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The Changing Manufacturing Landscape: From a Factory to a Network

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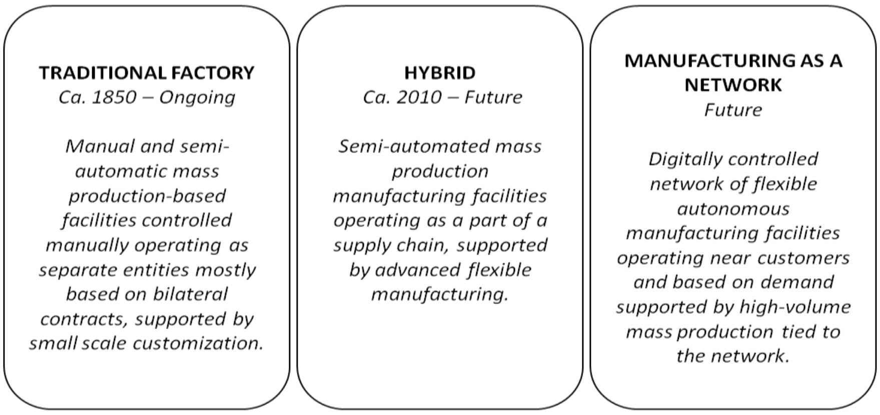
ABSTRACT

This chapter focuses on the technological, the managerial, and the societal transformation from the old manufacturing system into the new, discussing the drivers, the challenges, and the opportunities connected to the transformation. The suggestion is that we are moving from a Taylorist-Fordian factory model towards "Fanufacturing-as-a-Network", which indicates new types of busines possibilities, risks, and transformative implications to the society at large. Traditionally, manufacturing happens within factory walls, where a factory is understood as a place for mass production of goods. It is an assembly of machines and workers who are organized and managed to maximize efficiency and productivity. "Manufacturing-as-a-Network" is unlike the factory as we know it and answers to the needs of the post-industrial society. It is a network structured to perform specific and tailored products in collaboration with customers, for customers, and sometimes by customers.

Keywords: Industry 4.0, manufacturing, factory, business-model, network

1.Introduction

The industrial and manufacturing landcape is undergoing a major change. We are moving from Taylorist and Fordian model of mass production and scale economies towards a networked and autonomous model of production. In this chapter, the attempt is to outline the history, the present, and the future of this development, by focusing on the changes that take place with regards to how manufacturing is organized. The main argument in this chapter is that the concept of "factory" is radically changing. Activities that take place in the traditional "factory floor" or "within factory walls" are being revolutionized by digital technologies and digitalisation and for some industrie transform into a digitally controlle manufacturing network, see Figure 1.



TRADITIONAL FACTORY
Ca. 1850 – Ongoing

Manual and semi-automatic mass production-based facilities controlled manually operating as separate entities mostly based on bilateral contracts, supported by small scale customization.

HYBRID
Ca. 2010 – Future

Semi-automated mass production manufacturing facilities operating as a part of a supply chain, supported by advanced flexible manufacturing.

MANUFACTURING AS A NETWORK
Future

Digitally controlled network of flexible autonomous manufacturing facilities operating near customers and based on demand supported by high-volume mass production tied to the network.

Figure 1. Transformation from a traditional factory to manufacturing as a network

The change in the industrial landscape which we are witnessing is not only technical, but *socio-technical* (Geels, 2004). This means that not only digitalization changes how industrial work is done, but also who (or what) does the work, how this work is organized, and how it affects the broader economy and the society.

In section 2, the the history of production is briefly visited in the context of a factory, informed by Taylorian and Fordist models of industrial production. The change towards post-Fordian production is discussed, where the role of a worker is that of a highly skilled operator of and among increasingly autonomous machines. In section 3, the new management models and technologies that are driving the change towards a networked manufacturing model are discusse. In section 4, the new perspective – which is here called "manufacturing-as-a-network" is outlined.

2. History of manufacturing: change within factory walls

2.1 Regime of accumulation

In his book "The Principles of Scientific Management", published in 1907, Frederick Winslow Taylor defined the role of the factory as follows: "In the case of a more complicated manufacturing establishment, it should also be perfectly clear that the greatest permanent prosperity for the workman, coupled with the greatest prosperity for the employer, can be brought about only when the work of the establishment is done with the smallest combined expenditure of human effort, plus nature's resources, plus the cost for the use of capital in the shape of machines, buildings, etc. Or, to state the same thing in a different way: that the greatest prosperity can exist only as the result of the greatest possible productivity of the men and machines of the establishment" (Taylor 1911).

Taylor applied scientific method to the study of work. He conducted time-motion-studies and based on data, he reorganized the factory work. Taylor's method eliminated useless tasks and unnecessary movements and created a comprehensive management system that reflected scientific ideals of accuracy and precision. According to Taylor, labor disputes could be eliminated if corporate leaders and managers adapted a new attitude towards industrial work. Maximizing output would automatically maximize profits and income for workers and this goal would make political and ideological disputes obsolete (Waring 1991).

Meanwhile, Henry Ford was building a new manufacturing system at the Highland Park automobile factory in Detroit. He combined special purpose machines with semi-skilled labor and organized them along the continuously moving belt. The assembly line combined several manufacturing concepts into the system that revolutionarized the manufacturing of automobiles. Pre-manufactured and interchangeable parts were placed on the moving belt where semi-skilled workers assembled them into the final product. The complex automobile could be manufactured without delays and optimally the assembly line cranked out a new T-Model Ford every 20 seconds (Hounshell 1987).

Mass production system became the dominant industrial paradigm in the United States during the early part of the 20th century. It replaced traditional manufacturing systems, which allowed skilled workers to contribute independently to the final product. Mass production system subjected workers to the manufacturing process that utilized economies of scale. As Taylor had promised, the standardized manufacturing system brought higher profits for owners and higher wages for the workers. This in turn, improved living standards in industrial societies. New manufacturing systems required massive capital investments, centralized managerial control and industrial hierarchy that copied modes and methods from the bureaucratic state. Hence, it was no surprise that the industrial landscape was taken over by large, vertically and horizontally integrated corporations (Chandler 1990).

Henry Ford and Fredrick W. Taylor were idealistic innovators who operated within a highly competitive American industrial landscape. They tackled the fundamental dilemma that had troubled factory owners and managers since the dawn of the industrial revolution. Factories combined human labor and machines and created, therefore, a series of qualitative and quantitative changes in production systems. How to organize this combination to maximize the output and productivity, but without creating labor disputes? Technological developments improved machine efficiency, but improvements in technology did not bring positive improvements in human labor (Warring 1991).

Taylor's system of scientific management tried to find generalized rules of conduct, based on "laws of nature" that would bring maximum output, high productivity, low cost, high wages, equitable distribution, reduction of unemployment, and rapid economic growth (Thompson 1916). Ford, on the other hand, tried to solve the dilemma by reconceptualizing the production process. He borrowed the idea of assembly line from other industrial sectors and coupled it with the innovations in interchangeability, new special purpose machine tools, standardization, single-model policy, simplification of design, radical de-skilling of work force, and centralized control of the flow of work (Hounshell,1985).

Neither Taylor nor Ford was able to solve the problems of division of labor within the factory walls. Taylor's ambitious search for one best way found too many human variables to be generalized as a law of nature. Ford's ambitious system believed that if workers would perform only one simple task, they would become parts of the machine system. However, human labor could not match the tempo of the machines and frequent speedups by managers created labor disputes. Therefore, the fundamental dilemma of the division of labor was embedded in the mass-production system. As Wang and Siau (2019) point out, the idea of the factory without human labor has been long ago elaborated in science fiction literature, but so far it has been socially and politically too hot a topic to be seriously discussed. Factories provided salaried work to millions of people and industrial societies depend on high employment, mass consumption, and tax revenues.

Hence, mass production systems have cautiously moved towards more streamlined production systems that require more technology and less human labor. In the early days, technological innovations took over tasks that required extensive physical strength and speed. The next steps were machines that performed high precision tasks. More recently, computers with massive calculation capacity are installed to control complex vertically and horizontally integrated production systems. This has changed the division of labor within factory walls. Tasks that were previously performed by de-skilled workers are handed over to machines. Human labor is still needed in tasks that require cognitive skills, planning and refining industrial processes, this was already observed by Pine thirty years ago (Pine 1991).

It is often believed that manufacturing systems are shaped by technological developments only. This narrative is challenged by the historical record: since the birth of the factory, manufacturing systems have interacted with political, economic, and social systems on several different levels. They have reorganized and reconfigured the human-machine relationship, which affects lives of millions of people. In addition, they have established regimes of accumulation that determined economic developments in industrial societies. Finally, manufacturing of inexpensive industrial goods affected the life-styles and consumptions habits of people living in industrial societies.

The effects of the mass production system shaped the industrial landscape during the 20th century not only in North America, but also in Europe, Soviet Union, and Japan. When the global political map changed at the end of the Millennium, Fordism spread rapidly to China, India, and other Asian countries, but also to South-America and to Africa. Wherever the mass production system was applied, it shaped social, economic, and political structures. Large factories, connected to the distribution, communication and energy networks shaped the industrial landscapes and rearranged geographic and demographic structures. As Bob Jessop (1992) concludes, "given that economic activity (mass production system) is always socially embedded, socially regularized, and socially regulated, the state must be involved not only in securing the narrow techno-economic conditions for valorization and labor supply, but also in the broader, socio-economic embeddedness, regularization, and regulation of economic activities. It is this broader context that provides the link between economic and social reproduction, between accumulation and societalization."

Did Henry Ford and Frederik W. Taylor invent a perfect manufacturing system that was applicable to all political and ideological systems? Fordism has demonstrated resilience and adaptability as it has taken over country after country during the 20th century. Where Fordism was established, societies have undergone fundamental structural changes. However, the interaction between the mass production system and modern industrial society is not a one-way street. Industrial societies control, govern, and regulate industrial developments to enhanced social and economic planning, maintain economic growth, and control social mobility. Fordism has proved to be one of the most efficient ways to organize mass production of industrial goods in modern societies. It has also proved to be an efficient way to ensure macroeconomic growth, full employment, and improvement in social welfare. Fordism has also successfully promoted urban-industrial development, which is dominated by middle-class and wage-earning families (Macdonald, 1991).

2.2 From economies of scale to economies of scope

What does it take to change the dominant production system? As discussed before, Fordism has penetrated deeply the structures of modern industrial society. It has created links to industrial, educational, political, social, and cultural institutions and shaped the ways of life of millions of people. Industrial societies have become dependent on Fordism and vice versa. This wedlock between society and industry is difficult to break without altering social systems, organizations and modes of behavior (Boyer & Durant, 1993).

What happened to Fordism after the mid 1970’s, is still an unanswered question. What is known is that advanced industrial countries went through fundamental economic changes, because of rapid increases in the oil price. This unexpected exogenous impulse drove Western economies into a stubborn recession. The tidal wave flushed over societies, which had become accustomed to a stable economic growth, increasing wages and profits, and highly standardized, but comfortable lifestyles. The oil crisis changed the long-term relationship between the mass production system and the modern industrial nation. Fordism had reduced relative prices and maintained mass consumption of industrial goods by rationalizing and standardizing industrial production. This, in turn, was based on the assumption, that low-priced industrial goods, produced in bulk, would always find a consumer (Boyer & Durant, 1993).

Although the oil crisis sparked the economic downfall in the 1970’s, it was just one factor among many that affected the future of the mass production system. Newly industrial nations in Asia, South American, and Africa had entered the global industrial landscape and they could offer Fordism abundant resources of low-wage semi-skilled workers. However, as Lipietz (1985) and others have demonstrated, Fordism adapted a wide variety of shapes when it took over the manufacturing processes in newly industrial countries. Brazil and other vastly populated countries in Asia and South-America developed a co-existence of relatively modern and dynamic sectors of production in dynamic urban growth centers and large rural regions, which supplied factories with low-wage and semi-skilled industrial labor.

In China, Fordism entered the era of development that was shaped by major internal structural changes. Because of its political, social and cultural background, the industrial trajectory in China has become more complex than just a regime of accumulation (Walker and Buck, 2007). China provides text-book circumstances for traditional Fordism with a low-cost labor resource, massive raw material and energy sources, and a vast population hungry for inexpensive industrial goods. As Lüthje (2013) points out, the industrial trajectory in China has been characterized by a co-existence of industrial sectors at various levels of development. There is also a wide gap separating the urban and the rural populations. According to Lüthje (2013), “this co-existence of industries, clusters, and regions with predominantly low-cost and labor intensive production based on rural labor on the one hand, and those with higher levels of capital intensity and social reproduction with mostly urban workforce, on the other, can be regarded as a key feature of China’s emerging capitalism. It is closely linked to a governance of one-party state with both, a quasi-federal and a highly centralized governance at the same time.”

Hence, after the economic crises in the 1970’s and the changes in the global political landscape during the final decade of the Millennium, there was not one, but many mass production systems co-existing in the world. While traditional Fordism was adapting itself to the politically, socially, and culturally complex societies in Asia and South-America, the advanced industrial nations in Europe and in North-America, and Japan and South-Korea tried to find ways to get out from traditional mass production paradigm.

Fordism was no longer a popular term and it was replaced by several new concepts. Structural crises in advanced industrial nations were identified as an “era of transformation”, “transition”, “post-modern”, “fifth Kondratiev”, “post-collective”, and “post-Fordist”. Although none of them could exactly describe the nature of the change, they all pointed towards the same direction. The era of mass production and mass consumption had come to an end, and advanced industrial nations had to find a new industrial paradigm that could satisfy customer needs, ensure economic growth, and improve the social and the economic standards. Although there were no inventors like Henry Ford or Frederic W. Taylor available, advanced industrial nations had a massive technological and intellectual capacity that could be redirected towards building the new industrial regime (Amin, 1994).

Flexible response to the global crises mirrored tensions that had built up within Fordism for a long period of time. Centralized control, monotonous and standardized work, and “one-size-fit-all” attitude towards consumer needs overlooked the social, economic, and cultural developments in modern industrial societies. As living-standards improved, people became more aware of individual and private needs. Mass production of industrial goods was still needed, but there was a growing demand of tailored, high quality products. There was also less and less semi-skilled workers available in the Western world, because of demographic changes and improvements in education.

Large-scale corporation, with the help of national and transnational innovation systems, developed technologies that lift them up in the technological hierarchies. Specialized new machines streamlined manufacturing systems and improved quality of products. These improvements were coupled with the managerial innovations that emphasized flexible specialization, decentralized management, and tailored solutions for identified customer segments. New manufacturing systems were operated by trained professionals, who replaced the semi-skilled labor force. Monotonous manual work along the assembly line was taken over by robots and automated machines, whose operations were managed and controlled by skilled workers and managers (Tomaney, 1994).

As Schumann (1998) defines, post-Fordist system supports a worker, who is technically autonomous and intervenes in the manufacturing process, if it doesn’t operate optimally. Hence, post-Fordism introduced a new division of labor within the factory walls. Human labor was given more independence and freedom, but the governance of the manufacturing process was handed over to the machines. As Schumann defines it: “if the technical system should work perfectly, the main responsibility of a system’s controller is to check and to service the machine. He himself does a perfect job if succeeds to anticipate deviation and breakdowns in the technical system and proceeds to initiate prevention.”

Post-Fordism took a radical step away from orthodox Fordism and proceeded towards a new regime of accumulation. It was dominated by machines and skilled workers. Mass production systems utilized economies of scale, but the focus was shifting from quantity to quality. This transition towards economies of scope was perfected in Japan, where novel mass production systems were developed in the latter parts of the 20th century. Lean manufacturing applied principles from Fordism, but placed them in the new manufacturing concept. As Jürgens and others (1989) observe, the Japanese manufacturing system builds on flexibility, in utilization of facilities and minimization of quality problems as they arise. Although the Japanese manufacturing system depended heavily on technological innovations, the real significance was not placed in machines themselves, but on how they were used in the manufacturing process (Sayer, 1986).

In summary, we have witnessed that post-Fordism has replaced Fordism as the dominant manufacturing system in advanced industrial countries during the first two decades of this Millennium. Many corporations have struggled to overcome the transition from orthodox Fordism to post-Fordism. The dilemma of division of labor remains as so far there is no consensus on how the problem will eventually be solved. In fact, post-fordism has created a permanent unemployment-issue for the advanced industrial countries and potentially doomed them into slow economic growth. In the meanwhile, orthodox Fordism and its applications are driving economies on high gear in developing countries.

2.3. The end of division of labor

Post-Fordism promised flexibility in production and individuality in consumption, new division of labor within factory walls and new prosperity to industrial countries. This promise was fueled by the collapse of the Cold War in early 1990’s and the end of the ideologically hostile world. Liberal market economy and corporate capitalism pushed aside the socialist planned economy. Global markets were unified by radical innovation in information technologies that made possible the borderless and continuous flows of goods and capital.

Post-Fordism used the concepts from old mass production systems, but modified them to satisfy the needs of globalization. It was no longer necessary to centralize production and establish hierarchical management structures. It was equally unnecessary to collect massive stockpiles of raw materials in one location and hire thousands of workers. With the help of information systems, streamlined logistics, and automated manufacturing systems, mass production of inexpensive goods could be decentralized, outsourced, and reorganized to meet the demand of global markets. As Gambao (1988) has argued, the demand of inexpensive consumer goods became homogeneous across national borders and continents. This changed the industrial landscape in the Western world, but also in Asia and other parts of the world. Domestic markets were no longer safe and protected against the invasion of inexpensive goods that were manufactured wherever in the world. In order to survive, companies had to implement new strategies that emphasized mobility and flexibility. Factories that were too far from customers, or inefficient, were either closed or moved to another location, where they could utilize cheap materials, labor, and energy and where environmental and labor regulation were less restrictive.

At the same time, global companies invested in high quality production in advanced industrial countries, which offered skilled labor, research and development resources, and high-income customers. As Kern and Schaumann (1987) point out, a new conscious of qualitative significance of human work performance emerged from the aim to design flexible forms of automation. As automation became the holistic principle in manufacturing systems, it still demanded a highly skilled and specialized labor force that could collaborate with sophisticated machines. Hence, the automation did diminish the role of human labor, but it did not shut out workers from factories. On the contrary, the relationship between machine and worker became more complex as the intelligent machines challenged the creative capabilities of skilled workers.

Hence, after a century long era of mass production, the fundamental question is still with us. Fully automated factories without workers are no longer a narrative of science fiction, but a reality in some industries. On the other hand, manufacturing systems that utilize traditional Fordism are still producing massive amounts of inexpensive industrial goods. As a result, the division of labor that first existed within the factory walls, is now existing between the advanced industrial and the developed nations. In the remainder of this chapter, is about the further changes expected to take place in the industrial landscape, as the trajectory of post-Fordism continues along with the rapid rise of digital technologies and automation.

3. Technological and Business Drivers that Underlie Industrial Landscape Change

This section describes important technological and business-model change-drivers that propel the migration of several industries towards a networked manufacturing-model. The networked manufacturing model is and must be accompanied with a networked model of business to support it, where each *independent* company in the network must have at least break-even profitability for the whole system to work.

The backbone of the networked model of manufacturing (and business) is the ability to control and manage the network – this is a more complex endeavor, than controlling and managing of a typical factory, where the activities take place in a highly concentrated setting. Importantly, from the management and decision-making point of view, the management of a typical factory is most often optimizing the activities of separate entities, while the management of a network of a digitalized networked company is optimization of a dynamic system that composes of several digitally interconnected subsystems. This digital connectedness carries a potential for a higher-level system (or super-system) optimum, while reaching it means solving several difficult problems.

Reaching a state, where a manufacturing company can be said to be digitally networked, means mastering and being able to orchestrate many technologies simultaneously that allow the company to manage the network. These technologies are digital components of the digital system that is the company and that can to a large extent all be controlled remotely. In the following subsections important components of a digital network-based manufacturing business model are presented.

3.1. Digitalization of Business- and Manufacturing Processes

Digitalization that is, the implementation of digital technologies to business processes and models (see, e.g., Bharadwaj et al., 2013; Setia et al., 2013), is to the manual flow of information what automation is to manual work. On a small-scale, digitalization may only mean the storing of data in a digital form, but the true potential of digitalization is reachable through the digital flow of information and knowledge. Here it is important to note that information and knowledge are not the same as data, as information can be understood as a "recipe" to do something and knowledge as the wisdom of understanding when and under which circumstances the recipe should be put to use. Knowledge, in other words, is information put in a context that typically translates to action. In other words, digital transfer of knowledge in the sense that is referred to here, is the transfer of "orders" or "requests" from the managing entity to a node, or nodes, in the networked model.

What then underlies the ability to relay orders to nodes in a network and what are the nodes? A key revelation is to understand that an autonomously functioning machine, or a robot operated warehouse, can be a node. Strictly speaking "a human in the loop" is not a necessity. The ability to relay orders is based on the interconnectedness of the nodes and the ability to "give orders" in the format that is understandable to the nodes. These observations may seem trivial and they may be trivial, when the ability to communicate requests to a single machine, or node, are discussed, but the situation becomes much more complex, when the ability to communicate requests to multiple nodes that operate with different underlying technologies (e.g., machines for different purposes, machines from multiple manufacturers) and in different fields (e.g., logistics, warehouses, manufacturing). What becomes important is the ability to create a direct digital communication interface with the nodes in the network, while the traditional way to interface the nodes has been communication between humans through a digital network.

The other side of the coin is the ability to receive information from the nodes, to be able to understand what the status of the network is, in real-time or close to real-time. This means that the nodes and, e.g., the machinery within a node must necessarily be properly instrumented. This instrumentation falls under the Internet of Things (IoT) paradigm that is a necessary component of networked digitalized manufacturing business models. Digitalization, from the point of view of business and manufacturing processess opens the possibility for systemic control and it is within the potential for efficiency gains through this control that possible breakthroughs can be reached. One can say that digitalization (instrumentation and digital communication) are a necessary baseline for a fully digital business model in manufacturing and elsewhere.

Novel management technologies have to be adopted to efficiently control the digitalized factory operating in an industrial network. One of the potential technologies that can be adopted also to management use in the context of a digitalized networked (manufacturing) company, is the "digital twin", a concept originally coined in the aviation industry to enhance efficient use of individual airplanes (see, e.g., Ríos, Hernández, Oliva, & Mas, 2015). In a broad sense, as Tuegel, Ingraffea, Eason, & Spottswood (2011) define the concept, a digital twin is a set of high fidelity, multi-disciplinary, computer models of unique physical products with their operational history. In essence, this means means that a digital counterpart of a physical entity exists in virtual space, which can be applied for the purposes of product design, maintenance optimization, and flexible collaboration between different stakeholders such as industrial customers and solution providers (see, e.g., Negri, Fumagalli & Macchi 2017; Kostis & Ritala, 2020). The recent literature (Rosen, von Wichert, Lo, & Bettenhausen, 2015) has extended the idea of digital twins to cover entire production lines, where the mutual co-ordination of equipment is needed. For a review of digital twin technology in manufacturing, the interested reader can refer to Holler, Uebernickel, & Brenner (2016).

In the context of a networked factory (or manufacturing company), a repository of digital twins that consists of smaller individually modeled manufacturing processes, or even single pieces of equipment is of essence. This same fact is already acknowledged Li (2018) who names digital twins as one of the cornerstones of the national digitalization projects of "Industrie 4.0" in Germany and "Made in China 2025". Examples of plant-plant level implementations of a digital twin include the cases presented in Liu, Zhang, Leng, & Chen, 2019 and Zhang, Liu, Chen, Zhang, & Leng (2017), who propose a two-level simulation of a manufacturing plant, where a high-fidelity virtual model is constructed and subjected to a dynamic, random simulation tests to study the robustness of the system. Running plant-level (or smaller) digital twins for the purposes of asset management today faces challenges such as the i) communication between physical and the virtual systems; ii) communication between virtual models, especially in cases, where more than one model is in place, see Schroeder, Steinmetz, Pereira, & Espindola; (2016); and iii) general availability of data issues, see Kunath & Winkler (2018). These issues toghether, with the confidentiality of data, are further highlighted, if and when the digital twin networks consist of nodes that are not under the same owner.

In fact, it may very well be that the ideas that underlie using digital twins to predictively analyze single machines and to study designs (in the design rather than in the asset management space) may not be fully compatible with what the management or "control" aspect of a networked factory needs. This is due to the "too high fidelity" for the purpose of management. Digital twins are commonly understood as very hi-fi virtual models that typically exist for single machines as envisioned originally (see, e.g., Tuegel & al. 2011). Creating a network of hi-fi models for management purposes is "overkill" from the point of view of the management needs. A leap in management efficiency can already be reached with much less detail, and only with information that satisfies management needs. This infers that for network-management purposes a more robust meta-level information layer is needed that is used to manage the network of digital twins, rather than using the full information available in the models. First virtual control systems of production facilities with smart interfaces are already in place and they may be the direction into which future control systems for networked manufacturing will go.

While the technical solutions for control develop, the discussion about who will be calling the shots and controlling the network as a whole via the tools is entirely another issue and depends on how the network is composed. If the whole network is owned by a single actor the issue may be clear, but when parts of the network are separately owned the relaxation of control decisions are based on trust and a common understanding of profit-sharing between the network (node) owners. Further discussion about these issues is left outside the scope of this chapter.

3.2. Automation and Manufacturing Robotics

Automation and robotics have been around in manufacturing already for some time. In fact, automation can be said to be the beginning of modern industry, as it was the machine automation of cotton mills that is widely perceived as the pivotal turning point that started the first industrial revolution. Those days of automation are, however, very far away from what is here envisioned the future will bring, because modern automation is "full automation" in the sense that manufacturing machines operate autonomously. Rosen & al. (2015) talk about *automatic operation* and *autonomous operation*. Modern manufacturing robots can be used to reach a higher level of automation by using autonomous robots that assist and co-work with digitally operated (or autonomous) machines and with humans and they can be used to bridge the gaps between automated parts of manufaturing processes. Such robots are referred to as cobots and their first generation already exists and is operational in the manufacturing industry (Li & al., 2020). Typically cobots are used in warehouses, where cobots are used to complement and to replace humans working in many sorting and picking tasks.

The ability to create autonomously operating manufacturing equipment, including cobots, requires the ability to fuse information from multiple sources (sensors) at any given point in time. Gabor & al. (2016) point to the ability of digital models to simulate data and thus produce planned reactions based on the data at hand, instead of resorting to the use of fixed rule-sets. Using machine learning (ML) that does not require user intervention to tailor action rules may provide good answers for autonomous operation and simple examples of using ML in manufacturing already exist, see, e.g., Priore & al. (2006, 2018). Previously using ML has been inhibited by lack of computing power, but today many of the previousl restrictions have been lifted due to faster communication ability and due to cloud-based fast computing. Advanced autonomous robots can be given a task (through a digital management system) that they will then fulfil – from the management system point of view autonomous parts in the network can be treated as black-boxes, only the completion, or the lack thereof, is relevant information at the high level.

3.3. Additive Manufacturing Technologies

Additive manufacturing, often referred to as 3D-printing, is a set of manufacturing technologies that are based on the seemingly simple idea of manufacturing solid objects by adding material layer-by-layer (Ngo & al. 2018). The material addition technologies are typically based on using liquifiable substances that can be precisely applied, such as resins and plastics, or on using powders (in connection with metals) and melting to attach the powder-based material. Melting metal powders can be done by, e.g., using precision lasers. What makes additive manufacturing very interesting from the point of view of digitalization is that the machinery is typically digital and computer operated. In essence, an additive manufacturing device is a universal manufacturing device that can manufacture any form or shape within the universe of possible shapes (size, complexity) to meet the customer demands, within the limits of the machin – this includes highly complex shapes that are otherwise impossible to manufacture by conventional manufacturing methods. Importantly, additive manufacturing also allows the use of less raw materials than traditional manufacturing methods (see, e.g., Ford and Despeisse 2016, Gebler et al. 2014) – this may be an important issue, especially in cases where the raw material used is expensive.

Additive manufacturing opens many avenues for developing and making manufacturing more efficient, more tailored (Chiu and Lin 2016), and more flexible (Achillas et al. 2015). While this is the case, the variety of new business models around additive manufacturing has been so far quite limited (Savolainen and Collan, 2020). Being in possession of a fleet of additive manufacturing machines, or "stations", allows a manufacturing network to flexibly produce a large assortment of components, which allows for a higher level of optimization of the manufacturing capacity use. Additive manufacturing has been shown to be able to exhibit economies of scale (Baumers et al. 2016) and the ability to reach high capacities is based on a combination of skills that include abilities related to manufacturing technology, abilities related to the management of the potentially produced components, and the ability to sell the capacity, or otherwise create a business that is able to utilize the capacity efficiently. Businesses that may be supported and that may rely on additive manufacturing of components on an on-demand basis include the service and maintenance business that relies on the availabilty of spare parts – there is a natural fit with additive manufacturing and maintenance although several unresolved issues exist (Holmström et al. 2016, Urbani & Collan, 2020).

Materials research is a field that is closely connected to additive manufacturing and will in the future widen the range of different materials that can be utilized in additive manufacturing. This development allows widening the range of components and architectures manufactured. Advanced materials, such as "advanced" metal alloys may allow for additive manufacturing of simple machines, or more precisely, components that have machine-like characteristics. Memory metal alloys, e.g., may be used to manufacture shapes that can be operated with electric current or magnetic fields and that allow the creation of before unknown types of active structures and capabilities in components.

3.4. Logistics Optimization and Supply Chain Risk Management

Interestingly, additive manufacturing is not only a revolution of manufacturing, but most importantly a revolution of logistics (Bogers et al. 2016). This is due to the fact that the raw materials used by additive manufacturing machinery are standard powders and liquefiable materials in standardized forms, the logistics and storing of which are most often cheaper than those of ready parts - especially from the point of view of the tied-up capital. This also means that a smaller variety of more standardized items in a larger quantity per item will be needed when manufacturing happens by way of additive manufacturing technologies.

While additive manufacturing will affect what is being shipped and where, there will most likely not be an abrupt fundamental change in the way global logistics work – rather there will be a gradual change that will start from the change in various niche areas, where additive manufacturing wins ground. For the great majority of products mass production will remain the most efficient and cost-effective way of production (even when logistics costs are added) for a relatively long time (Mellor et al. 2014; Holmström & al. 2016; Savolainen & Collan 2020). This means that what is known about optimizing logistics will be important also in the future, better yet, the importance will hardly be erased by additive manufacturing or any other manufacturing paradigm, as it is not foreseeable that manufacturing could happen without any raw materials.

Supply chain management is an important piece of the digital manufacturing puzzle, where just in time (JIT) delivery of goods and raw materials is a key issue in the context of inventory management for manufacturing and businesses also beyond manufacturing. The drive towards optimizing (minimizing) inventories via efficient supply chains is also a source of risks, some of which may materialize in situations of sudden shocks caused by, e.g., pandemics, and which may hamper the ability of businesses to operate normally. In such cases the flexibility offered by additive manufacturing can be used to remedy some of the problems, if the competences and readiness to do so exist. If the logistic chain cannot provide critical components that can be additively manufactured, a fleet of additive manufacturing systems can be turned into producing the critical components. In this way additive manufacturing technologies also work towards more resilient supply chains (Laplume et al. 2016). In a digitalized environment, where supply chain disruptions can be identified early on, firms with additive manufacturing capacity and the skills to use it to dampen the effects of disruptions may be able to gain competitive advantage.

3.5. Proactive vs. Reactive Management

There is increasing potential for competitive advantage creation in adopting predictive management in manufacturing. The digitalization of equipment in terms of higher numbers of sensors and real-time data-collection form the basis of implementing the statistical algorithms for predictive management of industrial equipment. In the realm of supply-chain management, the use of predictive risk-management models in networks is also a topic of growing interest (Hallikas, Virolainen, and Tuominen, 2002; Seyedan & Mafakheri, 2020). Having a predictive management ability means that management becomes proactive in terms of acting to affect an outcome, rather than acting as a reaction to something that has already taken place. A field within manufacturing, where proactive management has already shown to create competitive advantage is predictive maintenance (Urbani et al., 2020). Predictive analytics-based proactive management will most likely spread also to other areas of manufacturing.

Traditionally, the data-based management of industrial plants has concentrated on the existing sets of cumulative history data that serve as material for tuning predictive analytics. In the case of networked manufacturing, there is no single fixed factory "entity" that can be used for the systematic and systemic analysis of deviations. As therea are many possible constellations of a network with multiple complementing nodes that may be used to reach a desired end-result it may be impossible to possess complete data for predictive purposes. This calls for a different type of approach for system-level predictive management and finding system-level optimal management actions – one possible direction is the use of simulation in creating ex-ante possibility spaces that allow the identification of good system (nework) configurations for various situations. If it is not possible to obtain real-world historical data from the network, a precise-enough model of the network can be constructed and simulation is used to create the needed data. In large networks, the problem complexity may become an issue and it further simplification may be required. Techniques such as meta-modeling (Yang et al, 2018) offer simplification opportunities that may be used to simplify complex manufacturing model-parts to simpler input-output systems from the practical point of view.

In the long run the development towards more automated manufacturing management will change the role of the post-Fordian human worker increasingly towards those of "a maintenance" person" that is responsible for carrying out supporting tasks that keep the automated machine running. This may be viewed as a dystopic development, where the value of the human input decreases. On the other hand the construction and planning needed in making the development possible requires the ingenuity and work of humans for the foreseeable future. With the transfer of manufacturing to a more networked mode, also a transfer of the required competences of human resources is taking place.

4. Conclusion: Towards Manufacturing-as-a-Network

What is argued is that the new networked manufacturing model – fueled with new digital technologies and management mechanisms as discussed thus far – calls for viewing modern factory not as isolated nodes connected merely by logistics and supply relationships, but rather as a developing and dynamic network. In such a model, there is an increasing demand for organizational and individual abilities in collaboration and coordination, in addition to the traditional demands of efficiency and substance skills.

Even if the progression takes place at a different pace across the globe, the argument is that we are witnessing a gradual movement towards the Manufacturing-as-a-Network model. What does Manufacturing-as-a-network mean?

First, it refers to undertanding the networked factory as a complex adaptive system (e.g. Phillips & Ritala, 2019). This calls for viewing networks as “ecosystems”: networks of interdependent actors, technologies and institutions that together create value (Aarikka-Stenroos & Ritala, 2017). Ecosystems often span multiple industries and industrial logics, and they include co-specialization of assets across different complementary actors (Jacobides et al., 2018). From the perspective of Manufacturing-as-a-Network, this means that *independent* factory units of different sizes are *interdependent* via digital interfaces, creating potential for moving towards a seamless web of fully automated industrial landscape that is operating “24/7”. Such loosely coupled system is thus both distinctive and responsive (Orton & Weick, 1990), allowing for global, scalable, flexible, and generative model of manufacturing.

Second, manufacturing-as-a-network results in the emergence of new types of risks. Interdependence among different actors does not only provide flexibility and scalability to production, but it creates interdependence risks (Adner, 2006). For instance, when one “node” in a manufacturing ecosystem fails to operate, it might create bottlenecks to other parts of the system. Such risks can be mitigated by involving slack in the system, e.g., in terms of alternative producers, but on the other hand, modern production is aiming to cut out slack via, e.g., lean and just-in-time methodologies. Furthermore, in a large and interconnected ecosystem there are major risks of incentive misalignment. The higher the number of interconnected actors in the system, the higher the chance that the incentives to contribute to that system are not fully aligned as actors adopt different roles. Therefore, the “factory of the future” needs to balance system-related risks against the benefits of flexibility provided by those systems.

Third, manufacturing-as-a-network requires new types of management. Unlike traditional coordination of a firm viewed as a nexus-of-contracts, modern manufacturing networks require “orchestration” – a model of coordination that pursues to accommodate the incentive structure and division of labor among loosely coupled actors (see, e.g., Dhanaraj & Parhke, 2006). Orchestration of a complex networks of autonomous machines, technologies, and production elements requires major orchestration capabilities and skills, often possessed by industrial leading actors (Ritala et al., 2009; Hurmelinna-Laukkanen & Nätti, 2018). However, as an alternative to a hub-and-spoke model, where leading actors aim to orchestrate the rest of the network, more collective forms of governance could also be adopted (Fjeldstad et al., 2012).

Finally, there are major social and institutional implications. As already mentioned in the introduction, the manual work is increasingly moving to the automated processes and robots in the networked manufacturing model. This means that the industrial work moves from supervising machine operations and production lines towards overseeing the automated systems and training machine learning algorithms, for instance. Furthermore, there is also continuing demand for managerial skills in orchestrating (see, e.g., Ritala et al., 2009) networks of actors, and developing overarching undertanding of how the factories’ and production units roles are best positioned in a global production network. These progressions mean that the decreasing demand for manual labor is going to continue, including a “race-to-the-bottom” in wages, while the remaining positions might increasingly go to highly-paid experts.

To conclude, in this chapter, it is noted that it has been demonstrated how the changing industrial landcape has moved from Taylorist and Fordist effectiveness and standardization-based models towards a Post-Fordist networked industry model. This change has been fueled by the surge of new digital and manufacturing technologies and by the related business models. There are major implications of adoption of these technologies and resulting ways of industrial production and work. Table 1 summarizes the arguments about how Manufacturing-as-a-Network differs from the Taylorist-Fordian view of a factory (manufacturing).

Table 1. Shift of paradigm from Taylorist-Fordian factory to Post-Fordian networked manufacturing

	Taylorist-Fordian view of Factory	**Manufacturing-as-a-Network**
Manufacturing takes place in	In a highly specialized, efficient and optimized production unit as a part of global value chain(s). The operation is constrained by demand	In an industrial network, which acts a flexibility resource within the constraints of economic profitability
Underlying business logic	Simultaneously scale production volume and improve quality of the outputs	Increase production scope and output quality to gain valuable roles in the network
Ideal management model	Coordination and control	Orchestration of a loosely coupled system; collective autonomous governance
Role of machinery and robotics	Automatic-fixed AND manual-mobile	Autonomous machinery and mobile cobots
The main type of manual work	Supervising fixed machine operations	Overseeing and developing the automated production systems; supporting continuous operation of machines
Payment for manual work	High wages ensured by national labour unions	Global competition and race to the bottom in low-tech wages; highly skilled workers benefit
Risks	Demand related risks, declining competitivity	Interdependence risks, replaceability risks

Going forward, one important question is, whether we will witness a move from loosely coupled industrial governance, where different producers compete agains each other with their networks and ecosystems towards a tightly coupled production model. In principle, a tightly coupled system with fully automated supply and demand, logistics, and manufacturing could be an ideal way for the global networked manufcturing. This type of a system would minimize slack, waste, and risks, while maximizing output. However, if such system is highly centralized among one or few global technology companies, there is risk that the efficiency gains are reaped as monopoly rents. This would leave less room for competition, innovation, and diversity. Therefore, it is expected that manufacturing of the future is run by global “manufacturing networks of the future” – networked production systems that compete head to head with automation, flexibility, and quality.

To conclude, this chapter helps to track the progression in the industrial landscape and the changing role of a “factory” from Taylorist and Fordian history towards the networked, automated and interconnected future of manufacturing. The arguments made are based on the existing evidence and progression, but of course the future development can take alternative paths that have not been taken into account. Therefore, there is a place for more research that would study the changing aspects in the industrial landscape from different perspectives.

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