Les Cahiers du Digital

#1

Industry 4.0: the 4th Industrial Revolution

Volume 1 – Technological and Economic Challenges

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The aim of the *Les Cahiers du Digital* collection is to enrich the teaching provided at HEC Liège, thanks to the contribution of experts who possess proven field knowledge on key topics related to digital transformation.

The handbooks are written in a clear and accessible style, in order to allow our students to correctly grasp the major challenges of digital transformation and to arouse their curiosity, so that they wish to explore the topic further, including through their theses.

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Introduction[1]

Over the last 10 years, Industry 4.0 has been considered almost exclusively from a technological point of view and has sometimes been assimilated to an upgraded version of Lean Manufacturing.

The definition of Industry 4.0 in Germany in 2011, “producing customized goods at the same cost as mass-produced goods” was at first fully in line with this productivist logic. Fordism had created tremendous economic and social growth in the 20th century, and digital was bound to follow suit. The productivity gains that were running out were to be followed by the new Eldorado of real-time personalized production.

But this already misleading interpretation is becoming dangerous as Industry 4.0 and the COVID-19 crisis accelerate the transformation of value chains, business models, organizations and ways of working. Industry 4.0 is not an augmented version of Fordism or its successors. It fully deserves its status as an industrial revolution because it turns it upside down and paves the way for a renewed industry.

Faced with sequential and analytical approaches, focused on the pace of the budget, the partial introduction of technological building blocks and the expectation of proof through the calculation of a return on investment, the need for a systemic and constructivist approach to Industry 4.0 is no longer debated today. The bias of this first interpretation was understandable. Capitalism is a machine that seeks productivity gains everywhere, with the recurrent obsession of lowering costs, as Daniel Cohen recently reminded us in an article in *Le Monde*.[2]

But the world has changed and the “desirable economy” described by Pierre Veltz[3], calls for other resorts for a hyper-industry located within territories[4].

In this first *Cahier du Digital*, we will analyze the promise of Industry 4.0 and its technical mechanisms, and we will propose an analysis grid to decipher the variations of Industry 4.0 at the plant level. We will also observe its impacts on the value chain and business models with the emergence of platforms.

This first volume will be followed by a second one which will address the human and organizational challenges of Industry 4.0, as well as the geopolitical dimension of digital transparency and continuity within production chains.

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1 We would like to warmly thank Daniel Atlan, former General Manager Human Resources ArcelorMittal Mining, for our stimulating exchanges, his contributions and his critical eye.

2 Daniel Cohen, « La crise se paye elle-même par les taux bas », *Le Monde*, October 24, 2020.

3 Pierre Veltz, *L’économie désirable, Sortir du monde thermo-fossile*, Paris, Seuil, 2021, p.39.

4 Pierre Veltz, *La Société hyper-industrielle. Le nouveau capitalisme productif*, Paris, Seuil, 2017.

We will conclude with a warning regarding the techno-determinism that too often underpins work on Industry 4.0 and will alert readers to the importance of steering a transformation that is being built in real time, in the very time we are living it.

Industry 4.0: Storytelling at the Service of Transformation

CHAPTER 1

Chapter 1 - Industry 4.0: Storytelling at the Service of Transformation

Industry 4.0 emerges in the period 2000-2005, at a time when Germany is wondering about the future of its industrial model. Although Germany is positioned in the mid-upper end of the market, the country is facing increased competition from new entrants and, since reunification, a relocation movement towards Central and Eastern European countries that is destabilizing its industrial base, particularly the productive clusters made up of thousands of *Mittelstand* companies. The share of value in exports produced on German soil is declining and the economist Hans-Werner Sinn describes the phenomenon as a “bazaar economy[5]”. At the same time, the ambitions of the GAFA are asserting themselves at the margins of the industry and Google is increasingly perceived as a threat. The alliance of German manufacturers to buy the Here mapping application at the end of 2015 so that they don’t have to install the Google Map system in their vehicles says a lot about their fear of letting the wolf into the sheepfold[6].

The Industry 4.0 project thus emerges from a broad reflection led – and co-managed – by representatives of industry, research and public authorities to reinvigorate the competitive advantages of German industry in a context of growing shortage of skilled labor.

Why a 4th Industrial Revolution?

Between 2011 and 2019, Industry 4.0’s place at the Hannover Fair, the leading general industry fair in Germany, has been growing steadily. On this point, Industry 4.0 appears as a formidable marketing operation for the benefit of German industry. But beyond the slogan, this movement has also led all providers of component, machine and industrial computing solutions to build offers labeled 4.0 and driven the buyers of these solutions, large groups and industrial *Mittelstand*, to question the impact of 4.0 on their industrial schemes and business models.

Mobilizing Germany’s industrial fabric was the work of an alliance between the State – with the Ministry of Economics (BMWi) and the Ministry of Education and Research (BMBF) in the lead –, industry and research collectively forging the storytelling around Industry 4.0.

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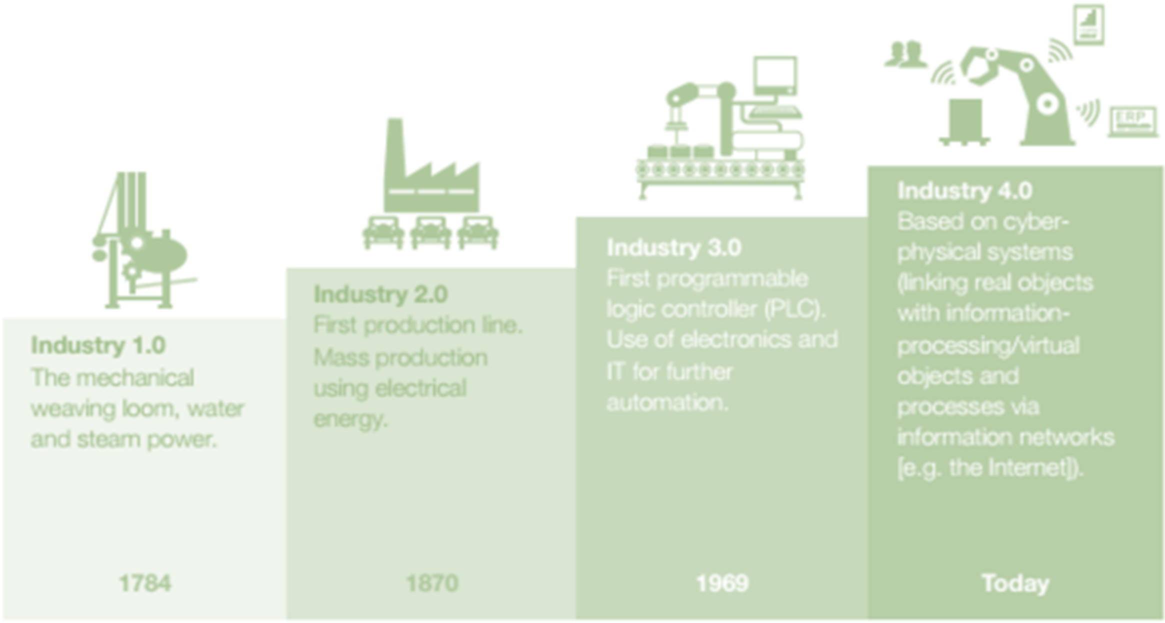
5 Hans-Werner Sinn, *Die Basar-Ökonomie*, Berlin, Econ Verlag, 2005.

6 Dorothée Kohler, Jean-Daniel Weisz, *Industrie 4.0 – Les défis de la transformation numérique du modèle industriel allemand*, Paris, La Documentation française, 2016, p. 53.

The figure below is emblematic of the storytelling that the Germans have built around Industry 4.0. It was promoted by the federal government and the Länder, as well as by industrial players, trade unions and chambers of commerce. Its message was unequivocal: digital transformation has the status of a 4th industrial revolution!

Fig. 1: The four stages of industrial revolutions



Source: ©DFKI, 2011 issu de Acatech, Forschungsunion, *Umsetzungs-empfehlungen für das Zukunftsprojekt Industrie 4.0: Abschlussbericht des Arbeitskreises Industrie 4.0*, April 2013, p.17.

The ambition of Industry 4.0 is to produce customized goods at the same cost as mass production, whether it is yoghurts, shampoos, cars or intermediate products for other manufacturers.

In the Fordist logic, standardized goods are produced with constant productivity gains obtained through scale effects and a work organization that breaks down the tasks to be performed. The third industrial revolution was marked by the introduction of numerical control and the rationalization of production flows. The fourth one implies a new production of information flows between machines, people and machines, machines and products, and products and end users.

Far from focusing on a catalog of technological building blocks such as cobotics, augmented reality, 3-D printing, the Germans set about constructing a narrative around the concept of a “cyber-physical system of production” which is considered to be the driving force of this industrial revolution.

Industry 4.0 thus updates the old cybernetic utopia in Norbert Wiener-style of a system capable of maintaining its equilibrium without any external intervention. This dream extends to the entire supply chain of materials, products, fluids, energy. A plastic extrusion machine installed at the Hanover Fair in 2015 is thus able to adapt its production to the electricity price on the Leipzig spot market. A production line automatically adjusts its output according to logistical events (traffic jams, delivery delays, etc.).

This internal connection of the elements of the factory and its opening to the environment implies a thorough rethinking of industrial IT organization schemes.

The Challenge of Industrial IT

The primacy given to the meta-technology of cyber-physical systems is a German specificity in the way of approaching digital transformation. In this vision, which sometimes borders on science fiction, the cyber-physical system of production designates a virtual entity that emerges from the ability of the thousands of elements in the factory to coordinate with each other and with the external environment.

A cyber-physical production system refers to the ability of the players operating within the plant, men, machines and equipment, to interact and coordinate in real time manufacturing, logistics, engineering and management activities. It is materialized by the creation of a real-world digital twin that enables the physical production flows to be monitored, controlled and adjusted.

The challenge for production information systems is immense. It is no longer a question of managing standard operations with maximum repeatability, but of designing specific production processes according to the part to be produced and the information received from the environment in real time.

Industry 4.0 thus challenges the automation pyramid that links from the bottom to the top sensors and actuators to SCADA[7] systems, ERPs[8] and ultimately to the company's information and decision making system, called business intelligence.

Operating in real time, at the rate of milliseconds or even microseconds, the system must be completely decentralized so that the equipment can operate in a self-regulated manner.

The pyramidal organization is thus replaced by a network structure (see Fig. 2).

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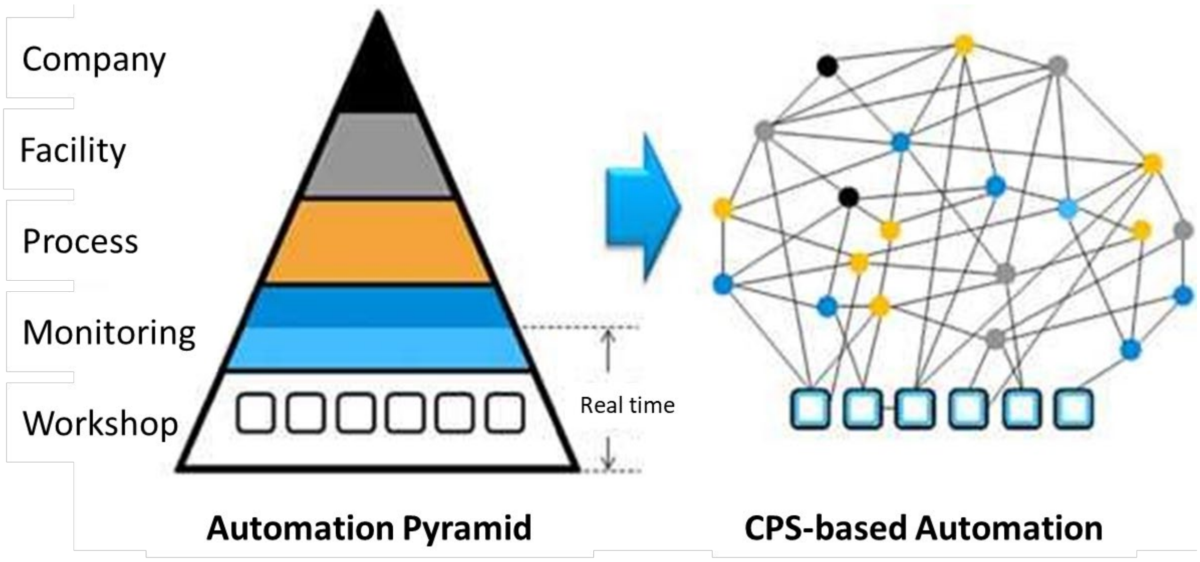
7 A SCADA (Supervisory Control And Data Acquisition) system is a control and data acquisition system that allows the coordination in real time of different instances.

8 An ERP (Enterprise Resource Planning) is a computer tool that allows to manage all the processes of the company: trade, accounting-finance, human resources, production.

Fig. 2 – From pyramid to network



L. Forstner, M.Dümmler: *Integrierte Wertschöpfungsnetzwerke – Chancen und Potenziale durch Industrie 4.0*. Elektrotech. Inftech. 131, 2014, pp. 199–201.

Unlike the 3rd industrial revolution, which saw the development of electronics and computers in factories, Industry 4.0 is characterized by the networking of all the elements involved in production, including the various services.

Production is no longer made up of isolated elements linked, in the best of cases, to a centralized and vertical ERP-type system that allows production information to be sent upwards and planning instructions to be sent downwards. Production is self-organizing and decentralized at the workshop level.

It is this decentralized linking and coordination of all these elements forming a system that gives Industry 4.0 its uniqueness. Like an aircraft flying on automatic pilot whose sensors supply flight parameters to algorithms that constantly recalculate the trajectory and actuate the control surfaces, the factory is piloted by a cyber-physical production system. The cybernetic factory becomes at once an ideal, a concrete field for experimentation and transformation, and a place where a wide variety of production scenarios are built in real time. This factory constantly adjusts its scenarios according to market situations and opportunities.

In this context of real-time scripting of production, the annual budgeting process becomes an almost anachronistic ritual. What is important is the upstream modeling of the different partitions that can be played to fit as closely as possible to the multiple demand profiles.

The Promise of Industry 4.0: Reconciling the Strengths of Craftsmanship and Mass Industry

In contrast to the Fordist promise of productivity gains and of diffusion of consumer goods made possible by concomitant increases in wages, the unitary series advocated by Industry 4.0 is meant as a response to customized mass production. The satisfaction of a happy few's needs must be followed by an on-demand mass production model with a high degree of variety: after training shoes costing several hundred euros and whose soles are made according to the morphology of the foot comes the muesli produced on demand with a blend chosen by the consumer.

In the B2C[9] world, Industry 4.0 is not so much about creating new markets as it is about replacing mass markets with on-demand production. The result is more customer satisfaction and less waste. From books, to pizzas, yoghurts, shampoos, soaps, toothpastes or hair coloring products, store shelves are filled with items, many of which will be discarded if they don't find customers within the required timeframe.

Unitary production somehow tends towards more sobriety. Personalization seeks to reconnect with the principles of craftsmanship.

Unitary production is at the core of craftsmanship: high variety and low volume. The third industrial revolution, driven by automatons, numerically controlled machines and robots, did not call into question the foundations of fordism, but extended its goal of extreme standardization supported by constant gains in terms of cost, quality and deadlines.

The trend since the second half of the 20th century has been towards an increasing personalization of certain industrial goods, driven both by the necessary adaptation of global goods to local specificities and by the growing demand for individualized goods (see Fig. 3).

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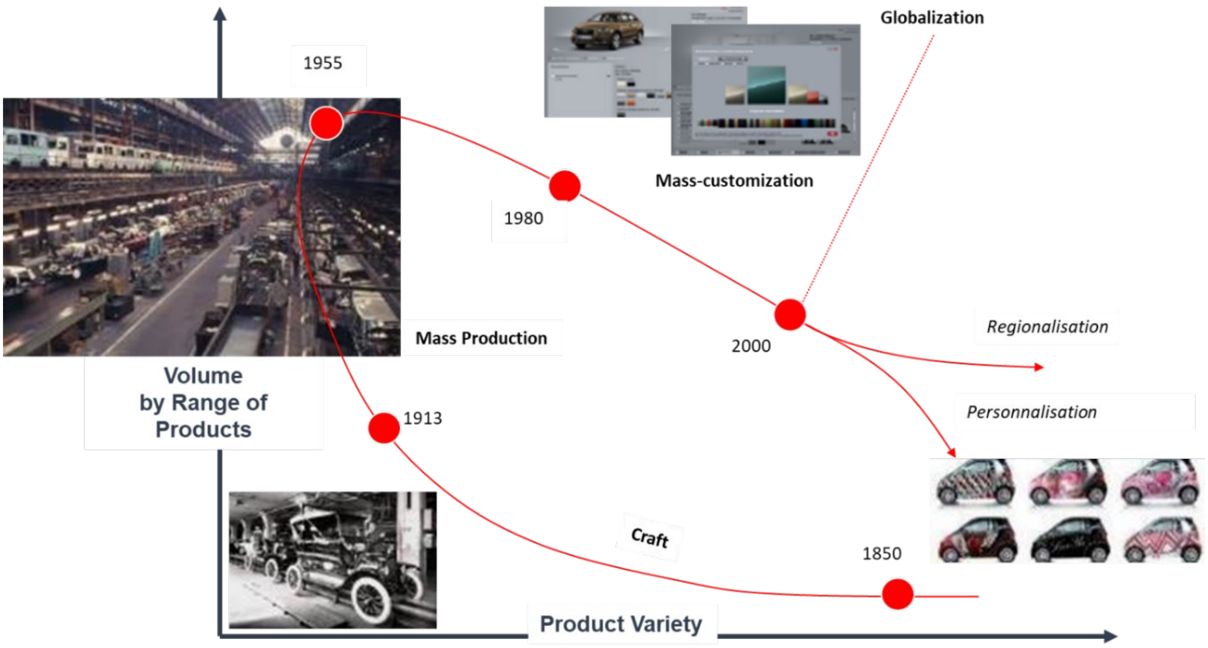
9 The abbreviation B2C, "Business to Customer", refers to industries that are directly related to the end customer.

Fig. 3 – From Craftsmanship to Mass Customization



Source: Yoram Koren, *The Global Manufacturing Revolution, Product-Process-Business Integration and Reconfigurable Systems*, The University of Michigan, 2010.

Adaptation to the needs of differentiated customers was managed by dividing and treating separately the standard part and the specific part of the products. The automotive sector, which produces cars under different brands from identical platforms, is a prime example of this.

This delayed differentiation is aimed at conquering new productivity gains by responding as quickly as possible to customer needs with customized products.

With the ambition of unitary series, Industry 4.0 goes far beyond this organized differentiation.

But how can unitary series be successful when small series and prototypes are generally the nightmare of Fordist industries?

In the workshops, the changeover times between the manufacture of two different series of parts or products (cleaning, dismantling and reassembling tools, adjustment, restarting a series...) are a key issue for productivity in the factories. They can last from several hours to a few days depending on the activities. The prowess of the unitary series is obtained thanks to the digital meshing of the whole production. It adjusts in real time to the customer's needs and manages the variety of the produced parts. Series changes are made in the range of a minute, or even almost instantaneously thanks to the mobilization of new technologies.

A Technological Revolution

CHAPTER 2

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Chapter 2 - A Technological Revolution

It has now been more than ten years since the Industry 4.0 concept was officially presented to Chancellor Angela Merkel at the Hannover Fair. Since this event, the term has flourished and there are now in the field, within industrial companies, thousands of Industry 4.0 projects which take very diverse forms and encompass a variety of perimeters depending on the technologies deployed.

Of course, not all Industry 4.0 projects aim at the unitary series. But they question the initial industrial scheme to make it more flexible and adaptive[10]. “Industry 4.0 is the end of the cable,” are some manufacturers already anticipating, implying that miles of cabled network infrastructure will soon be replaced by wireless technologies.

The Market of Technological Building Blocks

A variety of digital technologies can be deployed within a production tool (see figure 4). Labeled “Industry 4.0”, these building blocks concern a specific project and a department of the company: production (specific sensors, predictive maintenance, advanced robotics, cobots, digital twin...), design office (integrated design and project management platforms), logistics (real-time tracking and tracing system). This path towards the digitization of the industrial tool aims to introduce technological building blocks to progressively connect all the elements contributing to production.

These technologies are based on the Industrial Internet of Things. It enables all connected elements to communicate with each other, but also provides the basis for the artificial intelligence embedded in these objects. Algorithms, based on linear discriminant analysis, clustering or neural networks, are becoming increasingly sophisticated. Increasing computing power allows them to exploit exponential volumes of data, to the point of learning from their trial-and-error process: this is called “machine learning”. The integration of this artificial intelligence in new tools provides the industrial tool with new technologies.

In the field, we most often encounter 5 types of technologies in France and Germany. They are representative of Industry 4.0.

- Generative design
- Predictive maintenance

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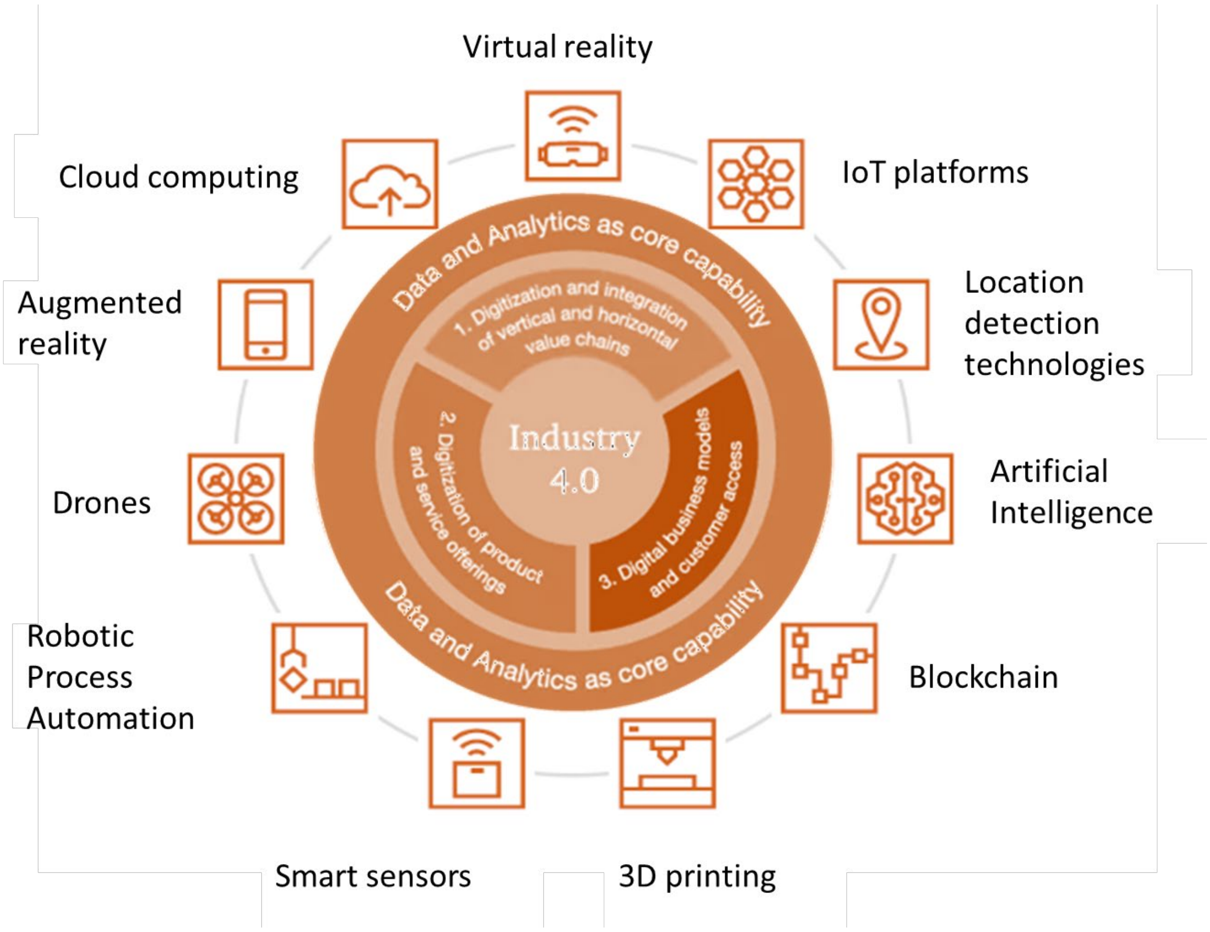
[10] Dorothée Kohler, Jean-Daniel Weisz, *op. cit.* p. 31 and p. 97.

- Industrial vision
- AGVs
- Digital twin

Fig. 4 – The Technological Building Blocks of the Industry of the Future



Source: PwC & Agence du Numérique, *Industrie 4.0: quels sont les facteurs déterminants pour devenir une « industrie du futur » ?*, 2020.

Optimized Conception, Generative Design

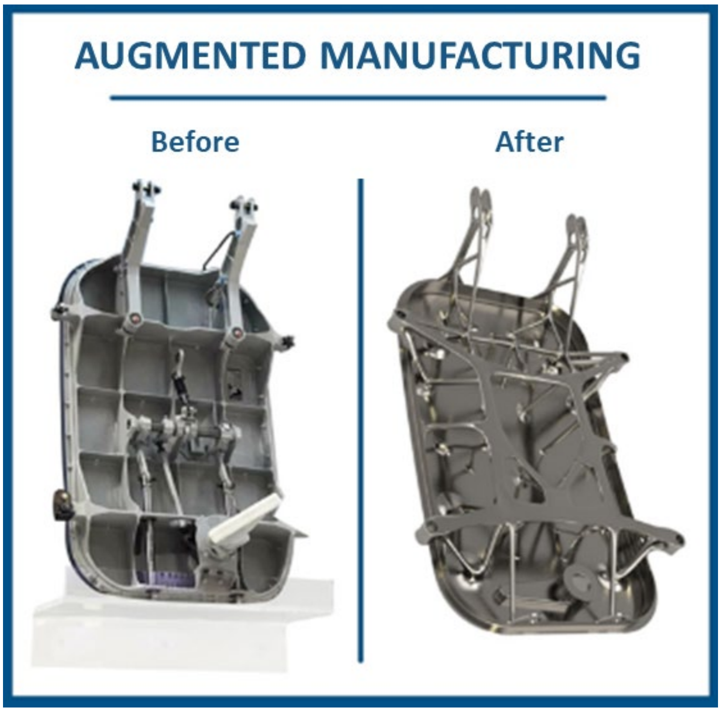
In computer-aided design, topological optimization makes it possible to initiate or rethink the design of a part, resulting in a lighter product and optimized characteristics in terms of thermal deformation and resonance.

Thanks to the possibilities of calculation and storage, generative design offers a set of possible solutions with substantial savings in terms of development time and industrialization costs. Designers define the functions and constraints, and dedicated algorithms generate several design proposals for the part that meet these functions and constraints. Designers can select the one that appears to be the most suitable.

Figure 5 shows an application where the weight gain was about 30%, where development time was divided by 4 and industrialization costs were reduced by half.

These technologies are often coupled with 3D printing to address the complexity of the shapes, difficult to obtain with conventional casting or machining processes.

Fig. 5 – An aircraft hatch created by topological optimization



Source: Ventana Group

Predictive Maintenance: Producing Without Breakdowns

In the production process, predictive maintenance is a privileged entry point into Industry 4.0 for manufacturers.

Curative maintenance consists in interventions intended to manage an identified problem or a breakdown. Preventive maintenance includes interventions intended to prevent the possible occurrence of an incident by changing, among other things, wearing parts whose cycle time is close to the maximum duration of use.

Predictive maintenance causes the maintenance intervention according to a foreseeable incident. By linking certain operating information (vibrations, temperature, noise) from existing or specifically installed sensors to incidents that have already occurred, the algorithms can define scenarios and thresholds from which the occurrence of a breakdown is almost certain.

IA, a Control Optimization Tool

In high value-added industries such as aeronautics, artificial intelligence is designed to improve the efficiency of part inspection.

A non-destructive testing technique such as dye penetrant testing can reveal cracks or fissures on parts by using a product that penetrates to the location of the defect. An optical inspection identifies where defects appear.

In this case, artificial intelligence systems allow to capitalize on human experience in defect detection. Once the databases have been created, which gather all the defects observed over a long period of time and the results of past interpretations carried out by traditional processes, the artificial intelligence engines are able to identify possible non-confirmities and alert the controllers.

In other industries, visual detection is at the heart of value creation. Manufacturers of industrial waste sorting machines are also innovating in intelligent vision to identify and select the different kinds of plastics contained in a collection stream. In this case, where human sorting skills are still essential to achieve the level of sorting quality needed to reuse plastic waste, advances in artificial intelligence are needed to increase the degree of automation of these plants.

AGVs, the Automation of Internal Flows

Automated Guided Vehicles (AGVs) are electric trucks guided by markers on the ground or directly by geolocation. They are autonomous because they can anticipate collision risks and recalculate their trajectory in real time. Used in large numbers in logistics warehouses or postal sorting centers, these AGVs have made their entry into factories where the routes are more complex.

New factories, whose design is guided by responsiveness to demand and individual product variations, are turning logistics flows into a strategic variable. The company’s management system is moving away from a vertical, centralized structure towards a decentralized network of production units supplied by AGVs.

Fig. 6 – AGVs at SEW Usocome

Source: SEW Usocome

The introduction of AGVs leads to a radical rethinking of internal factory flows. In the automotive industry, for example, the linear production line where assembly operations were carried out is disappearing in favor of multiple islands scattered throughout the factory. The body of the car travels on an AGV and joins these islands according to the operations to be performed.

At SEW Usocome, a manufacturer of geared motors, the diversity of products is extreme. The components used to assemble the parts circulate on AGVs between the central automated warehouse and the assembly stations, which are organized in mini-factories within the site (Figure 6).

The Digital Twin, Multiple Applications

The digital twin is a virtual double of a physical element that reproduces its operation based on real data. It allows to simulate the production process to evaluate scenarios and anticipate certain production events.

This digital twin is very valuable because it allows first of all to optimize design choices by simulating the operation of complex sets. This avoids the need for numerous, time-consuming and costly test, trial and error processes.

Fig. 7 – Digital twin

Source: Siemens

The digital twin is then a means of simulating the operation of an existing component, element, robot or machine according to multiple criteria: speed, temperature, pressure, etc. This simulation makes it possible to optimize the course of production operations and improve equipment maintenance. They are the source of new services: for example, in France, Dassault uses this technology to optimize the maintenance of the Rafale aircraft fleet. In the automotive industry, digital twins are used to simulate processes during the launch of new models, thanks to a virtual ramp-up of production lines.

This technology can also be used to enable new learning on a complex machine through a virtual training environment.

Finally, a digital twin, even a relatively simple one, is an important asset in a pre-sales process to allow a customer to visualize the proposed industrial solution, such as a special machining unit.

Each component of a production system can have its own digital twin, and these can be combined to create a digital twin of a piece of equipment, a production island, or even an entire factory.

This is how digital twins of machines, engines (aircraft, submarine) or even whole cities are created – as is the ambition of a Dassault System project with Singapore.

In the end, these 5 technologies enable gains in line with the cost-quality-time triptych:

- reduction of manufacturing costs by improving equipment productivity,
- greater flexibility of the production tool and better availability of the machines linked to lower maintenance costs,
- reduction of costs related to non-quality with the improvement of equipment operation and control systems,
- reduction of storage costs and logistics costs thanks to real-time production.

These technologies also reduce the complexity costs due to the variability of products and allow to move in the direction of the unitary series which is the purpose of 4.0. More than a sum or a catalog of technologies, it is in relation to this goal that it seems most appropriate to build and order the different configurations of Industry 4.0 observed on the field.

Factory 4.0 and its Various Declinations

CHAPTER 3

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Chapter 3 - Factory 4.0 and its Various Declinations

Beyond implemented technologies and in the face of the extreme diversity of Industry 4.0 projects, is it possible to provide an analysis grid that characterizes its forms of deployment within factories?

Industry 4.0 stands out above all through the reduction of complexity costs, related to the management of product variety, which is at the heart of its promise and where most of the expected gains reside. This is why it seemed relevant to us to try to identify the various declinations of Industry 4.0 by classifying them according to a double logic of series size and required variety (see Fig. 8). Faced with the profusion of Industry 4.0 projects, we propose a synthetic reading grid that groups them into 3 models:

- hyperautomation,
- standardized differentiation
- adaptive modularity

Hyperautomation

Hyperautomation concerns highly automated mass production activities (electronic cards, injectors for diesel engines, etc.) whose production lines have been equipped to ensure the digital continuity of the manufacturing process, thanks in particular to RFID[11]. The aim is to push the cost-quality-timeframe triptych to the extreme, with almost total transparency on production operations. For example, the client, a car manufacturer, follows in real time the production of its supplier, a subcontractor of rank 1. The entire factory can be modeled as a digital twin and both operational staff and decision-makers can monitor their production parameters in real time.

In this model, the production flow remains linear and preventive or predictive maintenance, as well as the control of parts assisted by artificial intelligence, are central to ensuring the smooth running of operations.

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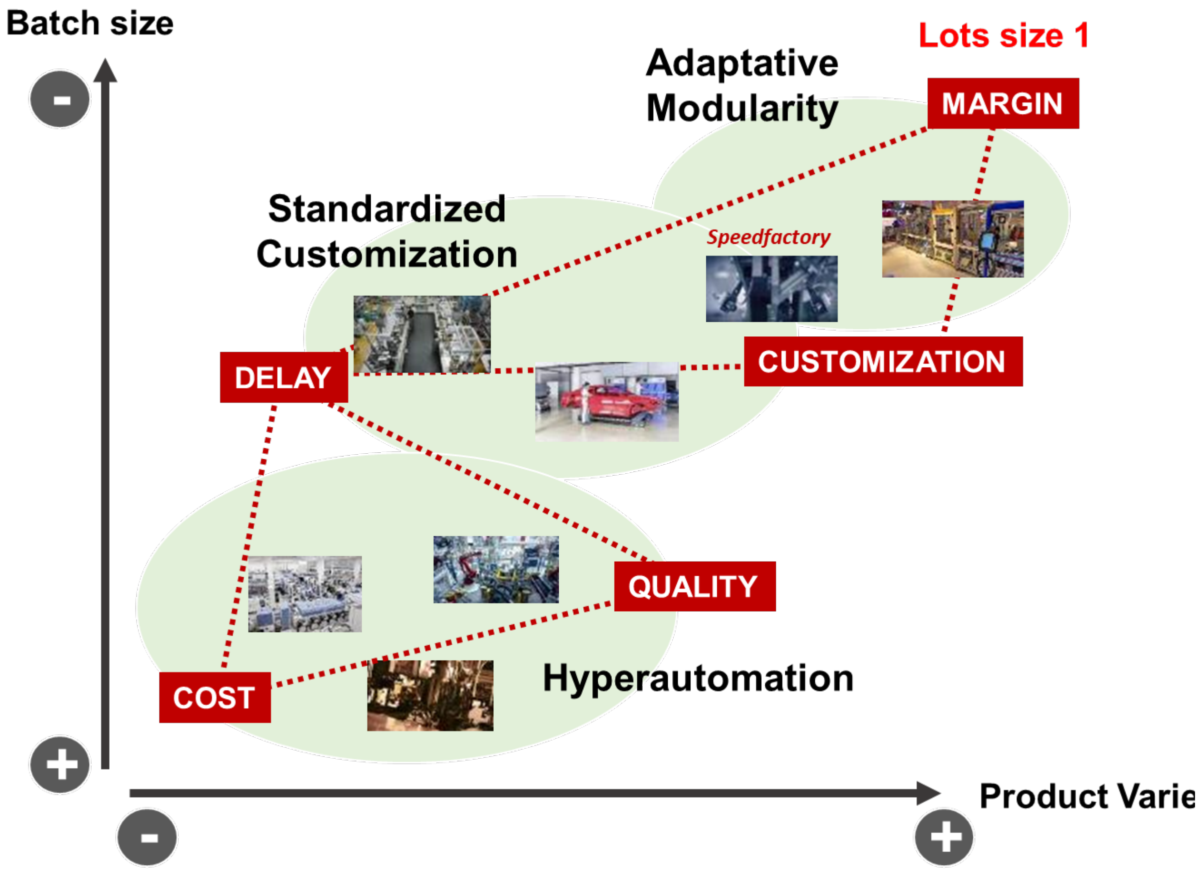
11 RFID for “Radio Frequency Identification” is a technology for identifying products and equipment by radio frequency.

Fig. 8 – Industry 4.0's three declinations



Source: Dorothée Kohler & Jean-Daniel Weisz (2021) ©KOHLER C&C.

Traditionally highly automated industries such as electronics and automotive are representative of this model. The Amberg plant in Bavaria, dedicated to the manufacture of Simatic electronic boards for Siemens automation systems, has long been a 4.0 showcase for the brand. The key words here are a scrap rate of a few parts per million and an automation rate close to 75%.

Standardized Differentiation

The second model, standardized differentiation, includes factories that have organized themselves to produce a very large variety of products, often with several million possibilities. The production flow is no longer linear, but broken down into multiple islands or mini-factories.

Fig. 9 – Siemens Amberg Factory

Source: Siemens AG

This system is entirely decentralized and production scheduling is modified in real time. The impact of production hazards is considerably reduced compared to a linear flow and this organization allows for the management of variety in real time according to pre-established manufacturing ranges.

In the Audi pilot plant in Ingolstadt, the car bodies in production are transported on AGVs and assembly operations are carried out in autonomous islands (see Figure 10). The line has no longer to be stopped due to a production incident. The production flow can be reconfigured in real time in line with production contingencies or customer decisions. Up to a late stage of production, the customer can still change a choice of options or variants.

This model can also be found in the food industry, where it is no longer a question of producing batches of a given product, but of manufacturing it on demand according to the consumer's wishes. For example, Siemens was presenting a demonstrator at the 2018 Hannover Fair that can make a fruit yogurt with a composition based on customer demand. Beyond its ability to meet customization demand, this model avoids making large quantities of a similar product that may not all be sold.

Fig. 10 – The Audi factory in Ingolstadt

Source: Wewo technomotion

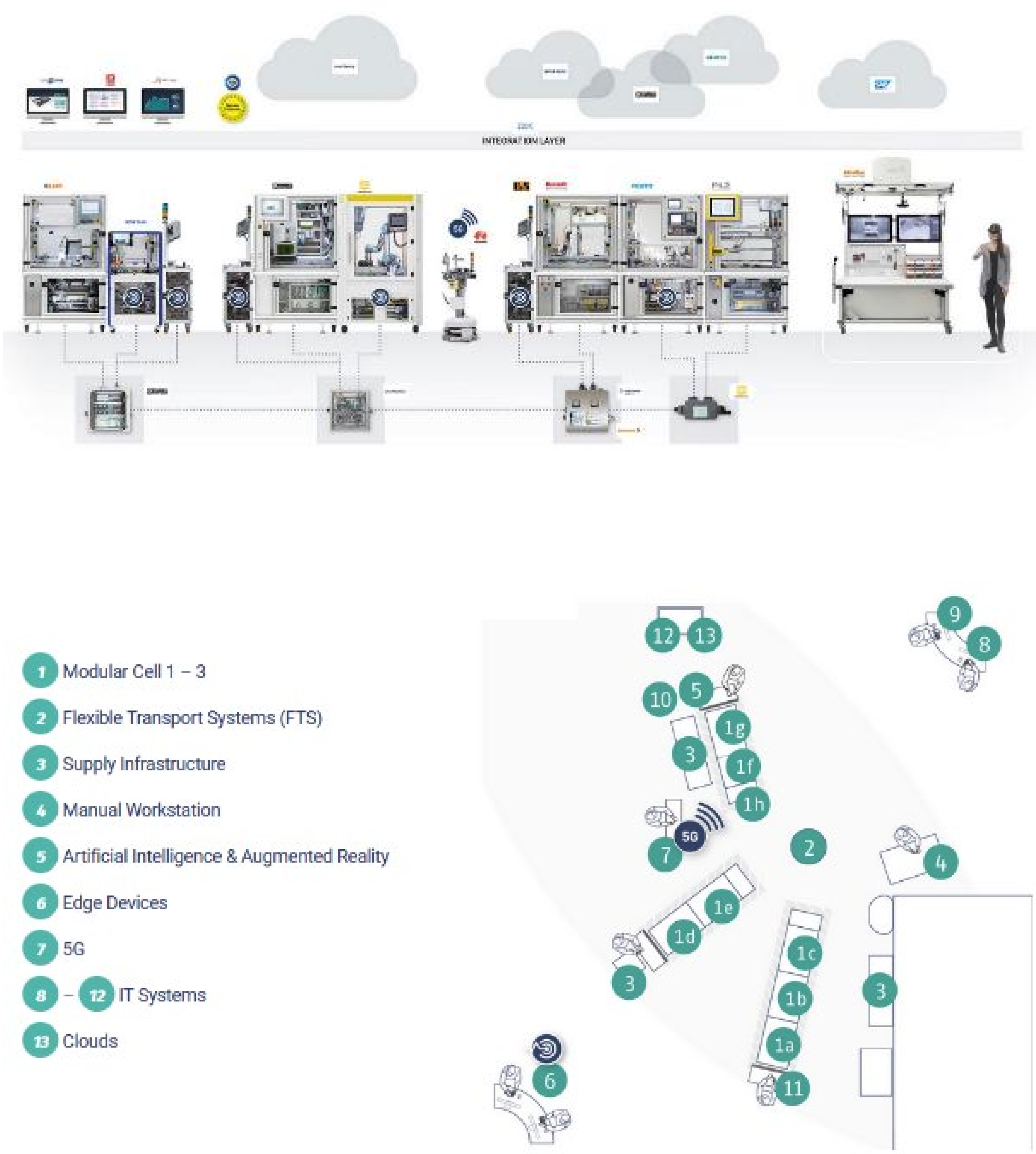
Adaptive Modularity

The third model, modularized and autonomous manufacturing, is the grail of Industry 4.0, so to speak. In this model, the manufacturing line is not a prerequisite. The production system will organize itself autonomously to customize the product.

In practice, this utopia of the customized unit series designed with the customer remains in the realm of fab labs and demonstrators, such as the Smart Factory of the German Research Institute for Artificial Intelligence in Kaiserslautern (DFKI).

This demonstrator is the result of the assembly of different technologies with the support of research institutes. It consists of modular, plug-and-work installations assembled from standard components.

Fig. 11 – The Smart Factory KL Demonstrator



Source: Smartfactory KL

With nearly 45 partners from industry and research gathered in the project, this demonstrator gathers 2 production islands and a manual workstation linked by a flexible transport system[12]. A product is manufactured by passing successively over modules from different manufacturers: Bosch Rexroth, IBM, Cisco, Festo, Pilz,

12 More information on the demonstrator's website: https://smartfactory.de/en/industrie-4-0-plant/industrie-4-0-plant-2018/.

Phoenix Contact, Harting, Lappkabel... (see figure 11). These modules are all capable of decrypting in real time the information transmitted by the product from an RFID chip containing the specifics of its manufacture and the calibration of the machines[13].

The demonstrators are not spectacular in themselves, and anyone can take pictures. The spectacular part lies in the interoperability of these machines from different manufacturers, and upstream in the collective experimentation of the product's manufacture in order to combine these often competing expertises. It is therefore not what is produced that is spectacular but the learning of a collective process of conception and fabrication.

What strikes the visitor about these demonstrators is the number of players involved, both in industry and in research. "Experimenting together" is a motto that has been translated into concrete action in the field. The demonstrator highlights the sharing of resources among different companies of different sizes. The juxtaposition of company logos is proof that it has been possible to break away from the innovation process itself. The idea is to create Industry 4.0 champions and to communicate to the outside world the ability to create collective leadership. Moreover, the demonstrator is also intended to swarm and produce effective means of replication[14].

The objective of the Smart Factory KL demonstrator is twofold: to illustrate the feasibility of a modular production system and to show the interconnection and interoperability capacity of systems proposed by different solution providers.

In the end, these three declinations of Industry 4.0 - hyperautomation, standardized differentiation, and adaptive modularity - are less to be considered as stages of development that must be traversed to reach the horizon of unitary production than as models that can coexist within the same industrial scheme of a sector or within the same industrial group. Unit production is often the last stage of a customer-oriented value chain, and the question then arises of how to reconfigure this chain according to downstream customization needs.

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13 Dorothée Kohler & Jean-Daniel Weisz, « Décrypter la naissance de l'Industrie 4.0 en Allemagne et ses enjeux », in Wolfgang Asholt, Mireille Calle-Gruber, Edith Heurgon & Patricia Oster-Stierle (dir.), *Europe en mouvement. Nouveaux regards,* Paris, Hermann Editeurs, 2018, pp.193-212.

14 Dorothée Kohler & Jean-Daniel Weisz, *ibid.*, pp.206-208.

Moving from the Value Chain to the Constellation

CHAPTER 4

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Chapter 4 - Moving from the Value Chain to the Constellation

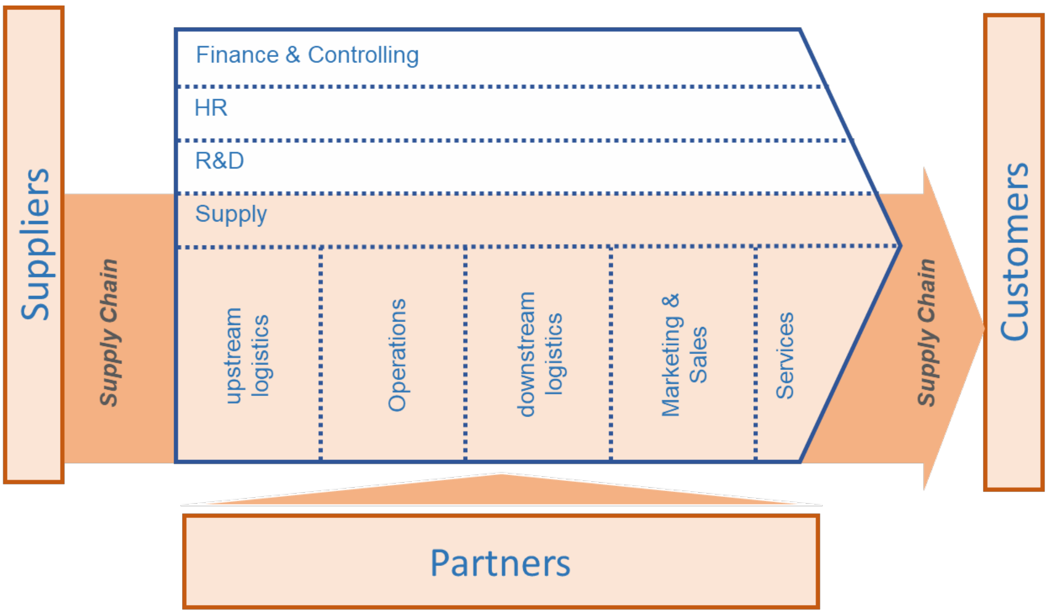
Whichever Industry 4.0 configuration is chosen, it profoundly transforms the company's value chain. Digital continuity abolishes the silos between the company's functions, between the office and the workshop.

A Radical Transformation of the Company's Value Chain

Michael Porter has represented this value chain as a linear, ordered continuum, separating production and support activities, with suppliers and customers at each end (see Figure 12).

In an analytical world where hierarchical order prevails, work follows standardized processes and procedures. Objectives are broken down into tasks to allow each component to be controlled and monitored. Attention to budgets, compliance with processes and procedures consumes much of the time. Continuous improvement and best practice rituals allow for progress. Quality, cost and time indicators are used to measure progress.

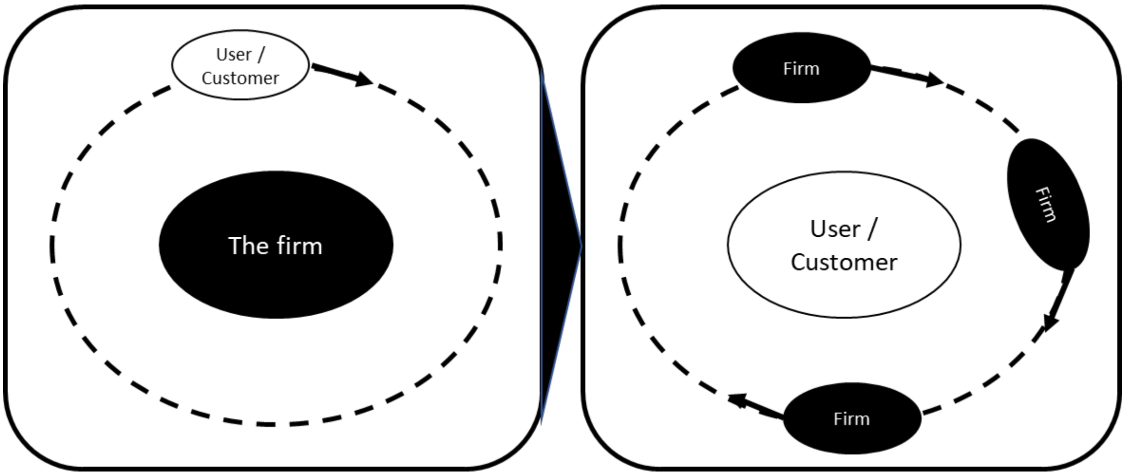
Fig. 12: Yesterday's Value Chain



Source: Dorothée Kohler, Jean-Daniel Weisz, *Industrie 4.0, les défis de la transformation numérique du modèle industriel allemand*, Paris, La Documentation française, 2016, p.42.

In this configuration, the industrialist considers themselves to be the epicenter of the ecosystem and the customers gravitate around them, as Steve Denning illustrates (see Figure 13). New technologies and the acceleration of change and innovation are shaking up this established order. Steve Denning points to the Copernican revolution that is taking place by reversing the power relationship between manufacturers and customers. From now on, manufacturers gravitate around customers and their trajectory will depend on their ability to create value for customers.

Fig. 13: The Copernican Revolution in Management



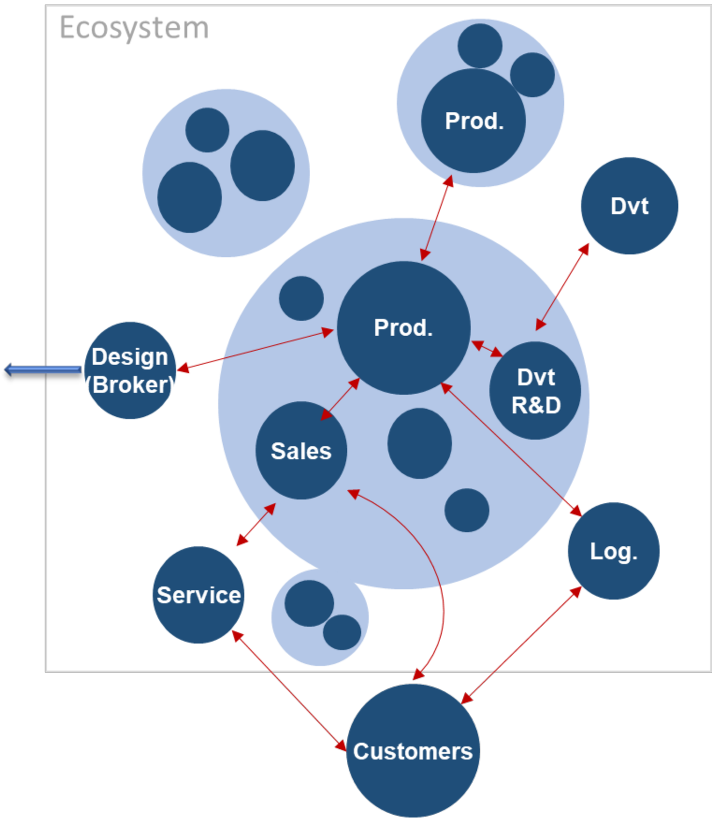
Source: Steve Denning, « What 21st Century Management Looks Like », *Forbes,* September 20, 2020.

The change in the economic landscape brought about by the digital revolution makes this organization rigid and compartmentalized between support functions and manufacturing operations, out of step and inoperative in an environment where scalability, reactivity and adaptability of the value chain will be sought after.

We are moving from a model where the company is self-centered on its technical know-how and where orders are given to each department by the manager to a model where the customers become the “boss” of the organization. This game change implies a “reset” of the value chain, its structure and its functioning, but also of the managerial culture.

One of the fathers of Industry 4.0 in Germany, Henning Kagermann, proposes to represent the organization in independent entities, like archipelagos, linked together (see figure 14). From now on, it is the quality of the interaction that creates value. The efficiency of interactions requires short circuits. Some lines of business self-manage, interacting directly with the customer, experimenting in particular with methods inspired by design thinking. There is a collective and common framing of the problem to be dealt with in relation to the context, then a diagnostic phase is carried out to understand what works well and what doesn't. Based on observation, the first experiments are conducted to identify the real issues and to design the most appropriate solution. The teams learn from the client and learn to move in a complex ecosystem by testing different problem-solving scenarios. It is no longer a matter of executing to meet a set of specifications defined within the framework of a strategy extrapolated from a duplication of the past.

Fig. 14: The Breakdown of the Value Chain into Archipelagos



Source: Henning Kagermann, *Impuls – Zukunftstbild Industrie 4.0,* Bitkom Kick-Off „Industrie 4.0", Berlin, January 9, 2013.

The architecture of the company is disintegrating, expanding and articulating archipelagos focused on specific lines of business: manufacturing, development and innovation or logistics. The cyber-physical system does not stop at the factory's borders. It interconnects with logistics flow monitoring systems and penetrates the factories of suppliers and contractors. The customer can thus follow in real time the progress of the production of parts intended for them at their supplier's. The supplier's company becomes "transparent". Volkswagen's diesel engine assembly plant, for example, has real-time information about the manufacture of injectors at Bosch, the quality level, the stock level. The manufacturer can monitor what is being manufactured by their suppliers, and is virtually present in the factory, and therefore in a position of control.

It is certain that a century-old company whose life is punctuated and absorbed by budgetary exercises, the launch of cost-cutting campaigns, repeated waves of outsourcing of functions considered not to be part of the core business, with reduced innovation, low design intensity, ad hoc competitive intelligence and a distended customer relationship, will be strongly threatened in this new environment. On the other hand, the company's performance will increasingly depend on the quality of interactions with the different customer communities, on the ability to capture market changes in real time, to anticipate disruptive factors, to redefine the positioning of its business model and, for the employees, to redefine the conditions for appropriating new learning and new skills. Hierarchies hinder cooperation by controlling the flow of information and knowledge. As Yaneer Bar-Yam explains in *Complexity Rising*[15], hierarchies become less useful as complexity increases. Cooperation creates the lateral connections necessary for successful work in a complex environment.

Learning to Cooperate as a Factor of Competitiveness

The world of 4.0 is first and foremost made up of connections. Beyond the silos, it is in the interstices between functions, between scopes of application, between sectors that new value is created. These interstices give rise to hybridization between industrial sectors, such as between health and textiles, between mechanical engineering and information technology, or between information technology and agriculture. Alliances are created, hijacking the value chain and leading to skidding off outside the strict perimeter of the industry.

For example, the Audi plant in Neckarsulm produces the Audi A6. Once the car body has been painted, the car doors are shipped 5 kilometers away to Offenau to have all their components and equipment assembled. The doors are returned to the assembly line to be reassembled on the body with which they have been painted. The most surprising thing about this example is not the industrial prowess in terms of flow organization, but rather the partner to whom these industrial operations were entrusted. It is DHL, a logistics operator. The choice of entrusting DHL with the door assembly operations was motivated by two reasons: firstly, its logistical expertise in supplying a large quantity of parts to be assembled, and secondly, its affiliation with the collective tariff agreement for logistics and not for the metal industry. Audi benefits from a differential of between 20 and 25% between the two tariff agreements.

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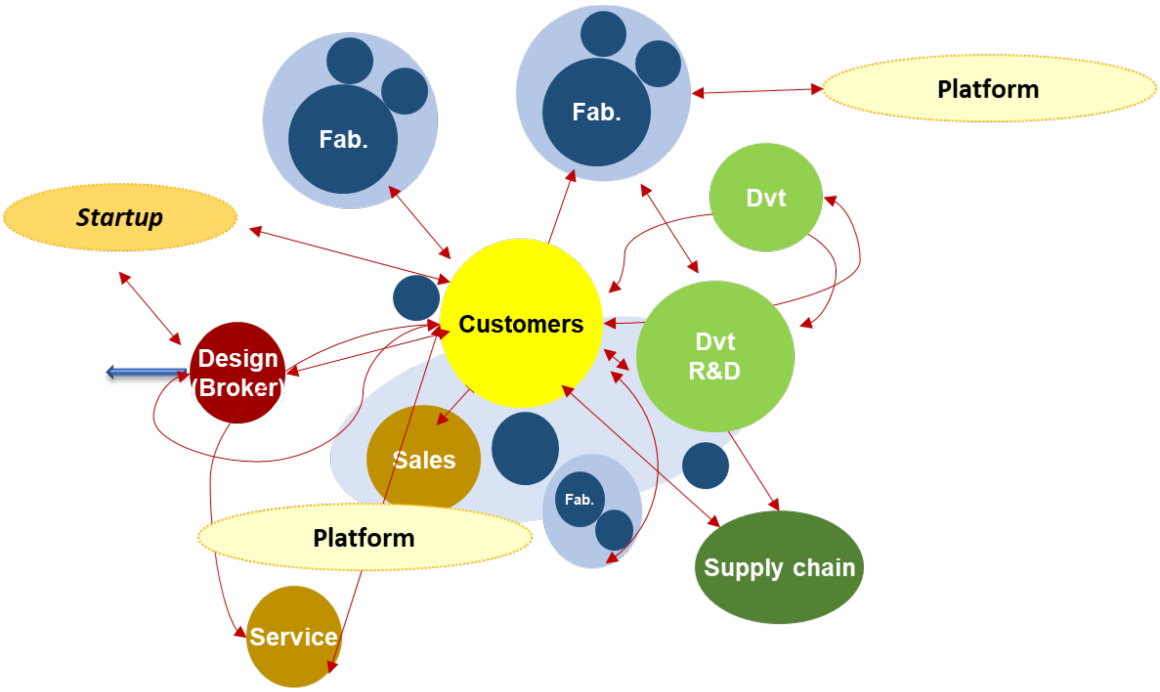
15 Yaneer Bar-Yam, "Complexity Rising: From Human Beings to Human Civilization, a Complexity Profile", *Encyclopedia of Life Support Systems*, 1997.

Fig. 15: The New Value Constellation



Source: Dorothée Kohler, Jean-Daniel Weisz, « Industrie 4.0 comment caractériser cette 4ème révolution industrielle et ses enjeux », *Réalités industrielles, Annales des Mines*, November 2016, p. 56.

Towards Relational Competitiveness

If the pressure on costs has increased with the Covid crisis, with demands for gains of 15 to 20%, the ability to forge alliances and partnerships is playing a growing role. As Pierre Veltz points out, "[large companies] have gradually discovered that the highly routinized Taylorian forms of organization, which are very effective in a stable environment, are proving to be increasingly unsuited to new competitive and technological contexts[16]".

We observe in contractors in certain sectors how parent companies become the heads of the network. They increasingly shed manufacturing and assembly functions, which are now entrusted to subcontractors, in order to concentrate on command functions,

16 Pierre Veltz, *La Société hyper-industrielle. Le nouveau capitalisme productif*, Paris, Seuil, 2017; and « La société hyperindustrielle et ses territoires », *Futuribles*, n° 409, November-December 2015, p. 13. Translated by the author.

with an increase in the power of supply chain, innovation, design and marketing functions.

The fourth industrial revolution is reshuffling the cards of competitiveness. Beyond cost and non-price competitiveness, it is contributing to the emergence of a third form of competitiveness that we call relational competitiveness[17]. This relational competitiveness is based on specific modes of interaction between economic players inside and outside the value chain: relationships with the ecosystem, with suppliers, with customer communities, with employees, with development partners (research institutes, universities, start-ups, etc.), and with adjacent sectors. The ability to form alliances, to hybridize with other lines of business, is now considered one of the key components of entrepreneurial performance.

Faced with the costs and time required to internalize competencies in the areas of industrial IT, data processing, design, 3D simulation, and prototyping, many company managers are opting for a new strategy that leads them to seek new allies. For example, Vathauer, a market leader in mechanical, electronic and mechatronic drive systems for conveyor systems, has teamed up with Weidmüller, a much larger company specializing in industrial connectors, to develop an Energy Recovery System (ERS) product that saves up to 78% of energy by recovering and re-injecting the motor's generative energy into the electrical grid. This innovation, cross-fertilization, makes it possible to offer conveyor systems composed of different modules with autonomous propulsion controlled in a totally decentralized manner[18].

German family businesses are already anticipating the rise of this relational competitiveness: according to a study, they estimate that Industry 4.0 will lead them to cooperate with more than 70 new partners within 5 to 10 years[19].

In the It's OWL Cluster[20] in East Westphalia, about 100 companies benefit from the technological spin-offs of projects developed with the support of the laboratories of the University of Applied Sciences Ostwestfalen-Lippe and the University of Paderborn.

It is therefore not the least of the paradoxes of this digital revolution that it imposes a reinforcement of cooperation, of relationships, of human interactions, while digital tools have often been used to eliminate intermediaries. In other words, the disintermediation

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17 Dorothée Kohler, Jean-Daniel Weisz, *Industrie 4.0 – Les défis de la transformation numérique du modèle industriel allemand*, Paris, La Documentation française, 2016, p. 141 and Dorothée Kohler, Jean-Weisz, « La compétitivité relationnelle, enjeu de la révolution numérique », *Les Echos/Le Cercle*, April 5, 2016.

18 Dorothée Kohler, Jean-Daniel Weisz, *ibid.*, p. 97.

19 „Industrie 4.0: Volks- und betriebswirtschaftliche Faktoren für den Standort Deutschland. Eine Studie im Rahmen der Begleitforschung zum Technologieprogramm Autonomik für Industrie 4.0", Berlin, BMWi, March 2015.

20 https://www.its-owl.de/home/.

linked to digitization has as its counterpart the reinforcement of the value of human interactions.

This splitting up of the value chain and this hybridization of sectors poses a powerful challenge to the institutions governing industrial relations and, more generally, to organizations defending collective interests. Behind these technical developments lies a reconfiguration of the distribution of economic power within the sectors. For if tomorrow the contractor is able to track the construction of added value among its tier 1, 2, 3, 4 suppliers, etc., the asymmetry of information will disappear and reduce the room for maneuver of subcontractors. It is even possible to imagine supply chains that will be largely managed by the contractor. This is what Bernard Charlès, CEO of Dassault Systèmes, said after signing a 30-year contract with Boeing to implement its 3DExperience digital platform: "Boeing will control all levels of subcontracting, from the largest to the smallest partners, from end to end... It will be able to impose and control the flow of exchanges between its divisions, with its partners and between its partners... We no longer work according to the subcontracting chain, but rather to the value chain[21]".

Industry 4.0 is therefore not limited to questioning industrial schemes and technology roadmaps. As these examples show, it leads us to rethink each industrial value chain, to define a new interweaving of interactions and to learn how to cooperate. Cooperating means being able to explore paths on the periphery of the company, and knowing how to identify the links that the company can create to help it grow. It also implies getting away from war metaphors (target markets, chains of command, hunting, ...) to share knowledge and experience and not just "work together". To cooperate is to be attentive to the emerging qualities that are born in a collective.

One last emblematic example: the design of the iPhone was only possible because Apple was able to recover and federate research efforts from very different horizons: DARPA (Defense Advanced Research Projects Agency), the Army Research Office, CERN. This example highlights how innovation in this new environment requires great talent to recover, integrate and connect research carried out in the public and private sectors.

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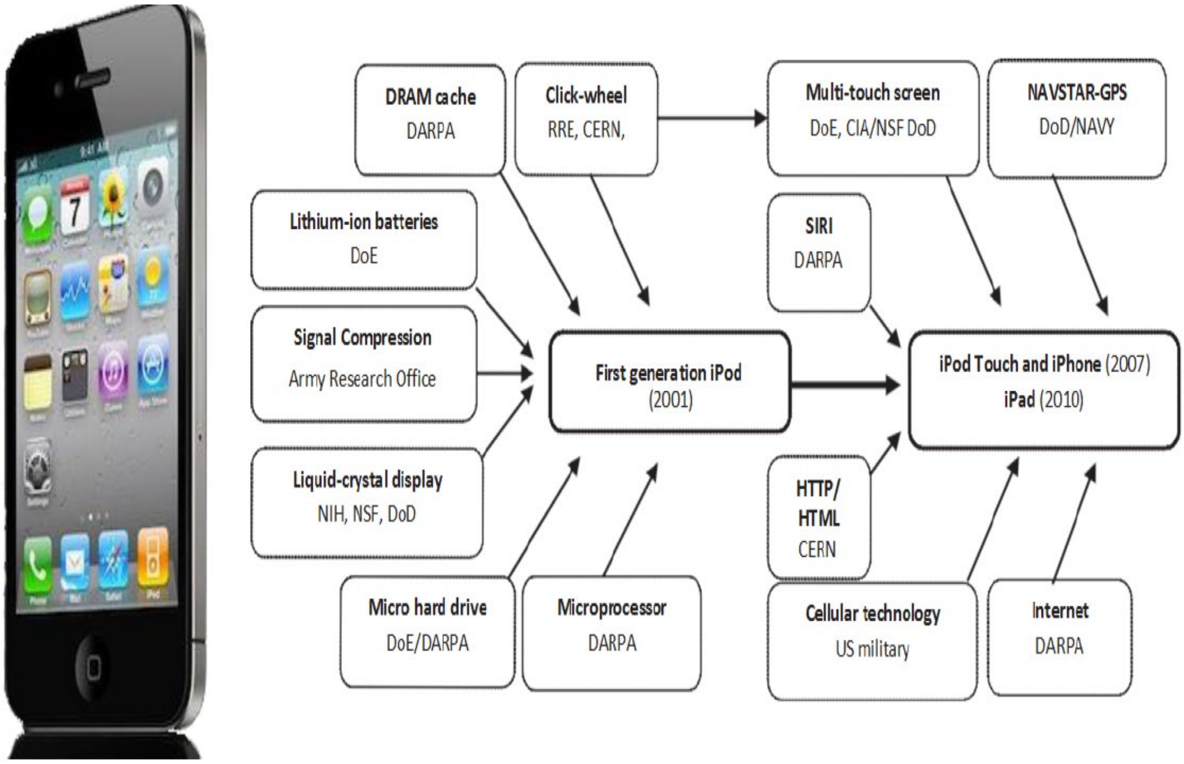
21 « Boeing conclut un contrat de 1 milliard de dollars avec Dassault Systèmes », *Le Monde*, July 25, 2017. Translated by the author.

Fig. 16: What Makes the iPhone so Smart?



Source: Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*, PublicAffairs, U.S., United States, 2015, p.109.

Industry 4.0: a Reconfiguration of Business Models?

CHAPTER 5

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Chapter 5 - Industry 4.0: a Reconfiguration of Business Models?

By claiming to want to produce unit series at the same costs as those of mass production, Industry 4.0 displays an ambition that questions both the company's industrial scheme and its value chain. Digital continuity does not stop at the company's boundaries, but includes the customer downstream and the entire supply chain upstream. By circulating data throughout the value chain, it enables the collection of information on customer usage and the construction of a diversified offer.

Creation of Service-Oriented Industrial Value

Digital continuity offers a vast field for the development of services around the use of products for both B2C and B2B companies[22].

In the B2C world, the development of the economy of use or functionality tends first of all towards a logic of sobriety[23]: fewer cars will be produced since they will be shared among multiple users. But many services can be developed around usage, sometimes more profitable than the sale of industrial goods. In this case, it is in the manufacturer's interest that the product, which supports the service, last as long as possible and can be upgraded.

In the world of industrial equipment, for many years now, manufacturers have been making most of their margins not on the sale of machines, but on related services: maintenance, spare parts, optimization, upgrades, etc. Some are developing on-demand service offers, like Jungheinrich, which offers Activ contracts with four levels of service for its forklifts (see Figure 17), reducing the risk and cost of machine downtime[24]. These services are organized around a forklift truck fleet management application called ISM online[25].

Connectivity now enables real-time monitoring of equipment health and usage, opening the way to new services such as predictive maintenance. However, these services are not only a mere enrichment of the offer: they deeply modify the business

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22 B2C (Business to Customer) refers to companies that sell their products to the final consumer; B2B (Business to Business) refers to companies that sell components, equipment, etc. to other industrial companies.

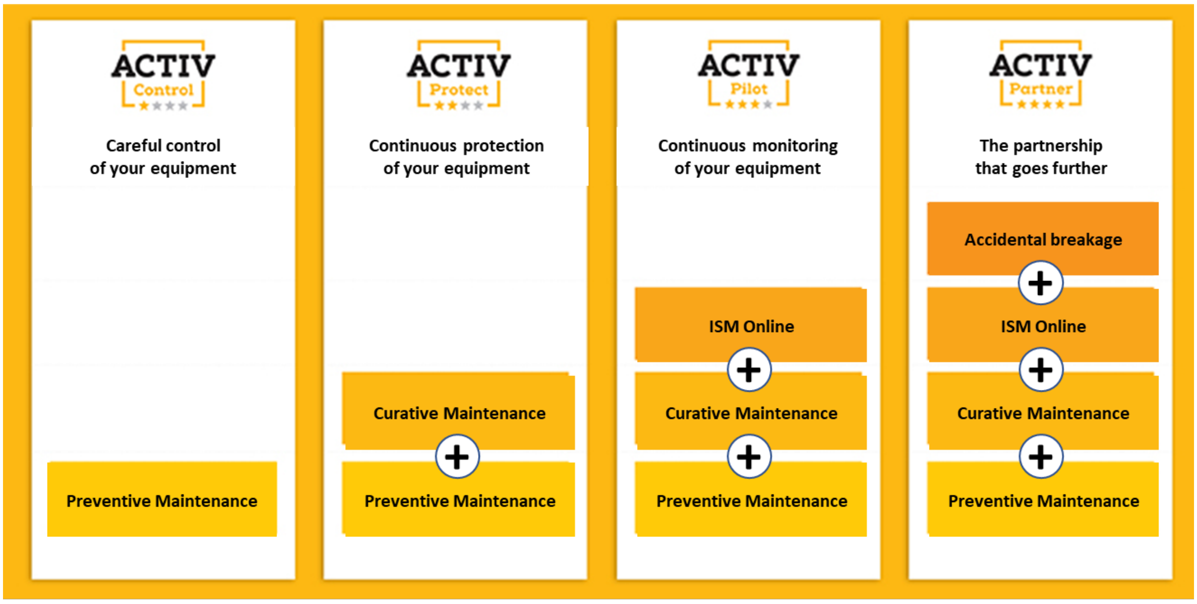
23 Pierre Veltz, *L'économie désirable, Sortir du monde thermo-fossile*, Paris, Seuil, 2021, p.39.

24 Dorothée Kohler, Jean-Daniel Weisz, *Der Deutsche Mittelstand in Frankreich*, Wiesbaden, 2019, p. 141.

25 ISM Online is a secure application that provides an overview of the forklift fleet at all sites with commercial and technical data on the forklifts and tracking of their operating costs, even if they are not from Jungheinrich.

model of companies. Indeed, selling hours of machine usage or a number of parts based on guaranteed performance rather than a machine installed in a building, selling hours of workshop lighting rather than industrial lighting equipment, selling kilometers traveled rather than tires, all this is a new business, with significant financial and digital implications[26].

Fig. 17: The Service Offer for the Management of a Forklift Fleet



Source: Jungheinrich.

The company must acquire new know-how to offer contracts in which risk management and financial engineering become central.

Industrial Service Platforms: New Offer and New Information Systems Architecture

Meanwhile, these digital-related services offered with the equipment are becoming interoperable with the company's industrial IT system and are gradually encroaching on the territory of company management software.

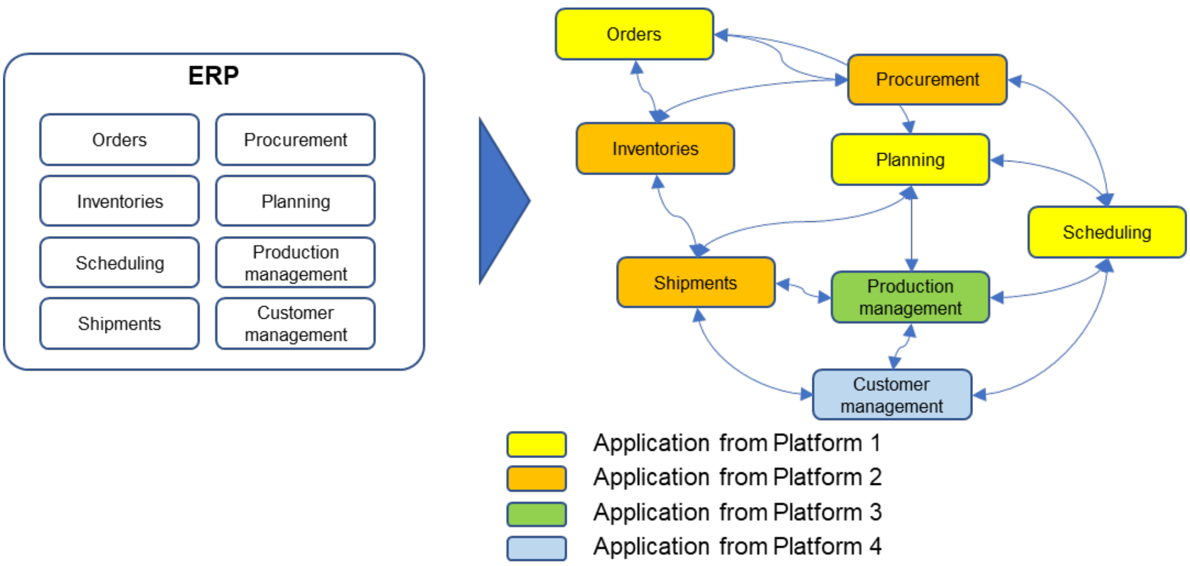
These services are most often grouped together on application platforms that can be dedicated to a single solution provider or opened to multiple companies that offer their software solutions, unlike the enterprise resource planning (ERP) software, which aims

[26] Pierre Veltz, *L'économie désirable, Sortir du monde thermo-fossile*, Paris, Seuil, 2021.

to offer all the solutions a company needs to manage its orders, supplies, inventory, planning and scheduling, production management, etc.

These platforms are based on a modular logic: the company "glues" together softwares from different horizons to meet its specific needs (see figure 18).

Fig. 18: From Integrated ERP to the Multiplication of Modules from Platforms



Source: Dorothée Kohler & Jean-Daniel Weisz (2021) ©KOHLER C&C.

Digital continuity thus allows the emergence of platforms, new infrastructures for the economy[27] to use the terms employed by Henri Verdier and Nicolas Colin, eventhough this theme is rarely addressed. A digital platform is an interface that brings together multiple players and facilitates their interactions. Less well known than e-commerce platforms, industrial service platforms have become a crucial issue for economic players.

In Industry 4.0, industrial equipment is intended to be managed in real time by applications and algorithms. At a first level, there are application libraries, comparable to those available on our cell phones. Industrialists can select the most useful ones, for example a computer-assisted maintenance management application. They can also develop these applications for their own needs and then offer them for sale on these platforms. These applications are adapted to the specificity of each industrial activity.

27 Nicolas Colin, Henri Verdier, *L'âge de la multitude: Entreprendre et gouverner après la révolution numérique*, Paris, Armand Colin, 2012, p. 159.

At a second level, there is the infrastructure that allows these applications to function. Unlike our smartphones, these applications are not downloaded to run on a local microprocessor. They are located in the cloud, i.e. in a storage space and with outsourced computing power. The know-how of giants like Amazon Web Services or Microsoft Azure is to offer computing power capable of keeping up with rapidly changing demand. This is what is known as “scalability”, the real-time resizing of the system according to the volume of demand and the ability to support the increase in power of applications, whose number of users is growing exponentially, without bugs and without service disruption. The American Internet giants excel in this “industrialization” of IT services and have become unavoidable.

If the 2nd and 3rd industrial revolutions took advantage of the scale effects of assembly line production and automation, the 4th industrial revolution benefits from the real-time scalability of these platforms.

The Industrial Services Platform, the New Infrastructure of the Production System

For a manufacturer, the question of the platform arises at two levels: that of the application services it offers to its customers and that of the services it uses itself to ensure its production. Traditionally reserved for B2C manufacturers, platforms have now also become a key issue for B2B manufacturers.

The example of Trumpf is illustrative. In the early 2010s, this manufacturer of laser cutting machines took part in a project initiated by the German Federal Ministry of Education and Research, entitled “Marketplace for Technology Data”, which led to the creation of an industrial services platform called Axoom. It is a library of industrial applications that company managers can use to meet their needs: order management, production monitoring, customer relationship management, etc. A start-up was specially created to build this infrastructure with the support of other industrial companies such as Zeiss (optics) and Linde (industrial gases).

In doing so, Trumpf is stepping outside the boundaries of its business model, since this platform is not intended to offer only applications for managing its own brand of machines, and it encroaches on the scope of MES (Manufacturing Execution System) and ERP (Enterprise Resource Planning) systems[28] of traditional IT solution providers.

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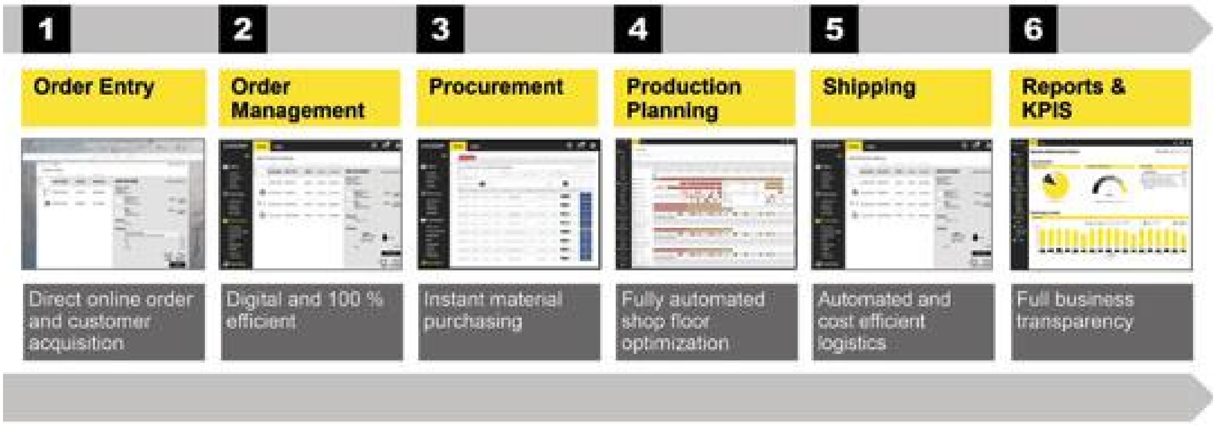
28 An MES (Manufacturing Execution System) is a production management software that interfaces with the ERP and SCADA type supervision systems.

Fig. 19: The Scope of Trumpf's Axoom Platform



Source: Trumpf

If a company whose vocation is primarily industrial can position itself as an Information and Communication Technologies (ICT) player offering application libraries to its customers, it is also a client of these applications for the digitization of its production processes. It is a two-sided system that blurs the boundary between the internal and the external business environment.

Platforms: an Independence Issue for the Industry

Digital solution offers are multiplying. Will industrial SMEs be able to learn to work with different systems to manage their production, their transactions, their customer relations, the design of their products and the industrialization of their processes when they are already having difficulty mastering their ERPs?

This question points to the company's ability to generate learning processes, particularly in the field of IT, when it was previously focused on manufacturing.

Industry 4.0 implies that all systems are interoperable and that all software building blocks communicate with each other in real time. This need for interoperability tilts the balance in favor of publishers with integrated solutions.

These publishers being mostly large (SAP, Bosch, Siemens, Schneider Electric), the managers of smaller or even medium-size companies may be reluctant to entrust them with the digitalization of their production chain. They would then become very dependent on these players, their operational efficiency being conditioned by the performance of their digital infrastructure and the downloading of the most recent versions of digital tools. This digitization also raises a number of questions: who owns the company's data in transit or stored with the digital service provider? What about intellectual property? Who has access to the customer's usage data, which enables the calibration of new services? What is the remuneration model of the digital service provider and to what extent is it possible to change providers? How to manage responsibility in case of incidents or crisis[29]?

In this field, where the largest equipment manufacturers are currently positioning themselves, alternative offers are appearing, such as that of Axoom, mentioned above, or the Adamos platform, which brings together several well-known manufacturers (DMG Mori, Dürr, Zeiss). They specifically target family businesses while seeking to capture the value of these new digital services.

Alongside these industrial service platforms developed by well-known players, a number of applications are emerging that themselves have the ambition to act as platforms. One example among many is a start-up called Mobility Work, which has created the first social network for machines to facilitate industrial maintenance management. This application not only provides access to computer-based maintenance management tools, but also allows users to share data about their machines (energy consumption, fluids, maintenance intervals, etc.) with other users of the same equipment and thus optimize their use[30].

Mobility Work's ambition is to position itself as a platform on the maintenance market, and thus disintermediate the relationship between industrial equipment manufacturers and their customers. The former are seeing their margins shrink and think they can make up for it on maintenance services and spare parts sales. But what will happen if the data collected by a new entrant like this start-up allows for predictive maintenance, and if it positions itself as an intermediary between the manufacturer and its service providers? In the future, the application could directly offer the supply of a part according to its availability in the world, like Amazon, or sell the intervention of a freelance maintenance technician registered on its platform[31].

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29 Extract from the article written by Dorothée Kohler, Jean-Daniel Weisz, « Industrie 4.0, une révolution industrielle et sociétale », *Futuribles* n° 424, May-June 2018, p.61.

30 Dorothée Kohler, Jean-Daniel Weisz,*op.cit.,* p.62.

31 Dorothée Kohler, Jean-Daniel Weisz, *Ibid*., p.62.

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Avec le soutien de :

W.IN.G

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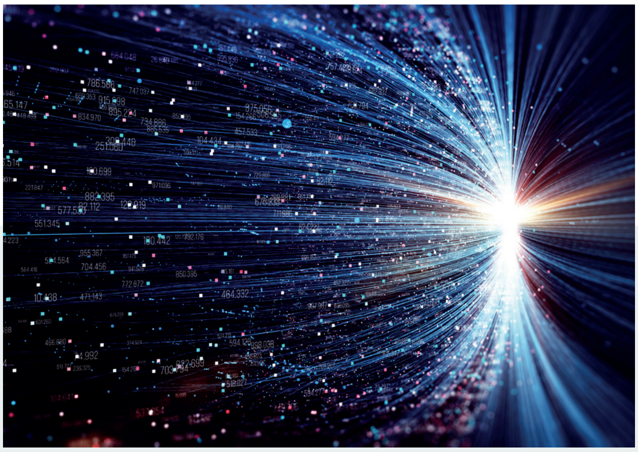

▶ QUI SOMMES-NOUS

W.IN.G by Digital Wallonia, c'est un fonds d'investissement dédié au financement en capital des start up Tech et Digitale en Wallonie.

▶ NOS MOYENS

Capitalisé à hauteur de 60 millions d'euros, W.IN.G by Digital Wallonia investit dans les start-up aux différents stades de leur évolution : de la phase de « pré-amorçage » (finançable dès 50 000 euros) à la « Série A » (finançable jusqu'à 2,5 millions d'euros).

▶ NOTRE APPROCHE

W.IN.G, est un investisseur professionnel et bienveillant. Nous challengeons dès le départ les start-up, entrepreneurs et porteurs de projets et poursuivons ce rôle de « sparring-partner », à la fois critique et engageant, au sein comme en dehors du Conseil d'administration.

Disponible, réactif et « supportive », notre comité d'experts vous garantit un processus d'investissement efficace et diligent.

▶ NOTRE ÉQUIPE

L'équipe derrière W.IN.G, ce sont 4 Investment Managers aux profils complémentaires et aux compétences variées ; mais aussi une Operating Team qui offre aux start-up une première intervention gratuite dans les domaines les plus pertinents (growth marketing, RH, vente, stratégie, finance).

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Par le biais de la Société Régionale d'Investissement de Wallonie (SRIW), W.IN.G bénéficie d'un accès à un réseau étendu de partenaires, d'entreprises et de fonds spécialisés.

▶ NOS RÉFÉRENCES

En quatre ans à peine, le fonds d'investissement W.IN.G by Digital Wallonia a déjà contribué à l'émergence de nombreuses startups reconnues au niveau national comme à l'international : **E-Peas**, **OnComfort**, **Mozzeno**, **ListMinut**, **WooClap**, **Neveo**, **Verbolia**, etc.

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