MANUFACTURERS, AI MODELS AND MACHINE LEARNING, VALUE CHAINS, AND 5TH GENERATION WIRELESS NETWORKS

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ABSTRACT

When AI models and machine learning are fully interconnected in factories with cabling-free 5G wireless networks, firms become "fully digital". This analysis argues that it is not the initial efficiencies gained by optimizing a plant's operations but rather a firm's ability to build a collection of knowledge about each step of its operations, what we call "knowledge synthesis". This is information about how each product is produced, how the process to produce it is managed and optimized, and the software and systems required. This knowledge is important because it permits firms to exploit network effects based upon connecting plants together or sharing expertise with partners. This greatly expands the potential for economic benefits from the use of AI and 5G. This review explores cases from firms with smart factories that have adopted AI and 5G communications including Moderna, Sanofi, Mercedes, Ford, and VW. It examines how these firms have benefitted from the move to smart factories with 5G communications networks. It also explores how firms have improved their value chains by building smart factories that connect nearly all manufacturing processes to machine learning and AI models that analyze machine and process data rapidly. Next, they take advantage of network effects – due to "knowledge synthesis" that permits early smart factories with 5G networks --to derive even larger benefits inside their production operations and in their supply chains. In both phases, the adoption of 5th Generation wireless in plants ramps up firms' abilities to interconnect their digital systems. Once the interconnected systems exist, firms exploit network effects to create "knowledge synthesis" or knowledge platforms to consolidate insights gained from optimizing many machines and processes. Using "knowledge synthesis", firms can also transfer knowledge from one group of equipment to another that is not optimized even when the equipment is in different facilities. This makes firms far more flexible, interoperable, and scalable.

KEYWORDS

"Fully Digital"Firms, Smart Factories, Knowledge Synthesis, Manufacturing Processes,Value Chains.

1. "FULLY DIGITAL" FIRMS

"Fully digital" firms create an integrated networking infrastructure in their plants and make analytics, using AI models and machine learning techniques, central to their plants' operations. Firms achieve this status while they also pass through two phases to change their value chains. In phase one, they build smart factories and connect nearly all manufacturing processes to machine learning and AI models that analyze data rapidly.[1] In phase two, they take advantage of *network effects that have even larger benefits inside firms and for supply chains*. In this phase, firms exploit the benefits of a fully digital ecosystem of factories that is often global in scope. Here too, they take advantage of network effects to reshape their value chains.

David C. Wyld et al. (Eds): SAIM, ACSIT, SNLP, ICITE, CoNeCo - 2021
pp. 17-31, 2021. CS & IT - CSCP 2021 DOI: 10.5121/csit.2021.111003

In adopting a “fully digital” infrastructure, a firm integrates three steps. First, it deploys a digital networking infrastructure that links together all machines. Second, it prioritizes the analysis of equipment performance and how to optimize and change related operations. This is much easier to achieve following the deployment of 5G communications within factories. Third, it constructs an ecosystem of insights from these analytics. This lets firms evaluate and optimize machines’ performance within a plant and across plants.

Sanofi’s new Continuous Biologics Manufacturing Facility [2] exemplifies what firms can accomplish in phase one. It is a digitally enabled, continuous manufacturing facility, where Sanofi takes advantage of AI analysis to evaluate process data in nearly real-time. In this factory, AI models’ results are transmitted quickly to workers’ iPads and displayed on large video screens. With this capability, Sanofi’s employees can quickly fine-tune any processes.

Once firms complete this initial phase, they: 1) make more efficient use of capital in optimized processes; and 2) continuously update and refine the machine learning models that help define how AI models analyze processes. Firms can add additional variables and conditions to improve their analysis of such processes.

In phase two, “fully digital” firms take advantage of network effects that have even larger benefits inside firms and in their supply chains. In this phase, firms begin to understand that a *fully digital ecosystem* can take advantage of network effects that have the potential for *unprecedented* impacts on how they reshape their value chains. The World Economic Forum and McKinsey have argued that the main benefit of adopting AI is the dramatic change in cash flow that “frontrunners”, adopters of AI in the first 5 to 7 years of its commercial use, obtain by 2025. This is due to the efficiencies that early adopters of AI can achieve. See [3, Fig. 1]

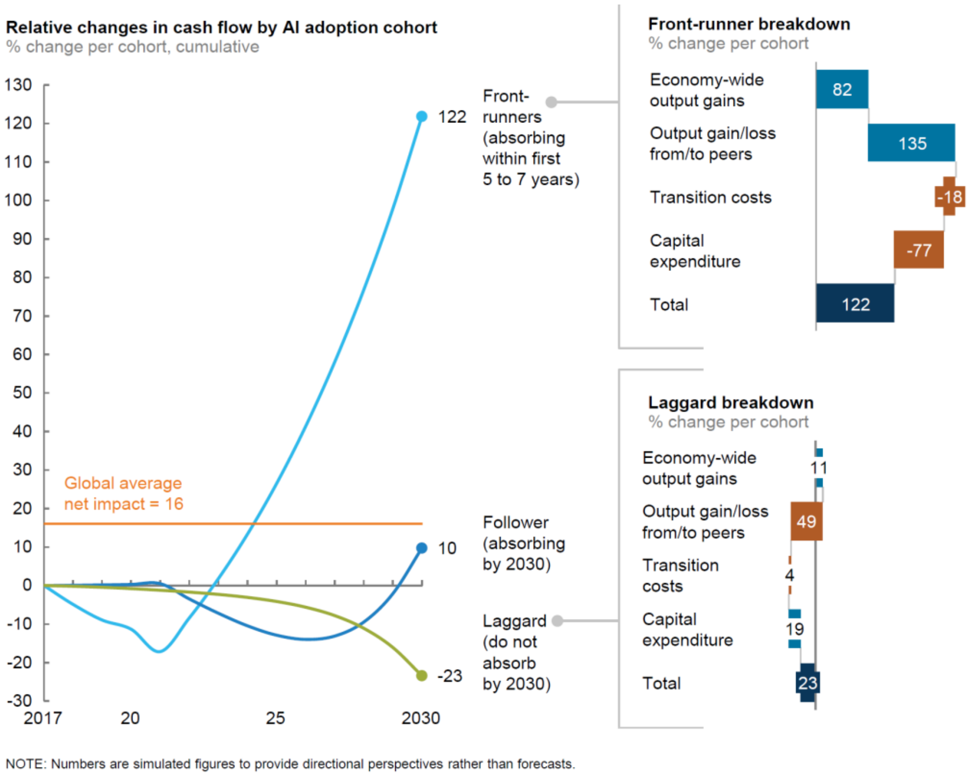

Figure 1. Faster adoption and absorption by front runners can create larger economic gains for these companies.

In this phase, firms begin to employ "knowledge synthesis", insights obtained by optimizing many machines that are part of a process -- for instance, assembly and stamping in an auto plant or producing printed circuit boards in an electronics plant -- to create a template or knowledge platform that indicates how the firm should optimize all the machines and software needed to produce a product. Firms utilize this knowledge inside a single factory or can share it among a group of "sister" factories.

To become completely digital, firms adopted digital technologies as well as new communications technologies, such as 5G private networks, and integrated them with AI and machine learning. DXC Technology defines this shift to data analysis-based interconnected machines and equipment as "industrialized AI". It believes that the definition includes automating, scaling, and operationalizing "siloed analytics capabilities". [4]

There are three ways [5] that firms create digital landscapes. These features are likely to emerge as the new enterprise architecture for data analytics, including AI and ML, and for rapid adjustment of business processes. The emergence of this architecture involves several steps.
First, firms integrate digital production with cloud computing and data analysis. A step beyond this integration is refining applications so that they are easier to analyze using the compute power that is available at the Edge that is usually far more limited than the computing capabilities in the cloud. For instance, two German auto firms have adopted paint inspection technology that Durr, a robotics manufacturer, created. Durr, reworked "its DXQ equipment analytics program with Software AG to record, analyze, and eliminate faults in the painting process." The process measures "230 different signals from each [robot], at any one point in time – out of 100,000 data points we are collecting" [5] to stop any paint jobs that have gone awry. The software innovation means that 230 data points are sufficient to identify live painting errors, not 100,000. If there is a problem, the software stops the line at once, identifies the painting error and flags the fault in the machine.

A fully digital firm with extensive sensor networks, AI models and 5G communications acts as a flexible matrix. It can rapidly collect data and information about how the firm operates. This flexible matrix structure moves beyond Industry 4.0 because its data analytics originate in sensor networks, that, due to 5G communications can send information rapidly to the Edge of networks and get it returned almost in real time. This feedback structure lets workers visualize performance and correct how processes are operating. It also connects to an extensive collection of cloud services.

Second, digital firms focus on the "knowledge synthesis" created from the analysis they have performed. This allows them to optimize design and development processes as well as many manufacturing processes. The result is not only cost reductions, but also the application of "lessons learned" in one section of a business to other operations.

We defined this concept after noting automakers' intentions to connect many of their smart factories with 5G private networks. For instance, Jorg Burzer, a Member of the Divisional Board of Management of Mercedes-Benz Cars has noted that "with the installation of a local 5G network, the networking of all production systems and machines in the Mercedes-Benz Cars factories will become even smarter and more efficient in the future. This opens up completely new production opportunities." [6] We also considered Volkswagen's plan to build 5G mobile networks in 122 factories in Germany in 2020 and "develop an 'industrial cloud' to combine the data of all machines, plants and systems from all 122 facilities of the Volkswagen Group and …. [possibly include its] global supply chain linking 1,500 suppliers and partners across 30,000 locations" [7] including those in China.

Volkswagen plans to achieve a 30 percent increase in system-wide productivity between 2018 and 2025 by making such changes in its factory ecosystem. It believes its "biggest optimization potential lie[s] in the production structures and processes, considered to be far too complicated in many places." "And there is also room for improvement in standardizing our global production network…that is why we are now introducing uniform structures at all factories along with uniform and comparable key performance indicators." [8] By comparison, the Nokia Oulu, Finland factory achieved more than a 30 percent increase in productivity in one year. It leverages a 5G private network as well as "IoT analytics running on Edge cloud, and a real-time digital twin of operations data." [9]

Volkswagen's shift moves the firm's focus from a "product to a process orientation". [10] Here, we develop new thinking about how factories will operate in the future extending our thinking to the future focus on processes.

"Knowledge synthesis" shortens the time to transfer knowledge from one set of processes to another. Firms support transferring insights from one part of their business to another. This reduces the time required to deploy new machines, software, and processes in one plant or in a related "sister" plant that produces similar products. This is largely thanks to connectivity 5G networks offer to global businesses. Moderna's rapid development of a coronavirus vaccine was possible by using "knowledge synthesizing", drawing on its own previous model of vaccine development.

After these steps, firms turn using AI into a process innovation strategy. They transform processes and develop innovative ways to create new or different types of products. They build digital architectures and processes that are based upon a digital twin infrastructure. Aerospace and auto firms have employed digital twins – virtual models of components – to model and test key parts of a product, such as its engines. Rolls-Royce and other engine manufacturers do this to speed testing and for the C-130 and F-35. The digital twin infrastructure is the foundation for moving to an all-digital-software analytics infrastructure over the next 2-3 years.

Morgan Stanley's and Wells Fargo's use of AI analytics to determine their banks' exposure to liquidity risk is a good example of how AI and ML have become central to a firm's performance. Using critical analysis based upon ML and AI models gave these banks predictions of their risk exposure. These proved to be far more accurate than calculating risk exposure with traditional regression models. Consequently, these banks migrated many of their most important assessments of risk to AI and ML models.

We have constructed a conceptual model of how applications and services change in moving to smart factories with 5G communications [11, Fig. 2]. We believe this model characterizes how smart factories and firms will use 5G communications and AI. We think it may be possible that other technologies could arise that would help firms transfer insights about processes between plants more rapidly. Perhaps this could happen after innovations that provide new ways to transfer exceptionally large files between specific locations.

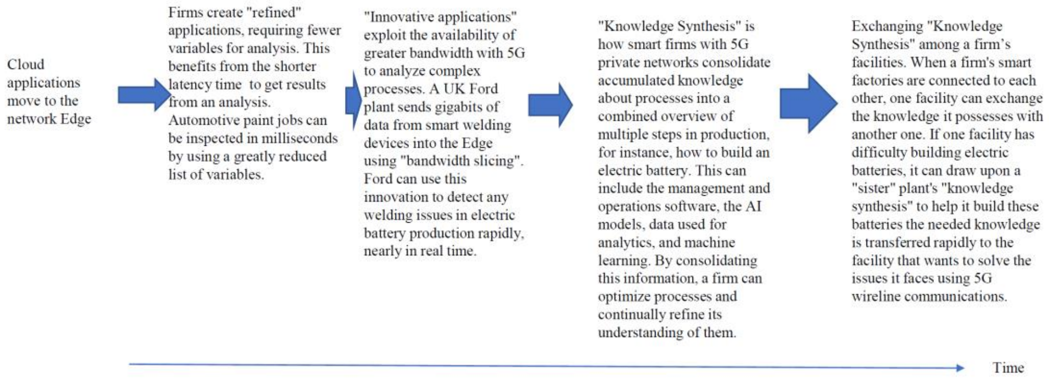

Figure 2. The Evolution of applications in smart factories and interconnected smart factories

2. FULLY DIGITAL FIRMS, NETWORK EFFECTS AND CHANGES IN VALUE CHAINS

Which firms have already become "fully digital"? Those that have integrated communications across a factory with 5G communications. As a result of this shift, firms operate in a paperless environment where data-analytics operations integrate AI and machine learning.

In September of 2020, these firms were present in four industries. In automobiles, "fully digital" firms included Volkswagen's Industrial Cloud and Digital Production Platform (DPP), in Wolfsburg, Germany, and its engine plants in Chemnitz, Germany and Polkowice, Poland. VW's DPP will also be installed in Porsche's plants – Porsche is part of the VW group -- in Leipzig and Zuffenhausen, Germany, in 2020. Also included in this group is the BMW Group i8 Factory in Leipzig, Germany, and its Regensburg, Germany, "sister" plant. At Daimler Benz, the Smart factory, "Factory 56", in Sindelfingen, Germany and Daimler's Full-Flex Plant for Mercedes' compact A-series cars in Kecskemet, Hungary are "fully digital". We also include Toyota's Tsusho Canada plant in Ontario, Canada, Ford's 5GEM plant in Dunton, UK, Subaru's Indiana Automotive plant, and the Bosch smart factory for auto parts in Celaya, Mexico.

The digital firms in pharmaceuticals include Moderna's plant that led the rapid development of a coronavirus vaccine in Norwood, MA, and Sanofi Genzyme's Continuous Biologics Manufacturing Capability, or digitally enabled, continuous manufacturing facility, in Framingham, MA. We also expect that similar Sanofi Genzyme plants in Toronto, Canada, Waterford, Ireland, Sisteron, France, Brazil, and China[12] are "fully digital" as is the Lonza Specialty Ingredients pharma plant in Visp, Switzerland, and Eli Lilly's Small Volume Continuous Facility in Kinsale, County Cork, Ireland.

In electronics and sensors, we find "fully digital" plants at Schneider Electric's smart factories in Amberg, Germany, and Le Vaudreuil, France. Schneider is expected to fully digitize plants in Lexington, Kentucky, Wuhan, China, Hyderabad, India, and Batam, Indonesia. We have identified "fully digital" plants at ABB (ASEA Brown Boveri) factories in Shanghai, China, and Heidelberg, Germany. Similar plants include the factories at JUMO GmbH & Co. in Fulda, Germany, that produce high technology sensors and Ericsson's plants in Louisville, Kentucky, Texas, Kista, Sweden, and Nanjing, China.

The sole "fully digital" firm we have discovered producing industrial tools is Sandvik Cormorant's factory in Gitmo, Sweden.

Although today's number of "fully digital" firms is small, many of them plan to convert nearly alltheir facilities into smart factories using 5G networks. This is likely to begin a major transformation of manufacturing and the modern corporation. In the future, it is likely that the corporation will be defined by how it uses AI and machine learning as well as 5G communications, Edge computing, and more extensive sensor networks that are part of the Internet of Things.

In today's environment of extremely rapid changes in technology, especially software to operate and analyze the operations of modern corporations, Peter Drucker's thoughts about management may need to be redefined. Where Drucker finds that organizations integrate specialized knowledge in a common task, [13] today's firm appears to operate more by capturing knowledge about processes where individuals, rather than managers, often decide how to implement new approaches and develop new software. This non-hierarchical management approach has more in common with a decentralization of power and creativity in the smart factory with 5G communications.

Firms are no longer "rules-based" but "efficiency-focused" [14]. Our definition of "efficiency focused" does not mean minimizing transaction costs. Instead, efficiency is due to how firms have made AI models and cloud computing central to their operations.

Both VW and BMW have invested in fully digital factories that provide high value for assembly processes. Network effects, or what I call "knowledge synthesis" is the second driver that changes value chains. Both VW and BMW expect to benefit from network effects by linking together similar processes within a single factory and, later, by interconnecting many plants linked through the cloud and 5G communications. This will join processes within different plants that use the same machines or employ the same manufacturing processes.

Value chains are likely to change in two ways in the auto and biopharma sectors. First, firms will rely upon AI models and machine learning to analyze processes. With machine learning models, it is possible to get a more sophisticated analysis of key stages in the assembly process. With auto firms, this level of information improves operations.

Second, with "knowledge synthesis", these firms transfer information about how one stage in the assembly process was optimized to other processes. Since "knowledge synthesis" lets firms take knowledge gained in one place and apply it to machines in another, it reduces the cost of experimenting with new processes. It also transfers insights about how to optimize a process at a low cost.

Moderna [15] has employed "knowledge synthesis" to accelerate the development of its new coronavirus vaccine. Moderna's messenger RNA-based framework builds on its previous research on streptococcal pneumonia and personal cancer vaccines, including algorithms and designs for testing. By applying previous genomic designs and frameworks, Moderna reduced the time to design, produce, test, and prepare the coronavirus vaccine to just 42 days.

Moderna's digitization is a central feature of its new facility outside Boston. Once digitized, every step on the factory floor and all the testing and development work in a lab is recorded electronically. The reasons to digitize include [16]: 1) the fact that all of its drug targets were based on messenger RNA -- since messenger RNA's structure includes DNA's four basic human genome chemicals, it could be easily described in an computerized data base; 2) similar data was being used in the previous drugs it was developing because they used variants of messenger RNA; and 3) Moderna wanted to work on multiple drugs that had different treatment approaches at the same time; if it considered working with a traditional pharmaceutical firm's structure and overlaying it with digital capabilities this would not be possible. The only way to achieve this type of flexibility would be to connect “hundreds of thousands” [17] of applications at an astronomical cost.

On the shop floor, Moderna optimized processes just as Volkswagen did. It reported a decrease in manual exceptions by 85%, shift labor by 40%, and batch review from 3 days to 3 hours [18]. Moderna also focused on ways to optimize laboratory instruments. In this area, sensor data from different instruments provides usage information as well as failure frequencies. Moderna used this to drive needed capital investments and set up usage-based calibrations for instruments.

Improvements in factory-level performance drive a fundamental restructuring of value chains, often due to operational enhancements. In the auto industry, these value chain benefits are focused not only on the assembly line and its stamping shop but also in engine and drive train production. These changes introduce a high level of new technology in specific parts of the value chain and spur firms to improve the technological sophistication of their supply chains.

The initial digitization at auto firms focused on the highest value-added parts of auto manufacturing. In Volkswagen’s case, they supported a “step change” in productivity.

Both VW and BMW focused on the stamping shop to address quality issues. This is one of the earliest, high value stages in auto assembly. Mistakes in this stage carry over into other stages. By reducing errors and imperfections here, auto firms increase the value they create.

Volkswagen’s Digital Production Platform (DPP) has also focused on engines. Volkswagen’s goal is to “to standardize and network all production-level machinery, equipment and systems, which currently use different software programs. Therefore, the Volkswagen Industrial Cloud could use application programming interfaces [19] to simplify data.” [20]

“Knowledge synthesis” also alters the value chain. It exploits what economists call network effects[21], where a good’s value or benefit increases as the number of users grows. The Internet is an excellent example; as more people used it, its value increased. The greater the spread of new efficiencies, the greater the return. With digital analytics, firms take advantage of “knowledge synthesis” by building insights and knowledge they gain when they optimize and adjust, or even redesign, a single process. Firms apply this framework or knowledge platform – insights and “learnings” -- to different products that are part of their operations.

“Knowledge synthesis” is only possible once a factory is fully digital. It acts as a driver behind a firm’s construction of highly connected 5G private networks within plants and between plants. It also drives manufacturers’ efforts to connect their analytic and optimization systems with their suppliers. These networking impacts result in substantial improvements in productivity and innovation.

In the coming decade, this process is likely to transform suppliers that have traditionally performed lower value-added operations for auto firms. Lower-level suppliers, so-called Tier 2 and 3 suppliers, traditionally are more labor intensive and they produce less technologically advanced parts and components. They can shift to higher value-added tasks because using AI and machine learning would result in tighter control over processes. As these suppliers employ quicker modeling of the changes a firm makes when it shifts manufacturing from one product to another, they can rapidly modify the way they manufacture an existing product.

This unlocks an opportunity for auto producers or similar final product producers to remake their supply chains. In auto production, especially for assembly and key subsystems, such as drive trains, final assemblers need to refashion tighter connections between their assembly plants and their supply chain's subsystem manufacturers. This ensures that smart technologies will reach external suppliers, raising their technical competence. It also provides a way for automakers to obtain supplier data that helps model changes in an area like brake design and to evaluate how a different design for brakes will perform in a product like an electric car. Conversely, large suppliers can use their own data centers and edge computing to evaluate the components, such as electronic batteries that they ship to automakers.

These cases illustrate how network effects might have an extraordinary impact on value chains as more firms adopt AI and machine learning.

3. 5TH GENERATION WIRELESS TECHNOLOGY IN MANUFACTURING FIRMS; EXAMPLES FROM MERCEDES AND VOLKSWAGEN

Fifth generation (5G) wireless communications permits factories to communicate almost instantaneously with computing power and applications at the Edge of computer networks. Factories benefit from 5G's ability to analyze operations with low latency and high bandwidth. This section enumerates the early benefits of adopting 5G private networks.

Auto firms have faced a difficult issue analyzing the quality of welding. When a weld has flaws, the welded part is useless. Ford has contracted with Vodafone to create a factory of the future for electric battery production in Essex, UK. Welding is critical to producing high quality batteries. To ensure high quality, the Ford plant's 5G private network transmits large quantities of data requiring lots of bandwidth, nearly half a million bits of data every minute, from intelligent battery welding tools. Over a thousand of these tools make welds on each battery. Ford's welding operations are managed by AI models at the end of the network, or its Edge, that rely upon rapid, high-bandwidth data capture. This is a new feature of 5G communications called bandwidth "slicing".

Another benefit of 5G communications in AI-connected factories is "personalization at scale" or customization. Mercedes Benz's newest factory at Sindelfingen, Germany, includes intelligent workstations where employees create tailor-made vehicles. Among the innovations that 5G makes possible is the use of autonomous guided vehicles that bring required parts to these workstations. At Sindelfingen, the "TecLine" intelligent workstations install engines, braking systems, drive trains, and body trim. They are a stationary workplace that replaces a moving assembly line. The "TecLine" draws its inputs from elsewhere in the factory. It is called a "cycle operation" [22].

This works in the following way. At the beginning of the trim line, Mercedes redefines the tracks for the driverless transport systems. This shifts production from a moving assembly line to a cycle, or static, operation. In the latter, a "vehicle remains in position and is not continuously moved along the line[23]. This makes sense for automated activities …when installing a glass roof. In addition, …the driverless transport systems [make it possible to expand] individual assembly units …without interfering in the building's structure"[24].

Mercedes' Sindelfingen, Germany, factory networks together machines and computer systems. Different "assembly facilities and materials-handling technology are "Internet of Things"-ready."[25] In this plant, "Factory 56", the assembly stations or intelligent workstations receive all the materials required for assembly. Mercedes calls this a "pick zone", or "TecLine" that employs intelligent picking systems. Mercedes supports these workstations with Big Data technology that collects and evaluates the information required to optimize operations and improve existing production processes.

Ericsson and Telefonica Germany are partnering to connect Mercedes' production systems and machines in "Factory 56". They are installing secure 5G communications with gigabit data rates and almost real-time latency – less than a few milliseconds – to complete the analysis of large amounts of data. This 5G network will "boost flexibility, production precision, and efficiency"[26]. It will also support data linking or product tracking on the assembly line, making all processes more robust and optimized. The assembly line or "pick zone" can change at short notice to address new market demands.

5G private networks and their connections to applications and services at the Edge of networks promote significant gains in productivity when they optimize operations.

Volkswagen is one of the pioneers in these efforts. It has linked production to analytic functions on a cloud computing platform. First, VW connected different machines to an Internet of Things (IOT) platform that sends performance results to a data model. Analytic tools analyzed and presented the results very quickly to staff and management.

The "fully digital" system at VW measures the operational equipment effectiveness (OEE) [27] of each machine. There is a *teamtafel*, a team dashboard, that displays the OEE score for different machines on the shop floor. VW is refining this calculation by creating services to augment the Amazon Web Services' estimates of OEE. VW is applying this architecture in its production system, not only its auto assembly plants, but also facilities that produce major components such as drive trains.

These changes allow Volkswagen to improve processes on the shop floor. It created a platform with "use cases", i.e., applications, developed with Amazon that improve process management. With AI and visualization in place, mangers no longer run the shop floor with paper-based reports. VW can use new technologies like AI to evaluate important processes, including the stamping process, to see whether defective parts exist among those pieces that have already been pressed. If they do, managers can eliminate parts with pressing defects before they are incorporated into vehicles further down the assembly line. There, they could disrupt production.

Workers on the shop floor benefit from machine learning and AI models. These tools evaluate performance data and send the results back to teams that can adjust machines' performance. Thanks to 5G communications and computing and analytics at the Edge of networks, factories benefit from the increased speed in obtaining performance information and results of analysis. This is a major advance over previous systems where information took a slow route to the core of cloud computing systems and back to the factory. The results from earlier analytic models took much longer to obtain and could not usually be used to make rapid adjustments. For more details, the reader is referred to [28, Table 1].

Table 1. How Volkswagen manages the shop floor

Structural changes	**How it works using the Internet of Things and 5G Communications**
1. VW has organized work on the shop floor in process steps.	1. An Internet of Things platform connects all of the heterogenous machines in every process step.
2. A single Production Logic Controller (PLC) controls all of the machines in a specific process.	2. Data from each step as well as all the operations is sent to a unified data model.
	3. The results of data analysis are displayed on two different screens
	a. A "team display" gives employees a view of process steps and machine performance.
	b. A management display of machine efficiency and the performance of each process.

The Digital Shop Floor Management system (DSFM) allows Volkswagen to control critical parts of its value chain [29]. It enhances problem solving since it retrieves data and delivers reports automatically. It improves machine availability because it transparently tracks activity and shares knowledge across plants. It also optimizes throughput times by focusing on bottlenecks, the value stream and reliable delivery. In sum, it increases productivity by uncovering data that describes production losses and revealing the factors that cause them.

The initial reason for implementing AI and machine learning is their role in optimizing "high-frequency, complex production processes"[30]. This was Volkswagen's focus during 2019, when it concentrated on high value processes where improvements help it produce cars more efficiently. One focus is the metal stamping process. Defects in the stamped metal products, be they fenders or doors, reduce the value achieved on the factory floor. This requires visualization, AI, and machine learning. The reader is referred to [31, Table 2].

Table 2. How Volkswagen brings intelligence to the shop floor

Volkswagen's Digital Production Platform Includes 3 digital production services	**Applications and analysis in the cloud**	**Applications and analysis at the Edge of networks**	**Use cases**
1. Digital shop floor management	1. Initial deployment in the cloud means that calculations take longer to complete the round trip from a factory to the center of the cloud and back to the factory.	1. Later deployment of applications at the network Edge relies upon a 5G private network in a factory linked to AI models.	1. Efficiency of the press shop or other parts of the production line.
2. Pressing stage optimization	2. This means the latency between the time to collect the data and receive the results of analysis takes about 200 milliseconds; this is considered too slow to respond to changes in performance data on the shop floor.	2. This speeds up analysis. The latency or time to send and recive the results of AI models at the Edge that receive data and perform analysis takes milliseconds. This provides results in nearly real time. It is easy to adjust processes with the AI models' results.	2. Reducing scrap in processes with great potential for errors, such as painting and welding.
3. Part localization	3. The amount of data that can be sent to the center of the cloud is limited by the size of the bandwidth available in the network connecting to the firm. This makes evaluating more complex operations difficult.	3. There is more bandwidth to send far greater amounts of data to the Edge for analysis. In addition, techniques such as "bandwidth slicing" lets firms evaluate gigabits of data far more rapidly at the Edge than at the center of the Cloud.	3. Part localization benefits greatly from 5G communications inside the plant. This makes customization possible at intelligent workstations in the plant.

Volkswagen's architecture is described in the following table [32, Table 3]. It describes how data moves from production equipment to the "industrial edge" where data is gathered before it is sent for analysis. The Edge is often the initial location for analysis, including the use of machine learning. In Table 3 below, this is the "enterprise cloud" and it supports the Digital Production Platform (DPP) Enterprise Cloud which includes applications and services.

VW's plant in Wolfsburg and Porsche's plants in Zuffenhausen and Leipzig have implemented DPP. Volkswagen designated these plants as centers for future innovation and the development of new business models. [33]

Table 3. How Volkswagen's digital production platform (DPP) coordinates manufacturing

Equipment Tier	**Connects to the Enterprise Cloud Through**	**The DPP Enterprise Cloud**
1. The production equipment tier	1. Operational technology - information technology gateway	1. DPP application landing zones
2. The industrial Edge tier	2. An Edge gateway	2. DPP Use Case Application Framework
3. Plant cloud tier	3. Amazon Web Services outposts, DPP plant/Edge services, and on-premises applications	3. Managed Landing Zones

4. CONCLUSIONS

Interconnecting machine learning and AI models with the help of 5th Generation wireless communications will change how businesses operate. It will place analytics at the core of the modern corporation and make the management of processes, not products central to the way firms operate. As a result, firms in several industries are changing their factory floors to incorporate much greater levels of intelligence. This means that highly capitalized and critical operations in firms' value chains, such as welding in the auto industry, can be managed much more efficiently. In addition, once firms compile the insights and skills needed to optimize processes that these new systems provide, they can synthesize this knowledge, what we call "knowledge synthesis", and employ it to optimize similar operations in the same factory or in a "sister" plant. This makes firms more productive and contributes to innovation.

It also opens the path for more extensive customization based upon the use of AI models, rapid data analysis and timely acquisition of parts needed for assembly. This has the potential to shift a large part of production from more automated production lines to intelligent workstations that assemble products that customers want customized. This "personalization at scale" may be one result of focusing analytics on processes. Thus, AI in manufacturing has the potential to support firms as they reorganize production. This could lead to new types of jobs with new work skills, not the displacement of employees by machines that perform workers' traditional tasks.

REFERENCES

[1] Sanofi's new Continuous Biologics Manufacturing Facility, or digitally enabled, continuous manufacturing facility, (2018) "*Sanofi - Les usines du future*", July 18. Accessed March 5, 2021. [Online Video]. Available: https://www.youtube.com/watch?v=4DKSrnavsuc

[2] Sanofi's new Continuous Biologics Manufacturing Facility, or digitally enabled, continuous manufacturing facility, (2018) "*Sanofi - Les usines du future*", July 18. Accessed March 5, 2021. [Online Video]. Available: https://www.youtube.com/watch?v=4DKSrnavsuc

[3] Bughin, Jacques, Chui, Michael, Joshi, Raoul, Manyika, James; & Seong, Jeongmin. McKinsey Global Institute (2018) "Notes from the AI Frontier: Modeling the Impact of AI on the World Economy. Discussion Paper, page 40. September. Accessed March 22, 2021. https://www.mckinsey.com/featured-insights/artificial-intelligence/notes-from-the-ai-frontier-applications-and-value-of-deep-learning

[4] DXC Technology (no date) "DXC Industrialized AI", *DXC Technology*, Accessed March 5, 2021. https://www.dxc.technology/analytics/offerings/139783/143879-dxc_industrialized_ai

[5] Blackman, James (2019) "AI on the line – how advanced analytics and artificial intelligence are transforming the production line", Enterprise IoT Insights, September 26. Accessed March 23, 2021. https://enterpriseiotinsights.com/20190926/channels/fundamentals/three-cases-of-digital-pyrotechnics-on-the-production-line

[6] Daimler AG (no date) "Mobile network of the future. The world's first 5G network for automobile production", *Daimler. com*, Accessed March 22, 2021. https://www.daimler.com/innovation/production/5g-network-production.html

[7] Blackman, James (2019) "Volkswagen to build private 5G networks from 2020; invites tenders from kit vendors", *Enterprise IoT Insights*, April 12, 2019. Accessed March 22, 2021.https://enterpriseiotinsights.com/20190412/channels/news/volkswagen-to-build-private-network-from-2020

[8] Tostmann, Dr. Andreas (2019) Volkswagen Brand Board Member for Production, as quoted in Volkswagen AG, "Productivity of Volkswagen plants to increase 30 percent", September 2019. Accessed March 22, 2021. https://www.volkswagenag.com/en/news/stories/2018/09/productivity-of-volkswagen-plants-to-increase-30-percent.html

[9] Nokia (2019) "Nokia's digitalization of its 5G Oulu factory recognized by the World Economic Forum as an "Advanced 4th Industrial Revolution Lighthouse"", Nokia Press Release, July 3. Accessed March 22, 2021. https://www.nokia.com/about-us/news/releases/2019/07/03/nokias-

digitalization-of-its-5g-oulu-factory-recognized-by-the-world-economic-forum-as-an-advanced-4th-industrial-revolution-lighthouse/

[10] "Volkswagen targeting further boost in factory productivity", *automobilsport.com*, September 27, 2018. Accessed March 22, 2021. https://www.automobilsport.com/cars-tuning--37,181194,Volkswagen-targeting-further-boost-in-factory-productivity,news.htm

[11] Author's conceptualization of the evolution of applications in smart factories and then in interconnected smart factories. This draws upon a review of many case studies.

[12] Sanofi (2018) "The Fourth Industrial Revolution", *Sanofi About Us* (Magazine), November 29, 2018. Accessed March 5, 2021. Available at: https://www.sanofi.com/en/about-us/the-fourth-industrial-revolution.

[13] Drucker, Peter F. (1992) "The New Society of Organizations", *Harvard Business Review*, September–October. Accessed March 22, 2021. https://hbr.org/1992/09/the-new-society-of-organizations

[14] Cheng, Colin (2017) "Innovation performance in service industries: unlocking the intricate effects of strategic orientations and the business model" in *Research Handbook of Innovation and Creativity for Marketing Management*, Shui, Eric Ed., Cheltenham, UK and Cambridge, MA, Edward Elgar Publishing, p. 53. Available for purchase at: https://www.elgaronline.com/view/edcoll/9780857937940/9780857937940.00010.xml

[15] Moderna Press Release (2020) "Moderna Ships mRNA Vaccine Against Novel Coronavirus (mRNA-1273) for Phase 1 Study: mRNA-1273 delivered from Company's cGMP facility in 42 days from sequence selection," Moderna Investor Relations, February 24, 2020. Accessed March 5, 2021. https://investors.modernatx.com/news-releases/news-release-details/moderna-ships-mrna-vaccine-against-novel-coronavirus-mrna-1273 and Telephone Interview with Marcello Damiano, , Moderna CDO and Operational Excellence Officer (February 25, 2020).

[16] Telephone Interview with Marcello Damiano, Moderna CDO and Operational Excellence Officer, (February 25, 2020).

[17] Telephone Interview with Marcello Damiano, Moderna CDO and Operational Excellence Officer, (February 25, 2020).

[18] Buckner, Patrick & Smith, Roland (2019) "Modernizing pharmaceutical manufacturing with IoT and AI/ML", talk presented at AWS re: Invent 2019 conference, Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019,session MFG 203, December 6, 2019. Accessed March 5, 2021. [Online Video]. Available: https://www.youtube.com/watch?v=dczU1w1BiJk

[19] "An application programming interface (API) is a computing interface to a software component or a system, that defines how other components or systems can use it. It defines the kinds of calls or requests that can be made, how to make them, the data formats that should be used, the conventions to follow, etc. It can also provide extension mechanisms so that users can extend existing functionality in various ways and to varying degrees". *Wikipedia,* "Application programming interface" Accessed March 6, 2021. https://en.wikipedia.org/wiki/Application_programming_interface

[20] Hessler, Uwe (2019) "Volkswagen to team up with Amazon in drive to boost productivity", Die *Welt.com*, March 27, 2019. Available at: https://www.dw.com/en/volkswagen-to-team-up-with-amazon-in-drive-to-boost-productivity/a-48083178

[21] Klemperer, Paul (2006) "Network Effects and Switching Costs: Two Short Essays for the New Palgrave", SSRN.com. August 2, 2006. Available: https://ssrn.com/abstract=907502 or http://dx.doi.org/10.2139/ssrn.907502

[22] Ranger, Steve (2020) "5G: Ford plans private network to speed up electric vehicle manufacturing", ZDNet, June 25, 2020. Accessed March 6, 2021. https://www.zdnet.com/article/ford-plans-private-5g-network-to-speed-up-electric-vehicle-manufacturing/

[23] Volvo experimented with this production structure in the 1990s.

[24] Daimler AG (no date) "In "Factory 56" Mercedes-Benz Cars increases flexibility and efficiency in operations," *Daimler.com*, Accessed March 6, 2021. https://www.daimler.com/innovation/production/factory-56.html

[25] Daimler AG (no date) "In "Factory 56" Mercedes-Benz Cars increases flexibility and efficiency in operations," *Daimler.com*, Accessed March 6, 2021. https://www.daimler.com/innovation/production/factory-56.html

[26] Ericsson (2019) "Ericsson and Telefónica to make 5G car manufacturing a reality for Mercedes-Benz", *Ericsson News*, June 27. Accessed March 6, 2021.

https://www.ericsson.com/en/news/2019/6/mercedes-benz-ericsson-and-telefonica-5g-car-manufacturing

[27] Hahn, Pascal & Wieland, Dr. Uwe (2019) "Transforming Automotive Manufacturing with Volkswagen", presented at *Amazon Web Services re:Invent*, Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019, session IoT 339, p. *15*. Accessed April 6, 2020. [Online Video]. Available: https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=automotive+manufacturing&searchType=session&tc=0&sortBy=daytime&dayID=130&p=&i(728)=33661

[28] Hahn, Pascal & Wieland, Dr. Uwe (2019) "Transforming Automotive Manufacturing with Volkswagen", presented at *Amazon Web Services re:Invent*, Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019,session IoT 339, p. *15*. Accessed April 6, 2020. [Online Video]. Available: https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=automotive+manufacturing&searchType=session&tc=0&sortBy=daytime&dayID=130&p=&i(728)=33661

[29] Hahn, Pascal & Wieland, Dr. Uwe (2019) "Transforming Automotive Manufacturing with Volkswagen", presented at *Amazon Web Services re:Invent* , Las Vegas, NV, USA,Dec. 2 to Dec.6, 2019, session IoT 339, p. 15. Accessed April 6, 2020. [Online Video]. Available: https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=automotive+manufacturing&searchType=session&tc=0&sortBy=daytime&dayID=130&p=&i(728)=33661

[30] Cooper, Sarah & Petri, Ulrich (2019) "Volkswagen takes production to the cloud", talk presented at *Amazon Web Services re: Invent conference*, Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019,session MFG 204. Accessed April 6, 2020. https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=Volkswagen&searchType=session&tc=0&sortBy=abbreviationSort&p=

[31] Cooper, Sarah & Petri, Ulrich (2019) "Volkswagen takes production to the cloud", talk presented at *Amazon Web Services re: Invent conference*, Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019, session MFG 204. Accessed April 6, 2020. https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=Volkswagen&searchType=session&tc=0&sortBy=abbreviationSort&p=

[32] Hahn, Pascal & Wieland, Dr. Uwe (2019) "Transforming Automotive Manufacturing with Volkswagen", presented at *Amazon Web Services re: Invent* , Las Vegas, NV, USA, Dec. 2 to Dec.6, 2019, session IoT 339, p. 15. Accessed April 6, 2020. [Online Video]. Available: https://www.portal.reinvent.awsevents.com/connect/search.ww?csrftkn=0E3X-0SLD-Y2W6-4E0C-VVQ9-UGCY-2U8W-QO5T#loadSearch-searchPhrase=automotive+manufacturing&searchType=session&tc=0&sortBy=daytime&dayID=130&p=&i(728)=33661

[33] Porsche AG (2020) "Porsche's Contribution to the Volkswagen Group's New Digital Production Platform", *Medium*, February 11. Accessed March 24, 2021. https://medium.com/next-level-german-engineering/porsches-contribution-to-the-volkswagen-group-s-new-digital-production-platform-708496577264

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