Industry 4.0: Navigating Pathways Toward Smart Manufacturing and Services

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1 Eroding Margins in Manufacturing Industries

The struggle of manufacturers in developed economies is real. The rise of global competitors operating at a lower cost, trade restrictions caused by the US-China dispute and local content requirements, and eroding margins in many product businesses all exert downward pressure on industrial firms' profitability. This is further exacerbated by the short- and long-term economic consequences of the COVID-19 pandemic. Many industries have seen equipment sales collapse, plants temporarily closing, and global value chains coming to a halt. Subsequently, some manufacturers are facing severe liquidity issues that endanger business continuity in the short term. The long-term consequences are substantial too. One lesson manufacturers learned is that value chains need to become more resilient to external shocks. For this to happen, global footprints need to be reevaluated. This need for change trickles down to operations. Production processes need to become more flexible to adjust for short-term changes in demand, and customer support has to be ensured even when travel restrictions apply.

These recent developments point toward the increased use of digital technologies in operations. This trend is not entirely new. Since 2010, political

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programs to drive digitalization in manufacturing have flourished under different names, such as "Industry 4.0" in Germany or "Smart Manufacturing" in the USA (Osterrieder et al. 2020). Amidst the abundance of interpretations (Benninghaus and Richard 2016), this chapter builds on the initial definition of Industry 4.0 as the "technical integration of cyber-physical systems in manufacturing and logistics, as well as the application of the Internet of Things (IoT) and Services in industrial processes" (Kagermann et al. 2013, 18, own translation). What has changed, however, is the urgency and speed of implementation. The COVID-19 pandemic has additionally served as a catalyst for digital transformation, where 3D printing, big data and artificial intelligence (AI), drones, robotics, and IoT were swiftly deployed to respond to the health and economic crisis, thereby spurring the mainstreaming of Industry 4.0 technologies in consumer and business contexts (United Nations Industrial Development Organisation 2020).

Figure 1 provides an overview of the diversity of application fields, technologies, and objectives related to Industry 4.0. Industry 4.0 implementation patterns can be distinguished in front-end application fields and base technologies. The front-end encompasses the fields of manufacturing, smart connected products, the new way of working, and the digitalized up- and downstream supply chain.

Although there are differences in the exact scope and focus, all concepts promote modern IT technologies and the usage of data in manufacturing

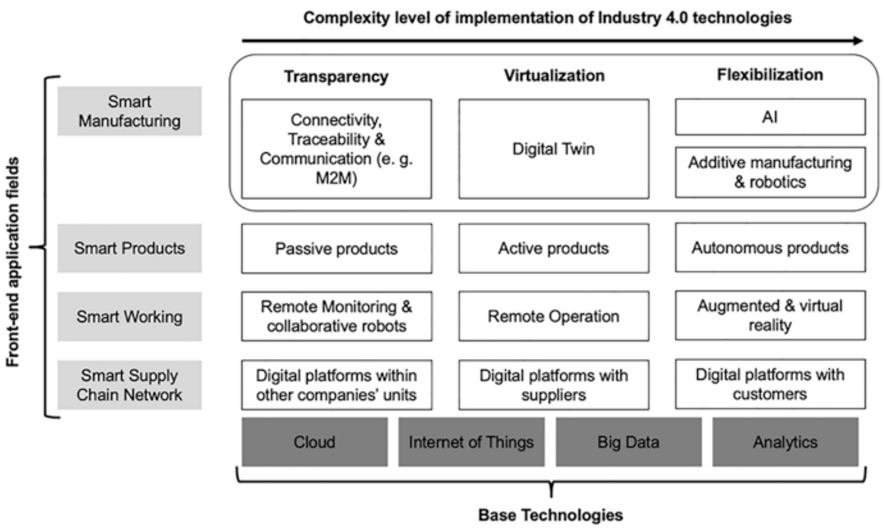

Fig. 1 General Industry 4.0 implementation framework, Frank et al. (2019)

(Thoben et al. 2017). Four key technologies for Industry 4.0 or smart manufacturing have been identified: cloud, big data, Internet of Things, and analytics. These are also understood as "base technologies" (Frank et al. 2019) because they serve as a foundation for different front-end application fields. The further the manufacturing company moves toward automation, flexibilization, and autonomy, the higher the complexity of implementation the company will face. Uncertainties about the success of implementation, in terms of innovation and profitability, determine the characteristics of the complexity of this transformation. To navigate through this jungle of opportunities, different dominant implementation patterns have been identified. We analyzed 27 generic smart manufacturing use cases in depth to develop the framework for the transformation journey toward smart manufacturing.

Digital technologies fuel two growth engines of manufacturing firms. First and foremost comes the stabilization and improvement of the core business along the iron triangle of cost, quality, and flexibility. For instance, in high-volume production, a sensor-based in-line quality inspection may close control loops, reducing the need for manual labor without compromising quality (Schmitz et al. 2019). Similarly, remote service operations can harness augmented reality and advanced analytics to assist customers in a faster, more targeted, and cost-efficient way.

Second, digital technologies allow manufacturers to exit their comfort zone and venture into new business opportunities. Consider *KUKA*'s "SmartFactory as a Service" business model. The robot manufacturer has teamed up with IT consultancy *MHP* and reinsurer *Munich Re* to offer production capacities "as-a-service," leveraging their respective core competencies of software integration, automation technology, and risk management (KUKA 2018). This is a bold move for *KUKA*, as their domain of activity shifts from selling equipment to taking over manufacturing operations for third parties and managing revenue and operational risks.

However, to realize such potential, firms need to navigate the labyrinth of digitalization, which boils down to three main questions. First, *why start?* Executives may feel a sense of urgency to "digitalize," putting pressure on the organization to launch digitalization projects but neglecting the need for strategic alignment. Digitalization for its own sake is unlikely to yield sustainable returns. Instead, top management needs to define a set of quantified objectives guiding all digitalization initiatives. Second, *where to start?* The number of digital technologies and potential applications within and beyond the firm can be overwhelming. Decision-makers need a compass directing them to potential use cases tailored to the firm-specific situation. Third, *how to proceed*? Regardless of the number of use cases selected for implementation, the right timing and sequencing of digitalization initiatives are essential. Focusing on a few promising opportunities avoids spreading organizational resources on too many digitalization fronts, which is likely to be costly and ineffective.

This chapter advances six steps to successfully navigate the transformation toward smart manufacturing and services:

1. Modernize core operational processes.
2. Clarify digitalization objectives.
3. Identify and select use cases.
4. Exploit efficiency potentials.
5. Adapt the organization.
6. Build new business models.

The pathways will be unfolded within the next section.

2 Pathways Toward Smart Manufacturing and Services

2.1 Modernize Core Operational Processes

Some basic homework needs to be done before going full throttle on digitalization. Catching up on state-of-the-art lean practices is fundamental to ensure transparency, robustness, and standardization of manufacturing processes. Survey data shows that industrial managers expect lean and digitalization to co-exist and mutually reinforce each other going forward (Benninghaus and Richard 2016). The complementarity of both is evident: high-quality data facilitates the identification of waste, while streamlined processes facilitate the integration of digital solutions in manufacturing (Lorenz et al. 2019).

Moreover, the eternal search for continuous improvement should be ingrained in the DNA of any organization embarking on the digitalization journey. Our work with companies suggests that digitalization initiatives often reveal archaic and inefficient operational processes that require serious revamp *before* introducing additional digital tools. Such routines often exist for historical reasons so that nobody in the active workforce questions them. They are difficult to break and thus reveal a lack of continuous improvement in an organization's culture, which is essential to build.

Consider the case of a global pharmaceutical company. After duplicating the syringe-filling process to a second site, quality problems emerged. An unusually high rate of cracked syringes led to costly product returns.

Subsequent in-depth analysis revealed similar problems that had occurred in the production ramp-up in the first site. However, because no “lessons learned” session was conducted when transferring the product to the second site, similar mistakes were repeated. Integrating systematic knowledge exchange in transfer projects was, therefore, imperative. Such measures can be effective before committing additional resources to digitalization.

2.2 Clarify Digitalization Objectives

Digitalization can change industry rules. Most notably, new entrants may be able to capture a growing share of profit pools. Think about *Microsoft*, who becomes increasingly interlocked in the value chain of manufacturing. The Azure Internet-of-Things cloud stores data from production processes to customer interaction. The augmented reality glasses HoloLens can be used to guide assembly but also remote repair operations. While tech companies can assist manufacturers in ramping up digitalization, they also pose a significant competitive threat, as they have the potential to substitute highly profitable activities, particularly in field interventions.

Consequently, some advisers promote a digitalization strategy at the corporate level. We view it in a slightly more nuanced way. Certainly, digitalization needs to be at the top of the executives’ agenda. A critical assessment of how digitalization might change a firm’s competitive environment and operating model is crucial. To us, however, digitalization is not an objective in itself. Instead, we see digitalization as an enabler for the corporate strategy, as a tool to achieve a set of superordinate objectives.

At the highest level of abstraction, executives are faced with the choice between exploration and exploitation. Digitalization can address both fundamental profit levers.

First, digitalization permits an increase in efficiency for current operations, thereby unlocking cost-saving opportunities. Second, manufacturers may tap on new revenue streams enabled by digital technologies, either by selling more of the same or by introducing entirely new offerings. Both tracks of exploitation and exploration can be explored simultaneously or subsequently, as we will discuss in more detail later.

Picking between either revenue or cost objectives of digitalization is not easy. In our work with industrial firms, we have requested executives to choose a side. While companies will often attempt to reach both objectives, an initial choice of direction is essential to prioritize between the plentitude of potential digital activities in a typical mid-sized manufacturer. The same applies when the starting point for digitalization is still unclear, as the next section argues.

2.3 Identify and Select Use Cases

The implementation is not straightforward because of diverse uncertainties, different circumstances, and diverse initial starting points (e.g. different automation levels). The questions where to start and on which use cases to focus on should be linked to the strategic and operational targets the company wants to address. This is why the first step should be the specification of the competitive priorities (quality, costs, speed, etc.) and the definition of their relative importance. Next comes the identification of application fields where the identified competitive priorities can be best supported. Based on that, the relevant use cases can be derived.

The selection of relevant use cases can be oriented along with the typical tasks to perform in a factory (planning, execution, and support). The framework (see Fig. 2) of existing generic smart factory use cases supports this selection process. The generic use case patterns in this framework are built upon a database of more than 500 use cases from practice. It helps companies reflect their own position and identify potential white spots for implementation to achieve higher efficiency levels.

2.4 Exploit Efficiency Potentials

Based on the selected use cases, the process of implementation and testing needs to begin. Many of the use cases, especially use cases that address higher autonomy levels in the factory and are based and depend on data (such as autonomous job scheduling, self-regulating material flows, and predictive maintenance), encompass a higher complexity. It is not foreseeable when and whether at all there will finally come the breakeven. Thus, there is no guarantee for the use case's success and, consequently, no guarantee for any return on investment. The "valley of tears" companies need to go through that considerably longer than in earlier technology investments. This is also why the implementation should not start with the modernization of the IT infrastructure and new sensors for the machine, for instance. This captures too many resources and efforts that do not directly create additional value for the company or customer. The focus in the early stages should be on feasibility testing and impact evaluation.

The procedure in such projects emphasizes a sound process understanding as a critical enabler for achieving sustainable improvements in machine availability and quality. Creating a common process understanding of all involved persons, such as operators, process engineers, and data analysts, is the pivotal

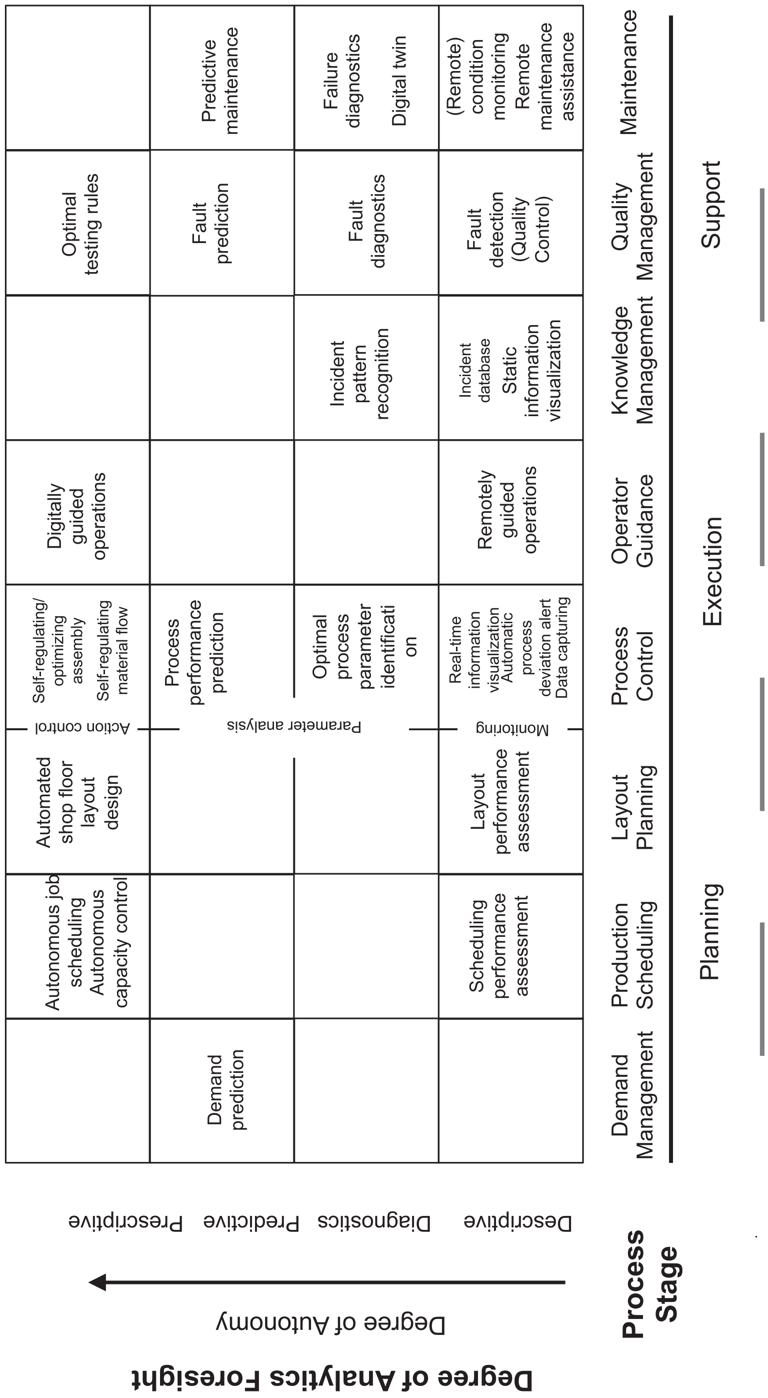

Fig. 2 Use case framework 27 generic use cases, Classen et al. (2018)

starting point in the journey of data-based predictive maintenance. Furthermore, stakeholders of the initiative need to assess the capability of the machine and supporting IT infrastructure to measure, collect, and make available relevant data. Only by thoroughly understanding the process and the kind of available data, plausible and well-founded hypotheses on quality issues and breakdowns can be derived and tested statistically. Without establishing process understanding first, people tend to jump to premature conclusions and derive solutions that do not address the real problem. Deriving irrelevant assumptions based on an inadequate perception of the process leads to a waste of resources, especially as the data-gathering process is a highly time-consuming and, therefore, expensive activity. Consequently, one needs to ensure to ask the right questions before deciding which data should be collected.

Furthermore, digital technologies help to tap in on significant improvement potential in service operations backstage, at the line of visibility, and frontstage. Foremost, there is ample room for improving support processes using digital means. In the last years, manufacturers have undertaken substantial efforts to introduce CRM systems for storing data from customer touchpoints. Still, more often than not, data collection is spotty or limited by technical constraints. With knowledge about customers and interventions on their installed base fragmented across the organization, loops from one service mission to another are not closed. Long repair times spent on identifying knowledge sources on a specific incident are rather the norm than the exception in our work with companies.

Moreover, the efficiency potential of digitalizing customer touchpoints seen in consumer markets can also be reaped in business-to-business services. While in their private life, professional buyers increasingly shop for everything from electronics to groceries online, the purchasing experience in their daily work dramatically lags. We worked with an equipment manufacturer on the introduction of a remote service. An online spare parts catalog was already in place. It consisted of a rudimentary directory of hundred-plus-page PDF files that listed spare parts numbers, pictures, and specifications. Unsurprisingly, any spare part sold, while yielding a substantial gross margin, also entailed high process costs. The company then developed a webshop that would significantly enhance customer experience and dramatically reduce process costs from handling orders.

Typically, webshops open the door for more comprehensive digitalization of customer touchpoints. Again, players in consumer markets have paved the way for reaching cost-effective service excellence by using self-service technology (Wirtz and Zeithaml 2018). Manufacturers leading in digitalization are following a similar path. German industrial conglomerate *Voith* positions "MyVoith" as a one-stop digital platform. MyVoith is the gateway to Voith's digital service world, offering over 20 applications, from webshops to asset management. In a similar vein, as of 2020, over 6000 customers of Swiss process equipment manufacturer *Bühler* use the "myBühler" portal to manage their installed base and order spare parts conveniently.

Consumer markets show that there is more to come. For instance, chatbots powered by artificial intelligence have earned their place in the financial services industry. *Capital One*, a US bank, has virtual assistant Eno to help prospective customers find the right credit card and provides active customers with financial information. Industrial service providers we worked with are also moving in the same direction to standardize customer support.

Arguably, the most discussed efficiency lever of digitalization can be pulled at the frontstage. There are many ways of digitalizing service missions. Swiss elevator manufacturer *Schindler* has been at the forefront of innovation on this matter, leveraging three digitally enabled tools to increasing service efficiency (Schindler 2020). New elevator installations are equipped with the "CUBE," an *edge device* continuously transmitting equipment status data, such as door movements and component wear. This data is monitored from *technical operation centers* and fed to field operation. If any issue is detected in the installed base, the center is responsible for coordinating reactions and deploying technicians. Finally, FieldLink—an iPhone *application* used in China—guides the field force during troubleshooting and helps find the right spare parts.

Still, for many manufacturers, the cost-saving potential in field missions remains substantial. A Swiss manufacturer of textile machinery was struggling with rising service costs in Asia. While China, India, and Pakistan were the largest markets in terms of new product sales, service revenues were negligible. Equipment sales generated sufficient gross margins to finance the relatively low labor cost of local service technicians. Therefore, providing free maintenance during the warranty period and beyond was still a viable option in most cases. Some breakdown incidents, however, required specialist advice from the second-level support in the Swiss headquarters. Due to the noisy working environment and language barriers, some incidents could not be solved over the phone, requiring a technician from the headquarters to be flown in. To reduce repair time and service costs, a digitally enabled remote service was needed.

2.5 Adapt Your Organization

Digitalization initiatives require top management commitment to drive visibility and perseverance. While use cases should be implemented at a small scale first, their success needs to be disseminated across the entire organization. We have seen tier-1 automotive suppliers appointing seasoned executives to lead specific task forces to coordinate digitalization activities across the firm. Given the firm size, the risk of losing sight of parallel activities was all too real.

Moreover, top management commitment cannot be just a fad. Our benchmarking data suggests that investments in digital technologies are typically expected to pay off after 2–5 years (Friedli et al. 2018). The reality can be slightly more complicated, though. Digitalization profit curves tend to be left-skewed because substantial initial cash outlays for hard- and software investments are required, with returns materializing only after a certain period of time. Against this backdrop, representatives from family-owned successful practice companies highlighted a favorable impact of their ownership structure. In the cases under study, top management proved to embrace a long-term perspective, encouraging digitalization initiatives despite them not breaking even in a short time period (Friedli et al. 2019).

Manufacturers need to develop a range of new capabilities to succeed in the long run. For many niche players, capabilities in the domain of large-scale data analytics are virtually nonexistent. At this point, the decision to buy or build analytical capabilities is of strategic importance. For some manufacturers, partnering with big tech companies is a way to kick-start digitalization. *Bühler*, for instance, leverages proprietary algorithms from *Microsoft* Azure to run its MoisturePro moisture control solution. Given their size and finite amount of resources, small and medium enterprises are especially more likely to buy plug-and-play solutions from established players instead of building these capabilities themselves.

But trying to simply buy analytic capabilities can also backfire, as the example of a German industrial solutions provider shows. In a pilot project, asset data was transferred to an IT start-up with the hope of extracting insights about failure patterns. However, the start-up lacked the domain know-how to feed the artificial neural network with relevant configuration parameters, leading to faulty conclusions drawn from the model.

Other firms may choose to build these capabilities for data privacy reasons. For instance, a Swiss watchmaker categorically refused the idea of tapping on external resources and tools for data analytics. As one of their managers said, "Such [analytic] tool—we will buy it and put it to work ourselves." While this allows them to operate largely independently from technology vendors, it also requires some larger initial investments with uncertain payoffs. In short, the decision to buy or build analytical capabilities depends on firm-specific factors.

Customer-oriented capabilities are required too. Our industry work points toward the predominant "box-mover mentality" as a major organizational barrier to digitalization. While firms have routinely developed goods and shipped them as is to customers, digitalization changes the rules of the game. Developing capabilities to pierce through the fog of emerging customer needs for digitalization is imperative. This encompasses agile innovation capabilities, where first pilots are co-created with customers and then iteratively improved based on early feedback loops. Embracing such uncertainty can be new to some manufacturers and requires management to embrace risk to a somewhat higher extent.

2.6 Build New Business Models

The moment of launching the second growth engine needs to be timed meticulously. If the core business is still underdeveloped in terms of digital capabilities, attempts to drive growth through new business models are compromised. This was essential learning for an industrial equipment manufacturer in the automotive industry. The service department had come up with the idea of a consignment stock for spare and wear parts embodied in a vending machine installed on the customer's shop floor. The customer value proposition seemed promising: the offering would cut machine downtimes and spare parts lead times while freeing up cash by reducing inventory. However, the manufacturer's logistics processes were not up to speed. Transparency about the availability of spare parts scattered around the globally dispersed warehouses was inexistent. Rolling out the consignment stock too quickly posed a risk of over-accumulating spare parts on a global scale. Opposition from the firm's subsidiaries managing the warehouses ensued. As a consequence, a much-needed initiative to improve the transparency of spare parts availability was launched, causing a delay in the consignment stock rollout, but eventually helping to catch up on long-time neglected improvement potentials.

Once the digitalization homework is done, manufacturers can switch to a higher gear. There are two strategic moves to innovate business models using digital technologies: leveraging the core and blazing a new trail. Both are introduced in Table 1 and unpacked subsequently.

Table 1 Two moves for business model innovation in industrial firms, author's own illustration

Move	Leverage the core	Blaze a new trail
Profit lever addressed	Revenue and cost	Revenue
Synergies with core business	High	Low
Industries served	Predominantly existing	Predominantly new or adjacent
Setup	– Existing brand and legal entity – New business unit within parent company	– New brand and legal entity – Spin-off
Examples	– Equipment-as-a-service (*Rolls-Royce*, *Hilti*, *Michelin*) – Logistics management (*SFS e-logistics*)	– Manufacturing-as-a-service (*KUKA*) – Platform-as-a-service (*BuildingMinds*, *Axoom*)

3 Leverage the Core

The first move consists of enriching the firm's core capabilities with value-adding activities that create revenue or cost synergies. Typical capabilities leveraged include product and service know-how, operations and supply chain capacity, and sales channels. Value is created for customers by reducing their working capital, transaction, or overhead costs. Usually, customers within already served industries are targeted, albeit from different segments. Because the overlap with the core business is significant, these business models are typically provided by the existing firm. Existing brand names and corporate structures are used to foster trust, while new sub-brands or business units may be formed for stronger separation from existing business models.

Construction equipment manufacturer *Hilti* has made such a move with their fleet management service. Customers pay monthly fees for tool usage, including an all-inclusive service package. This business model, initiated in 2001, rests on three core capabilities of *Hilti*:

(a) First, an industry-leading product quality in terms of reliability and performance, endorsed by the *Hilti* brand name.
(b) Second, service excellence. In their regular product business, *Hilti* promises product repair in "3 days or free." This is ensured by around 100 wholly owned repair shops subject to rigorous continuous improvement initiatives. The fleet management service leverages these operational capabilities.

(c) Third, their direct sales force. *Hilti* relies exclusively on direct channels, thereby drastically cutting time to market for new offerings. To provide sufficient leeway to scale service business models, a separate "Tool Services" business unit was spun off in 2018.

Digital technologies are a critical enabler for innovative business models. Take the example of Swiss component manufacturer *SFS*. Their core product portfolio encompasses fastening and building components. Product differentiation is difficult for many of these products, given their low price and interchangeability. To counter eroding margins and integrate deeper into customer processes, *SFS* has launched "e-logistics," a c-parts-management solution enabled by smart containers. Built-in sensors and data transmission technology allow customers to order spare parts by simply turning or pushing a button on the container. These containers trigger replenishment of c-parts manufactured by *SFS* or any other third-party supplier integrated into the e-logistics supply chain. Hence, e-logistics is a new business model building on two elements: (1) core capabilities in manufacturing and distributing c-parts and (2) additional activities providing incremental customer value and in this case, reducing overhead costs.

4 Blaze a New Trail

The second move is even bolder. When answering the question *In what business am I in?* manufacturers may choose to look for revenue opportunities outside the core. When synergies with existing core competencies are low, building up a new business under another brand name can help gain a foothold in entirely new industries, while limiting risks of brand damage if the new venture goes south.

A number of manufacturers have leaped forward by getting into the platform business. *Schindler* has recently formed *BuildingMinds*, a Berlin-based start-up offering a platform for real estate management. While Schindler elevators and escalators can be integrated into *BuildingMinds*, they are just one of the many building-related assets managed from the platform. Arguably, the overlaps between, on the one hand, manufacturing and servicing elevators, and, on the other hand, operating a building Platform-as-a-Service (PaaS) are limited. Given the low synergies between both businesses, operating the platform as a separate venture seems like a sensible choice.

In a similar vein, there is an ongoing race for the dominant platform in manufacturing. Industry heavyweights *GE* and *Siemens* appear to be slightly ahead with their Predix and MindSphere platforms, respectively. However, unlike their counterparts in consumer markets (think of *Amazon*, *Facebook*, and *Google*), no manufacturing platform has yet reached the critical mass to "take it all," as the adage goes. Smaller companies are active too. *ADAMOS* incorporates the attempt of industrial firms from German-speaking countries, including *DMG MORI*, *Dürr*, and *Zeiss*, to build a vendor-agnostic manufacturing platform. Thus, *ADAMOS* was built from scratch as a neutral venture. This has allowed other companies to buy shares from the *ADAMOS* consortium, as the professional service firm *PwC* did in April 2020 (PwC 2020).

Conversely, the bold move of going into the platform business may be reversed at any point in time. Two years after its inception, *KUKA* sold the PaaS offering "Connyun" to technology holding *Körber* in 2018 (Weinzierl 2018). About a year later, manufacturer *Trumpf* sold its "AXOOM" platform to an IT firm, while development activities pertaining to the connectivity of *Trumpf* machines were reintegrated into the headquarters (Pankow 2019). While *Trumpf* remained silent about the specific reasons for divesting from PaaS, it seems as if the stretch from the rest of the firm's activities was too large to justify further investments, such that the executive board decided to focus resources on activities nearer to the core business.

5 Conclusion

Six pathways toward smart manufacturing and services were introduced in this chapter. The first consists of the modernization of operational processes, which is imperative for manufacturers to stay in business, regardless of further digitalization initiatives. Second, the clarification of digitalization objectives is a necessity that has to be done before any further digitalization initiative is launched. Third, a use-case-based selection of activities is appropriate when starting on a clean slate. It gets digitalization moving without committing too many resources upfront. Fourth, there are clear cases for exploiting efficiency potentials through digitalization across manufacturing and service operations. Fifth, organizational adaptation is necessary to get digitalization activities off the ground in the first stage and succeed against the competition in the long run. Sixth, to profit from the potential of Industry 4.0, manufacturers can make bold moves by introducing new business models that either leverage their core business or blaze an entire trail in the ways of creating and capturing value.

The future will reveal whether manufacturers will sustain the pace of adoption of digital technologies witnessed in 2020. Now that many are up to speed in terms of connecting assets and operators and serving customers digitally, the real race for competitive advantage begins. Industrial firms that leapfrog the competition by digitalizing their operations *and* business models will be able to appropriate economic rents and stay on top of their game if they continuously innovate products, processes, and services.

Success Factors for Industry 4.0

- Robust processes: Leverage established techniques to standardize and streamline and fail-proof processes before digitalizing at scale.
- Relentless prioritization: Focus managerial attention and marshal resources to a limited set of key digitalization initiatives.
- Inexpensive pilots: Zero in on the use-case appropriate for your firm's situation, test and learn iteratively, and then scale across functions and sites.
- Customer orientation: Empathize with customers to pinpoint improvement opportunities along the customer journey.
- Long-term orientation: Consider the substantial time required for minds to change, capabilities to build, savings to materialize, and revenues to take off.

References

Benninghaus C, Richard L (2016) Industrie 4.0—from a management perspective. Final report. https://www.alexandria.unisg.ch/252971/. Accessed 6 Sept 2020

Classen M, Blum C, Budde L, Hänggi R, Friedli T (2018) Digitalisierung À La Carte. ZWF 113(12):850–854

Frank AG, Dalenogare LS, Ayala NF (2019) Industry 4.0 technologies: implementation patterns in manufacturing companies. Int J Prod Econ 210:15–26

Friedli T, Budde L, Benninghaus C, Elbe C, Pejić T (2018) Benchmarking digital technologies. Evolution of production in high-wage countries: general report. https://www.alexandria.unisg.ch/257625/. Arbeitsbericht

Friedli T, Classen M, Osterrieder P, Stähle L (2019) Smart services—transformation of the service organization. Benchmarking report. https://www.alexandria.unisg.ch/257104/

Kagermann H, Wahlster W, Helbig J, Hellinger A (2013) Umsetzungsempfehlungen Für Das Zukunftsprojekt Industrie 4.0: Deutschlands Zukunft Als Produktionsstandort Sichern ; Abschlussbericht Des Arbeitskreises Industrie 4.0; Deutschlands Zukunft Als Produktionsstandort Sichern. Forschungsunion, Berlin, 112 S. http://gateway-bayern.de/BV041628328

KUKA (2018) SmartFactory as a service. https://www.kuka.com/de-de/future-production/industrie-4-0/smartfactory-as-a-service-home. Accessed 18 Aug 2020

Lorenz R, Buess P, Macuvele J, Friedli T, Netland TH (2019) Lean and digitalization—contradictions or complements? In: Ameri F, Stecke KE, von Cieminski G, Kiritsis D (eds) Advances in production management systems. production management for the factory of the future, IFIP advances in information and communication technology, vol 566. Springer, Cham, pp 77–84

Osterrieder P, Budde L, Friedli T (2020) The smart factory as a key construct of industry 4.0: a systematic literature review. Int J Prod Econ 221:107476. https://doi.org/10.1016/j.ijpe.2019.08.011

Pankow G (2019) GFT Übernimmt Geschäftsaktivitäten Und Mitarbeiter Von Axoom. https://www.produktion.de/wirtschaft/gft-uebernimmt-geschaeftsaktivitaeten-und-mitarbeiter-von-axoom-113.html. Accessed 31 Aug 2020

PwC (2020) Industrie 4.0-plattform: PwC Deutschland Beteiligt Sich an ADAMOS GmbH. https://www.pwc.de/de/pressemitteilungen/2020/industrie-4-0-plattform-pwc-deutschland-beteiligt-sich-an-adamos-gmbh.html. Accessed 31 Aug 2020

Schindler (2020) Full year results presentation 2019. https://www.schindler.com/com/internet/en/investor-relations/reports/_jcr_content/contentPar/downloadlistcontent_7804229/downloadList/359_1581655255063.download.asset.359_1581655255063/schindler-fy-2019-presentation.pdf. Accessed 21 Aug 2020

Schmitz C, Tschiesner A, Jansen C, Hallerstede S, Garms F (2019) Industry 4.0: capturing value at scale in discrete manufacturing. https://www.mckinsey.com/~/media/McKinsey/Industries/Advanced%20Electronics/Our%20Insights/Capturing%20value%20at%20scale%20in%20discrete%20manufacturing%20with%20Industry%204%200/Industry-4-0-Capturing-value-at-scale-in-discrete-manufacturing-vF.pdf. Accessed 18 Aug 2020

Thoben K, Wiesner S, Wuest T, BIBA—Bremer Institut für Produktion und Logistik GmbH, the University of Bremen, Faculty of Production Engineering, University of Bremen, Bremen, Germany, Industrial, and Management Systems Engineering (2017) "Industrie 4.0" and smart manufacturing—a review of research issues and application examples. Int J Autom Technol 11(1):4–16. https://doi.org/10.20965/ijat.2017.p0004

United Nations Industrial Development Organisation (2020) COVID-19 implications & responses: digital transformation & industrial recovery. https://www.unido.org/sites/default/files/files/2020-07/UNIDO_COVID_Digital_Transformation_0.pdf. Accessed 18 Aug 2020

Weinzierl S (2018) Körber Übernimmt IIoT-Spezialist Connyun Von Kuka. https://www.produktion.de/wirtschaft/koerber-uebernimmt-iiot-spezialist-connyun-von-kuka-125.html. Accessed 27 Aug 2020

Wirtz J, Zeithaml V (2018) Cost-effective service excellence. J Acad Mark Sci 46(1):59–80. https://doi.org/10.1007/s11747-017-0560-7

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