laid off due to the company’s outsourcing process where only assembly was kept in-house. Production in Case A could be characterised as mass production; workers performed repetitive tasks on production lines in cycle times of down to 10 seconds. Case A’s production company had earlier taken place in Germany where the rate of automation of manufacturing equipment was relatively high. However, because of marked changes and because of expected cost savings, the plant was relocated to China. During this relocation, a de-automation process was made from implementing new local Chinese manufacturing equipment focused on manpower and less on automation. The Chinese company utilized a typical division of labour where managers and engineers, through a Scientific Management approach (Taylor, 1911), planned all work for unskilled workers on the production lines through the introduction of LEAN to eliminate waste. The authors will use the term $Lean_{minus}$ for this approach because it did not involve blue collar workers. Maintenance of the manufacturing equipment in Case A was carried out from a central maintenance department where almost all those employed had a BA degree with an engineering background but lacked vocational skills in maintenance and engineer fitting.

Case B is a Danish company manufacturing an industrial product, with both semi-skilled operators and a mixture of skilled people (former car mechanics, electricians, or bakers). Daily maintenance and changeovers were handled by the operators themselves. However, in the cases of more complex maintenance or breakdowns, skilled mechanics, production technicians, and engineers were involved. The company had been working with LEAN and LEAN automation (Kolberg & Zühlke, 2015) to involve operators in planning and operations. Employees had also participated in the design and development of the hybrid LEAN production U cells concept based on Chaku Chaku principles (Bilberg, 2005), in which the manufacturing process operator transports an item from one work station to the next, operates, and sets up each machine from the beginning to the end of the production. The order management system was reengineered in such a way that the user interface to the Enterprise Resource Planning (ERP) system could be

completed by operators themselves on the shop floor through pull information systems; thus, they make their own decisions of how to plan and to execute the production. In Case B, scheduling was therefore performed by the team in the cell. The communication infrastructure built into the revised ERP system was considered an operation management concept in a LEAN hybrid context where ICT was collaborating with humans. The development of this LEAN hybrid called for heavy involvement of all employees; the authors in this paper define it as Lean^{plus}. Thus, in Case B a number of complex decisions about production planning and control were made by the operators within the production unit with support from the ICT/ERP systems but without involvement from management.

Findings

The literature review and the survey of data identify how academic competencies have been evaluated for several decades. However, the literature and the empirical study also identifies how management in companies and policy makers (except from German speaking countries) find a need for a greater focus on vocational education in the future to be able to utilize advanced and flexible manufacturing and production systems.

The findings from our empirical study are illustrated in the table below and will be analysed and discussed in the next section.

Table 1 – Finding from empirical study

	Case A	Case B
Blue collar training on the line	½ a day	Simple tasks: 1-3 days Complex tasks: weeks
Quality issues	High division of work. Management realized quality issues because blue collar workers were missing basic understanding of production.	Single piece production caused fast identification and correction of quality issues.
Motivation and job satisfaction	25% turnover among blue collar workers. Expectation of salary raise and promotion	Highly motivated workers, who collaborated and helped each other.
Future expectation	Management realized that Scientific Management and LEAN had limitations. More automation expected.	Higher degree of automation was expected where operators and robots would work together.
Maintenance	Maintenance carried out by employees from central maintenance dept. Almost all workers have a BA-degree in engineering. Vocational skills missing.	Basic maintenance was handled in the unit. More complex maintenance was handled by specialists.
Improvements	Improvements planned and developed by management.	No fear of making mistakes among blue collar workers. Improvements were discussed with management in an open environment. Fast implementation was found to be important.

Skilled blue collar workers	Management found it hard to attract well-educated and well-experienced skilled employees.	Management found it hard to attract well-educated and well-experienced skilled employees.
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Analysis and discussion

Major findings will be analysed and discussed in relation to the current literature from the field of vocational skills, vocational education in manufacturing, and production relative to Industry 1.0, 2.0, 3.0, and 4.0, respectively

Poverty and the need for Industry 1.0

Before discussing the skills and education required for Industry 4.0, it is important to recognize that poverty is still a devastating issue on our planet. Nearly 1.3 billion people do not have access to electricity (Schwab, 2016) and 12.7% of the world’s population exists at or below 1.90 US\$ a day (The World Bank, 2012). This enormous population has not yet reached the basic level of the first industrial revolution; they are still looking for improvements in their standard of living. Improvements from the first industrial revolution, mechanizing basic needs, will be needed in the future. Vocational education and vocational skills are important elements in the development of basic needs.

Industry 2.0 - little focus on vocational skills

From the beginning of the era of Scientific Management (Taylor, 1911) in the early 1900s vocational education was not on the agenda; instead, the division of work played a main role. Management generally planned work in short cycles on the assembly line. Our study of Case A’s Chinese plant illustrated how Scientific Management, refined through LEAN principles (e.g. Womack et al., 1990), could still be used to improve production levels, where work tasks were shortened to cycles of 10 seconds. This LEAN_{minus} approach did not involve all employees in the development process. However, in Case A, the hierarchical top-down approach was used to improve quality issues; management found that production line employees needed to have a basic understanding of the product they were manufacturing in order to ensure quality. Therefore, learning programs were developed with the purpose of giving employees a broader understanding of the product they were manufacturing. Management also realized that while good manufacturing results were achieved through a LEAN approach (Bicheno, 2004; Womack et al., 1990), they would not be able to improve productivity by pushing blue collar workers much further through additional divisions of work tasks. Management therefore realized that the company would need to enter the era of greater automation, denoted here as Industry 3.0.

Maintenance, Industry 3.0 and vocational skills

All manufacturing equipment will sooner or later need maintenance to be able to make goods to the required standard. Both Case A and Case B illustrated how maintenance tasks of manufacturing equipment call for a number of vocational skills. In Case A, most employees in the maintenance department had a BA degree in engineering but lacked vocational training and skills to handle the variety of workshop tools and manufacturing equipment. Their lack of skills was particularly evident when equipment needed overhauling or when malfunctions, originating from mechanical, electrical, welding,

PLC, or other technologies, needed correcting.

In Case B, the production equipment was more advanced and called for a number of mechanical, electrical, pneumatic, and computer skills when fine-tuning, correcting malfunctions, or when worn parts needed exchanging. As illustrated in our literature review, several studies (Patriotta, 2003; Madsen, 2009; Wolf, 2011) have highlighted the need for vocational skills to handle complex equipment related to the third industrial revolution; a large number of different technologies are combined to set up efficient production facilities. Case B also illustrated a highly automated and flexible production line where Chaku Chaku principles (Bilberg, 2005) were used. In this case, LEAN principles were used to eliminate waste by involving the blue collar workers in phases of planning layout and in the development of the ERP information systems to support work planning. We use LEAN^{plus} to denote this kind of appositive attitudes towards LEAN.

Vocational skills even more needed in Industry 4.0.

Based on our study of the literature of manufacturing of the future, we have been surprised to experience how policy makers (Burnett & Thrift, 2014), governments (Wolf, 2011; Cedefop, 2012; China G20) and industrial organizations (Danish Industry, 2011) call for more focus on vocational skills to address manufacturing in the future.

Within the fourth industrial revolution, the market is expected to require flexibility and agile fluctuation with high product variability at reasonable cost (Leitao et al., 2016). Further, the fourth industrial revolution is expected to demand both vertical and horizontal cooperation from machine to Internet, machine to human, and machine to machine along the value chain in real time (Yu et al., 2015). Our study of Case A and, in particular, Case B revealed how well-skilled employees were needed to handle advanced manufacturing equipment. Maintenance tasks and identifying and solving malfunctions called for a number of vocational skills in which employees needed to have a holistic view when different technologies were merged together in manufacturing equipment. Case A engineers were generally unable to solve the complicated tasks, particularly in equipment maintenance, despite their level of education. This observation may support the new HR policy at Google and Ernst & Young where a university degree is no longer required for employment; instead, the ability to create, to cooperate, and to make things happen is more valued. If this trend strengthens in the fourth industrial revolution, extra pressure will be exerted on universities to develop complex equipment skills.

Industry 4.0 and future manufacturing may call for both theoretical and vocational skills to be able to master the complex technology of the future. The industrial employees of tomorrow may be like master dentists or master surgeons who have a deep theoretical knowledge and, in addition, have the skills to demonstrate proficiency in complex technology among different conditions.

Conclusion and further research

Based on a literature study and on two case studies, this paper concludes that more vocational skills and education will be needed to handle the more complex manufacturing facilities of the future's Industry 4.0.

The world seems to lack focus on vocational skills and vocational education. Scientific Management (Taylor, 1911) and concepts from the second industrial revolution including LEAN and LEAN_{minus} concepts still seem to be dominant within

manufacturing. However, the more complex technology of the future, to be seen in the fourth industrial revolution, will call for even greater vocational skills and education; it will put pressure on universities to supplement education of pure academics. In this paper we have used the term LEAN^{plus} to denote the environment where employees collaborate in complex manufacturing environments. Profound technological knowledge and skills will be required as well as successful competencies in collaboration.

As a UK study stated, apprenticeship and higher vocational education can be a choice between “a race to the bottom in skills and wages or a race for the top in the demanding 21st century economy” (Burnett & Thrift, 2014). The future will call for more studies of how universities and academics should focus more on practical, real world, concrete understanding and solutions to be able to add knowledge of operations and maintenance of advanced, flexible, and complex manufacturing systems within the fourth industrial revolution – Industry 4.0.

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