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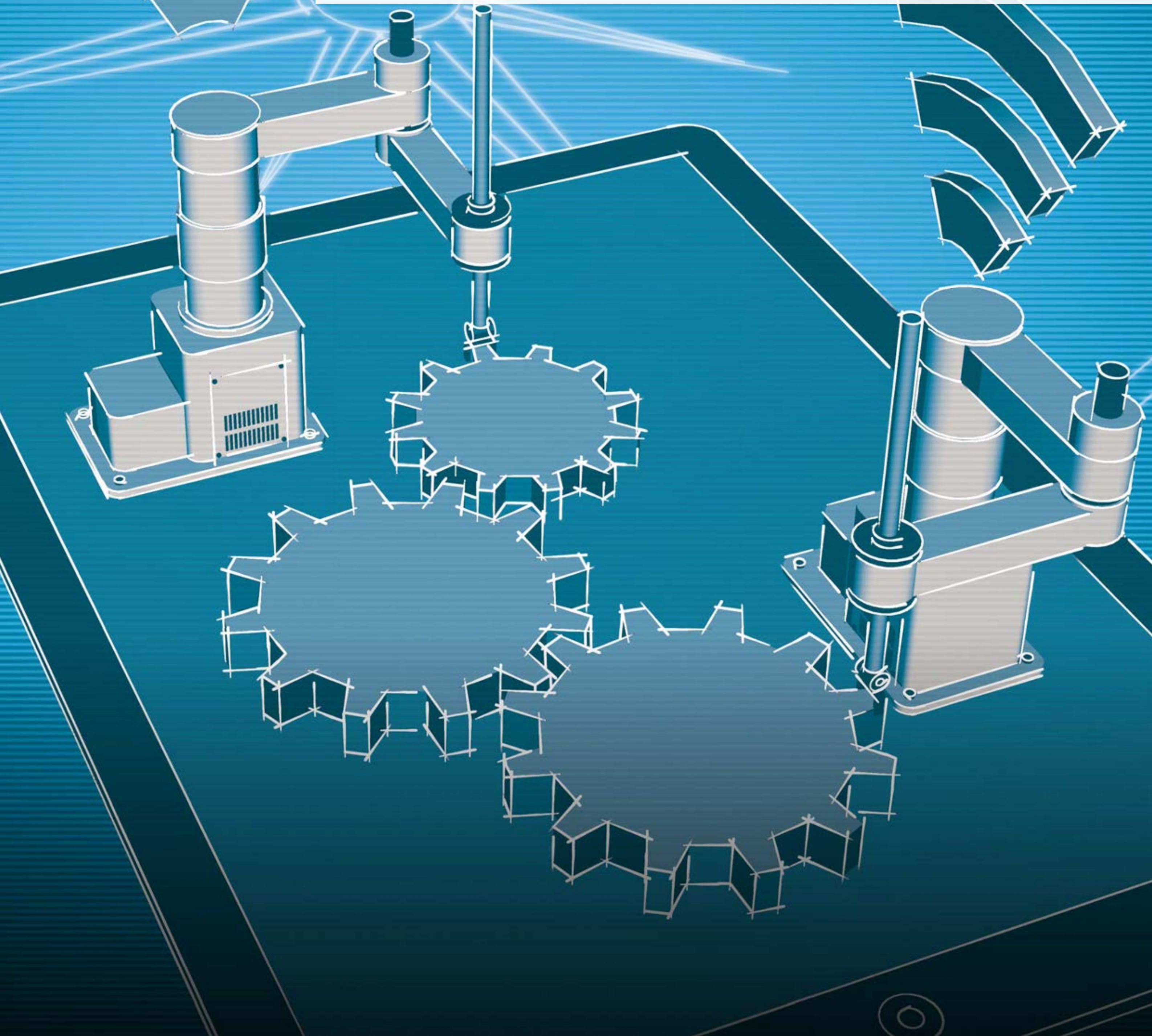
Industry 4.0
How to navigate digitization of the manufacturing sector

McKinsey Digital
2015



Industry 4.0

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Executive summary

Raising the topic of a fourth industrial revolution immediately prompts many questions: What does Industry 4.0 really mean? What does digitization entail for manufacturing? How profound will its impact be on our value pools? What are the near-term business opportunities for my company? Some clients also ask whether the term is simply hype. This myriad of mixed reactions reveals the intense uncertainty associated both with what Industry 4.0 actually is and how companies should respond to the changing industrial environment.

To clarify terms at the outset, McKinsey defines Industry 4.0 as digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyberphysical systems, and analysis of all relevant data. It is driven by four clusters of disruptive technologies. The first consists of data, computational power, and connectivity – low-power, wide-area networks are one example. Analytics and intelligence form the second, while human-machine interaction is the third, comprising, for instance, touch interfaces and augmented reality. Digital-to-physical conversion is the fourth: advanced robotics and 3D printing are two examples. All of these enablers are at a tipping point today – now is the time for manufacturing companies to decide how to respond to them.

As Industry 4.0 influences mission-critical applications in B2B processes, we expect the transformation to be far-reaching but the pace of change to be slower than in the digital disruption of the consumer Internet. Due to their long investment cycles, companies tend to be conservative in their decision making when it comes to fundamental disruption. However, while the majority of value created in prior industrial revolutions came from upgrading manufacturing assets in individual locations – 80 to 90 percent in the shifts to both steam and automation – capex-intensive upgrades are expected to account for only half of that (40 to 50 percent[1]) in Industry 4.0. Disruptive technologies that are in many cases not linked to major machinery upgrades will enable productivity gains and new business models, and fundamentally alter the competitive landscape.

McKinsey has conducted significant primary market research to develop a company-level perspective on this next wave of manufacturing, including a survey of 300 participants from three countries (the US, Germany, and Japan), supplemented by in-depth interviews with industry thought leaders and extensive research. The findings reveal that manufacturing companies should act along three dimensions to capture the potential of Industry 4.0: drive the next horizon of operational effectiveness, adapt business models to capture shifting value pools, and build the foundations for digital transformation.

1. Drive the next horizon of operational effectiveness

We believe that any optimization should be approached with the objective of maximizing value and have thus identified eight value drivers that will significantly impact the performance of typical manufacturing companies. For each of these eight value drivers, we have identified the most important underlying Industry 4.0 levers, resulting in a diagnostic framework we refer to as the "Digital Compass." Players can use it to systematically identify Industry 4.0 opportunities.

For brownfield sites, the value lies in end-to-end optimization of the "digital thread," (i.e., making better use of information not captured/made available/used today) and in eliminating inefficiencies caused by information losses at the interfaces of functions, sites, and companies. According to our survey, companies expect this end-to-end integration – from raw material all the way to the final product delivery – to yield a productivity improvement of as much as 26 percent.[2]

In greenfield scenarios, three distinct plant-of-the-future archetypes are emerging. Smart automated plants are fully digitized, and highly cost efficient. These address mass markets (i.e., very large series) and thus have limited product range. Customercentric plants address trend markets and are driven by "mass personalization." They are ultraresponsive plants working on single-piece flow and customizing products on an order-by-order basis. "E-plants in a box" are the third archetype, geared for targeting niche and remote markets. These small-scale, low-capex, mobile plants produce a limited range of products at competitive cost.

The key success factors for capturing opportunities from the next horizon of operational effectiveness are: integrating and analyzing data across sources and companies, sharing outcomes across the value chain, ensuring integration with physical production assets, and rethinking the design of classical production systems.

2. Adapt business models to capture shifting value pools

Disruptive Industry 4.0 technologies also unlock new value potential through new types of business models. One is represented by as-a-service offerings (e.g., leveraging pay-by-usage or subscription-based models, turning machinery from capex to opex for manufacturers. Monetization of platforms is another, such as technology platforms creating new ecosystems, or broker platforms for market making.

Intellectual property rights-based models are a third: licensing IPR might be a recurring revenue model, for example, or offering related consulting services. Data-driven business models monetizing data or insights from collected data are the fourth.

These types of business models are expected to shift value pools in existing value chains. Ensuring access to these value pools will therefore be pivotal for companies going forward. However, these shifts will also create opportunities for new players and cause changes in the competitive landscape, both in terms of new entrants competing for existing value pools and players tapping into new value pools that have not been part of the value chain before, such as suppliers of connectivity solutions. Since especially small start-ups and innovative companies are moving into these new dimensions fast, incumbent manufacturers and suppliers need to react swiftly to the strategic implications of Industry 4.0 for their business models.

We see three key success factors in adapting to disrupted value chains. The first is to take current assets as the starting point and develop new business cases based on these. The second is to secure control points in the shifting value chain and avoid areas that are becoming commoditized. The third is to understand the changing competitive dynamics and engrain agility in the company's DNA.

3. Build the foundations for digital transformation

Industry 4.0 disrupts the value chain and requires companies to rethink the way they do business. They need to drive the digital transformation of their business to succeed in the new environment. Five pillars will be critical for this transformation: first, companies need to build digital capabilities. This comprises factors such as attracting digital talent and setting up cross-functional governance and steering. Second, companies need to enable collaboration in the ecosystem. This requires getting involved in the definition of standards and cooperation across company borders through alliances, strategic partnerships, and cooperation in communities. Third, managing data as a valuable business asset will be important in securing crucial control points. Fourth, companies need to manage cybersecurity end to end to protect digitally managed shop-floor operations and proprietary data. Lastly, companies need to implement a two-speed systems/data architecture to differentiate quick-release cycles from mission-critical applications with longer turnaround times.

To leverage these multiple opportunities, companies need to embark on a digital transformation journey: a continuous, long-term effort is needed to successfully navigate the changing industrial environment of Industry 4.0.

1.

A set of disruptive digital technologies will transform the manufacturing sector by 2025

Why is it that Industry 4.0 is creating such interest? Companies are dedicating specialized teams and creating cross-industry networks to drive its development. One reason why industry players are investing such significant resources in Industry 4.0 is that traditional productivity levers have been widely exhausted. In the 1970s and 1980s, lean adoption was the enabler, with Toyota's system widely adopted in Western regions (mostly high-cost countries). Outsourcing and offshoring allowed greater profitability in the 1990s by moving low-skill manufacturing to low-cost countries (LCC). In the 2000s, the advantages of offshoring began to shrink as LCC wages rose and freight costs increased.

Time to market and customer responsiveness are today's key factors of competitiveness, and companies are investing in automation and robotics technologies that have the potential to meet LCC labor cost levels in any location. Companies are redesigning their manufacturing networks and moving closer to their customers and R&D centers (next-shoring). The pressure on companies continues to increase, and many are looking for new opportunities to boost productivity.

The disruptive technologies of Industry 4.0, such as IT-enabled manufacturing and increased computing capacity, hold the promise of smart factories that are highly efficient and increasingly data integrated. Data is the core driver: leaders across industries are leveraging data and analytics to achieve a step change in value creation. A big data/advanced analytics approach can result in a 20 to 25 percent increase in production volume and up to a 45 percent reduction in downtime.[3]

For the purpose of this report, we define all digitally enabled disruptive technologies that are likely to have a significant impact on manufacturing within the next 10 years as Industry 4.0 relevant. Some of these technologies are real innovations, such as augmented reality, while others – like big data and advanced analytics – have already been applied in manufacturing for some time now. At this point, the question arises: What is the novelty here? Is Industry 4.0 just another rehash of what has been known as manufacturing execution systems (MES) since the 1990s?

We believe otherwise. McKinsey's research shows that all of the following technologies, for various reasons, are at a tipping point today and are ripe to disrupt the manufacturing value chain. To be more precise, there are four clusters of technologies that need to be examined (Exhibit 1). Different drivers are leading to an acceleration of use on a large scale for each of these clusters.

Exhibit 1

A number of disruptive technologies will enable digitization of the manufacturing sector

Digitization of the manufacturing sector – Industry 4.0

Data, computational power, and connectivity	Analytics and intelligence	Human-machine interaction	Digital-to-physical conversion
Big data/open data Significantly reduced costs of computation, storage, and sensors **Internet of Things/M2M** Reduced cost of small-scale hardware and connectivity (e.g., through LPWA networks) **Cloud technology** Centralization of data and virtualization of storage	**Digitization and automation of knowledge work** Breakthrough advances in artificial intelligence and machine learning **Advanced analytics** Improved algorithms and largely improved availability of data	**Touch interfaces and next-level GUIs** Quick proliferation via consumer devices **Virtual and augmented reality** Breakthrough of optical head-mounted displays (e.g., Google Glass)	**Additive manufacturing (i.e., 3D printing)** Expanding range of materials, rapidly declining prices for printers, increased precision/quality **Advanced robotics (e.g., human-robot collaboration)** Advances in artificial intelligence, machine vision, M2M communication, and cheaper actuators **Energy storage and harvesting** Increasingly cost-effective options for storing energy and innovative ways of harvesting energy

SOURCE: McKinsey

Data, computational power, and connectivity. This cluster, which comprises big data, the Internet of Things (IoT), and cloud technology, is mainly driven by a significant reduction in costs that makes the ubiquitous use of sensors and actuators possible and allows for affordable yet powerful storage, transmission, and processing. For example, in the IoT, sensors and actuators embedded in physical objects are interconnected via wired and wireless networks. These networks churn out large volumes of data that flow to computers for analysis, while all physical objects are able to both sense their environment and communicate autonomously among each other. Today, all prerequisites for IoT applications are finally falling into place: interoperability is made possible by new communication protocols designed especially for seamless machine-to-machine (M2M) interaction. Connectivity is enabled by LPWA technologies that provide the wireless infrastructure to connect thousands of IoT nodes. And finally, affordability is being achieved with the forecasted IoT hardware prices of just USD 1 per IoT node in the near future (Exhibit 2).

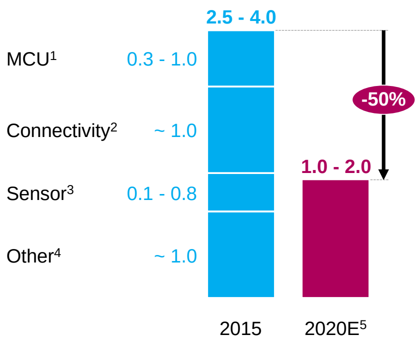
Analytics and intelligence. Significant knowledge advances have taken place in this area over the last few years. While for a long period of time, only simple and repetitive tasks could be performed by robots, advances in artificial intelligence and machine learning as well as the exponential increase in available data and improved statistical techniques enable digitization and automation of knowledge work and advanced analytics. IBM's cognitive system Watson,[4] for example, is able to answer complex questions based on insights synthesized from vast amounts of unstructured data. One prominent application of the software lies in cancer care. Several US hospitals use Watson to identify treatment options for individual patients by analyzing their medical information against research literature, case histories, and established treatment guidelines, along with feedback from expert oncologists. This is just one example of how knowledge-based activities can be automated to yield value, and represents a preview of the things to come.

Human-machine interaction. The driver of greater human-machine interaction is increased consumer familiarity with new ways of interacting with machines that come from the growing use of personal devices. Touch interfaces are already ubiquitous in the consumer world today and gesture recognition as well as virtual and augmented reality devices are increasingly in use. The familiarity with such devices will ease the implementation of human-machine

Exhibit 2

Now is the time – the cost of IoT nodes has come down drastically and is expected to fall further

Unit price, USD



- **No significant costs** associated with IoT connectivity anymore
- Prices expected to **continue to fall** over the next few years
- Additional cost savings potential from **future integrated design solutions**
- Calculation does **not include fixed costs** such as costs for infrastructure

1 Current prices range from USD 0.3 (e.g., Cypress 32-bit) to USD 1.2 (e.g., TI 16-bit), dependent on speed, quality, and integrated memory size (ranges for larger order volumes)
2 Combination of filter transceiver and antenna – additional costs for switches and amplifiers not included
3 E.g., temperature, position, pressure, gyroscope
4 Additional components like ADC converters, power management converters, capacitors, resistors, fuses, PCB (list not exhaustive)
5 2020 prices estimated by inflating current prices with a CAGR of -15% p.a.

SOURCE: www.digikey.com; expert opinion

interaction as a natural feature in the manufacturing environment. In fact, companies such as the German start-up Ubimax[5] already pioneer apps that run, for example, on smart glasses from different providers to make warehouse, assembly, and service processes more efficient through live instructions that are overlaid on the visual field of the worker wearing the device. Another dimension is the increasing physical interaction between machines and humans, where machines and humans both work in much closer physical proximity and where machines can ease previously strenuous tasks for humans. An example is the Festo ExoHand,[6] which functions as an exoskeleton emulating the anatomy and physiology of the human hand. It is worn as a glove and can support straining manual movements by transmitting human hand movements to a robot's hand. As a result, the worker can conduct a given task for a longer period of time and faster than before.

Digital-to-physical conversion. Here, a combination of decreasing costs, expanding range of materials, and advances in precision and quality are the drivers of relevance. For example, 3D printing has moved from only being applicable to polymers and metals to a broad range of materials, including glass, biocells, sugar, and cement. At the same time, the maximum size of 3D printing has increased by more than tenfold from the 1990s to today.* It is not just additive manufacturing that is becoming more relevant, but also technologies like advanced robotics and increasingly cost-effective options for storing energy and innovative ways of harvesting energy. Significant advances in artificial intelligence, machine vision, and M2M communication have been made within the field of advanced robotics, along with cheaper actuators.

The combination of technologies from these clusters not only enables the translation of the physical into the virtual world but also facilitates the link back from the virtual to the physical world.

1.1 In comparison to the third industrial revolution, the fourth will have high impact despite only limited replacement of equipment

The term Industry 4.0 suggests that this is the next major disruption to the manufacturing value chain. The hallmarks of the prior three major industrial revolutions were, in chronological order, the introductions of steam, electricity, and equipment automation.

> *Driven by the Internet of Everything, Industry 4.0 offers high potential impact at a relatively low cost. Every company and every industry will become a digital company resembling a technology stack – software apps enable agile processes and new revenue streams, as they turn data from connected "things" on the plant floor into real business outcomes. Investment is required in the right technologies and platforms. On the infrastructure side, the IT-centric centralized cloud model is not always complete – technical infrastructure must be tailored to work in tandem with the hyper-distributed Edge, millions of "things," running apps locally, self-learning, and in real time (e.g., the cloud might not be the best option for low-latency OT applications).*
>
> ***Leonard Sussenbach,*** Head of IoT Strategy at Cisco

* Based on SLS Sinterstation 2000 for 1990 and 3DS sPro 230 HS for 2014; however, figures are highly dependent on the exact part that is being printed.

If one analyzes each revolution's requirements in terms of what part of the existing manufacturing technology and equipment had to be replaced in order to realize the new value potential it promised, we see that the current revolution will require relatively little replacement. Specifically, companies expect about 40 to 50 percent* of the existing installed base of manufacturing equipment to be replaced in the course of Industry 4.0 (Exhibit 3). Replacement of existing tools with machines during the third industrial revolution (automation) is estimated at up to 90 percent. Under Industry 4.0, we believe that the main requirement will be upgrading existing equipment, mainly in the dimensions of sensors and connectivity. Since the fourth revolution is not "just" about exchanging assets, however, it also poses a managerial challenge of upgrading the machine park as necessary to reflect new requirements introduced by the disruptive technologies of Industry 4.0.

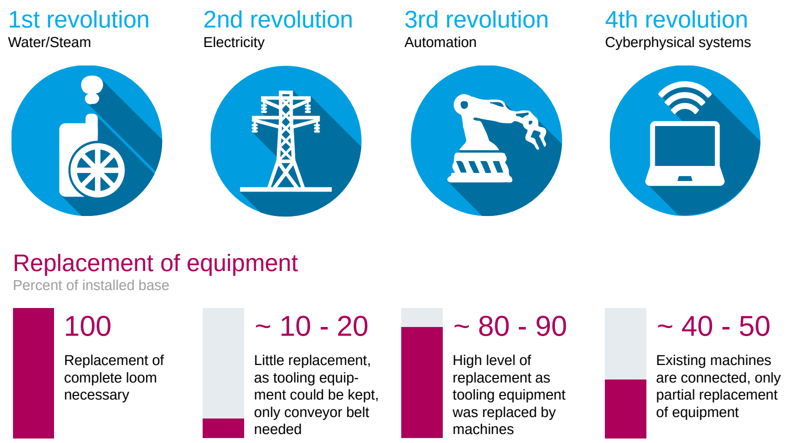
1.2 The pace of the transition will likely be gradual

For most manufacturing companies, a disruptive approach to implementing new and thus unknown technologies is rather risky. Industry 4.0 technologies are at the heart of most manufacturing processes and influence critical steps within the value chain. The cost of production downtime per day is high, and thus manufacturing companies will carefully weigh the benefits of introducing new technologies against possible risks to process reliability. As a result, companies approach fundamental disruptions with caution, so that change will be rather incremental (Exhibit 4). Due to the long life expectancy of manufacturing equipment, providers of process automation hardware and software (e.g., Siemens SIMATIC[7]) guarantee product support of at least 10 years. This results in long investment cycles and a more conservative approach to decision making.

* US: 53%; Germany: 44%; Japan: 47%; Source: McKinsey Industry 4.0 Global Expert Survey 2015

Exhibit 3

Compared to the 3rd industrial revolution, the 4th revolution will have relatively high impact at comparatively little replacement of equipment



SOURCE: Statistisches Bundesamt; Deutsche Bundesbank; Prognos; Thomas Nipperdey; McKinsey

Unlike prior industrial revolutions, Industry 4.0 is not about replacing the existing assets with new ones but about mastering the managerial challenges posed by the disruptive technologies along three different dimensions:

1. The next horizon of operational effectiveness
2. New business models as a result of shifting value pools
3. Foundations for the digital transformation of the company.

These dimensions are the focus of this report – for it aims to help leaders understand the impact of the disruptive technologies on their companies and navigate the changing manufacturing landscape by identifying the implications of Industry 4.0 at the company level.

Text box 1: Background on expert interviews conducted for this study

McKinsey conducted 50+ interviews with experts from manufacturing companies, technology suppliers, and start-up companies. We asked the experts for their views on how Industry 4.0 will change the industrial environment and for their perception of trends. We also tested the initial results of the McKinsey analysis with them. These views, from very different sectors and representative of various company sizes and corporate functions, contributed to a broad and deep understanding of the disruptions that can be expected from Industry 4.0 and helped shape this report. Key questions included the industry-specific relevance of disruptive technologies and Industry 4.0 levers (e.g., predictive maintenance, digital performance management), the changes that the new technologies are expected to bring to the companies (e.g., regarding the extent of manufacturing equipment to be replaced), and industry-specific challenges. Quotes from these expert interviews can be found throughout the report.

Exhibit 4

Pace of change will be slower compared to the consumer Internet due to large downside risks in case of failure

Production downtime risk	Cybersecurity risk	Quality loss risk
EUR 28 million	EUR 50 billion	60 million
Costs in the automotive industry per day[1] – weigh risks of introduction of new technology against process reliability	Annual damage to the German manufacturing industry caused by cyberattacks[2]	Number of cars that were recalled in 2014 throughout the US[3]

1 http://news.thomasnet.com/companystory/downtime-costs-auto-industry-22k-minute-survey-481017
2 http://www.vdi.de/artikel/gute-perspektiven-fuer-standort-deutschland-durch-industrie-40; only the officially reported cases – real damage is expected to be bigger
3 http://www.nytimes.com/2014/12/31/business/a-year-of-record-recalls-galvanizes-auto-industry-into-action.html?_r=2/

SOURCE: Press research

In order to develop a perspective in which all frameworks and recommendations are tailored towards companies, we have conducted significant primary market research, including in-depth interviews with leading industry thinkers (see Text box 1) and a survey of 300 participants from three countries (the US, Germany, and Japan) (see Text box 2).

Text box 2: Background on the McKinsey Industry 4.0 Global Expert Survey 2015

McKinsey carried out a global Industry 4.0 survey of 300 experts from all relevant industries. The survey was based on 21 questions and allowed different types of answers such as importance and significance-rating questions (1 to 6) as well as ranking questions.

The B2B panel was held in the US, Germany, and Japan in January of 2015, with 100 companies per country of which each had at least 50 employees.

The industries that took part in the survey were automotive OEMs, automotive suppliers, chemicals, consumer goods, healthcare, paper and packaging, software, transport and logistics, industrial equipment, industrial automation, and semiconductors. Both Industry 4.0 technology suppliers and manufacturers were part of the survey.

Key questions included whether Industry 4.0 was viewed as an opportunity or a risk; the relevance of Industry 4.0 disruptive technologies (e.g., big data, the Internet of Things, virtual and augmented reality); their impact on business models, competitiveness, competitive landscape, investment decisions and revenues; and the potential of Industry 4.0 value drivers (e.g., resources/process, time to market, asset utilization).

The key results from the survey are:

- **General findings**
  - Industry 4.0 will bring high impact at comparatively little replacement of equipment (about 40 to 50 percent of installed base) within the next 10 years.
  - In Germany, companies are still very careful regarding investing in Industry 4.0-related R&D (only 15 percent of total R&D) given that Industry 4.0 is already making up 19 percent of total revenue.
- **Concerning operational effectiveness**
  - Companies see labor, quality, and development time as the main areas for improvement – these improvements are expected to be driven by digitization of knowledge work, advanced analytics, and touch operation/interfaces.
  - Companies expect Industry 4.0 to increase revenues by 23 percent and productivity by 26 percent.
- **Concerning business models and the competitive landscape**
  - 80 percent of companies expect Industry 4.0 to impact their business model.

- — The majority of players expect new competitors to enter the market – there is, however, a large difference between technology suppliers (84 percent expect new competitors) and manufacturers (58 percent).

- — Only 46 percent of German companies expect new competitors vs. 63 percent of Japanese and 92 percent of US companies.

- **Concerning organizational readiness**
  - — 76 percent of technology suppliers, but only 48 percent of manufacturers feel well prepared for Industry 4.0.

  - — There are large regional differences with regard to how prepared companies feel about Industry 4.0 – 83 percent of US, 57 percent of German, and only 34 percent of Japanese respondents feel well prepared for Industry 4.0.

- **Concerning implementation barriers**
  - — For German companies, the biggest obstacles for implementing Industry 4.0 are: (1) process and control know-how for employees; (2) data security and safeguarding systems; (3) a uniform standard for data transfer; (4) end-to-end connectivity via wireless networks. The last three of these are connectivity related, making data security an important topic.

  - — Due to cybersecurity concerns, companies have become reluctant to use foreign IT providers: IT outsourcing is viable for 57 percent of German participants; however, only 15 percent of those willing to outsource would consider worldwide server locations. Similarly, in the US, 83 percent of companies are willing to outsource, but only 19 percent of those willing to outsource would consider worldwide server locations.

For further survey results, please refer to the Appendix.

2.

Companies need to push for the next horizon of operational effectiveness

Manufacturing companies are facing a consistently high level of margin pressure. For example, automotive OEMs are optimizing their products to realize every euro that can be saved on material or processing costs. After the past decades have seen the implementation of the lean concept, an outsourcing/offshoring movement, and finally the automation of labor, the industry is now in search of the next horizon of operational effectiveness. Digitization and Industry 4.0 are opening up new cost savings that have so far remained untapped.

2.1 New value potential can be created by eliminating inefficiencies across the "digital thread"

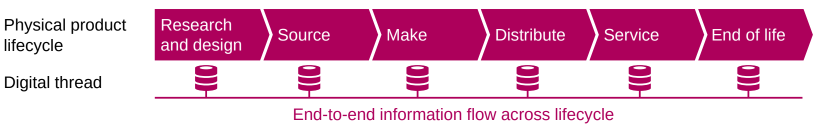
Industry 4.0 constitutes a paradigm shift from optimizing physical assets to optimizing how data and information are leveraged along the product lifecycle (Exhibit 5). This digital optimization builds on an end-to-end information flow – in short: a "digital thread" running through the entire product lifecycle as its digital representation. This digital thread starts with the digital design of the product, passes on through the digitally steered and controlled manufacturing process, leads to the digital monitoring of the end product in operation (e.g., for maintenance purposes), and finally ends in the recycling of the product, where digitally stored information can help identify parts for reuse.

At each of these steps, the digital format of the information works as an enabler: data can be exchanged easily, the process can be visualized and controlled via digital interfaces/tools (e.g., via tablets/smartphones), and interaction can be carried out via digital channels (e.g., remote servicing). Furthermore, leveraging and sharing information across the digital thread will enable stronger cross-functional integration and closer cooperation along the complete product lifecycle, even across steps where different stakeholders such as suppliers or customers are involved. The focus is shifting from one single production site to optimizing production networks that encompass multiple sites belonging to the company as well as those belonging to the company's suppliers and end users.

Exhibit 5

Disruptive technologies increase the value of digital information along the entire product lifecycle

The digital thread is the digital representation of the physical product lifecycle



4 activities are required to manage the digital thread

Information capturing and recording	▪ Relevant set of data to prevent information overflow ▪ Automated, real-time capturing via sensors ▪ Recording and storing of both historical and new data in a single information system
Information transfer	▪ Digitally transfer information across departments, production sites, value chain steps, and company borders
Information analysis and synthesis	▪ Identification of relevant data and analysis (ideally, automated) ▪ Synthesis of analysis into relevant insights
Turning information into outcomes	▪ Translation of analysis results into recommendations that suggest actions for workers or automatically trigger actions of machines ▪ Feedback and continuous improvement

SOURCE: McKinsey

Optimizing the digital thread is therefore all about making the best use of information. Industry 4.0 technologies are similar in that they offer ways of leveraging data to unlock its value potential, e.g., advanced analytics will turn information into outcomes that help decision makers, 3D printing converts the digital construction data into a tangible work piece, and predictive maintenance uses captured information to schedule the ideal maintenance times. A case example from the oil and gas industry shows that companies are currently losing up to 99 percent of their data through information leakages (Exhibit 6). After analyzing a mere 1 percent of the collected data, basically none of the results are used to drive decision making.

Key to capturing the new opportunities is actively managing the information along the digital thread in order to avoid information leakages. These leakages are spots in the digital thread where information gets lost although it could have been valuable for a stakeholder somewhere else in the value chain. Each information leakage therefore causes inefficiency. Managing the digital thread is comprised of four activities that are prerequisites for the creation of value from data:

Information capturing and recording. The foundation for using data to capture opportunities is of course the collection and recording of relevant information. Inefficiencies can only be eliminated if they are detected and documented, thus the physical production process needs to be mapped along the digital thread – based on the collection of real-time data in an automated way and with historical data points. This requires moving from selected, sampling-based measurements mostly for quality control purposes to a full coverage of the production process, using inline sensors and measurement devices to collect information for every single work piece. For example, in order for a set of automated welding guns to identify unbalanced usage and redistribute the workload among the single guns, sensors have to capture the individual wear. However, defining the set of relevant data regarding wear and distinguishing it from irrelevant data is an important step in becoming able to establish actionable causal connections and to avoid the waste of unnecessary data collection. Following the data collection, recording of relevant data (including some history) is required to enable later analysis.

Exhibit 6

In a case example, 99% of all data in an oil rig was lost before reaching operational decision makers

From a base of 30,000 data tags, close-to-zero tags are used to inform operational decisions

		Comment	Source
People and processes	0%	Schedule predominantly based on OEM-recommended maintenance intervals	Interviews with operational staff
Deployment	< 1%	No interface in place to enable real-time analytics to "reach" offshore	
Analytics	< 1%	Reporting limited to a few KPIs which are monitored in retrospect	BI and KPI walkthrough
Data management	~ 1%	Data cannot be accessed in real time, enabling only ad hoc analysis	Walkthrough of infra-structure and band-width between off- and onshore
Infra-structure	60%	Only ~ 1% can be streamed onshore for day-to-day use	
Data capture	100%	~ 40% of all data is never stored – remainder is stored locally offshore	Assessment of storage capacity (on the highest capacity asset)

~ 30,000 tags measured

SOURCE: McKinsey

> *Collecting and acting on all relevant information and thereby optimizing the digital thread is key to leveraging the potential of Industry 4.0. This is driven by the use of sensors, which enable significant automation and allow manufacturing sites to, e.g., become self-optimizing, and operators to access sites worldwide. To fully utilize the potential and optimize the digital thread, however, still requires uniform communication standards, as currently there are still too many different protocols in use.*
>
> ***Christian Ott,*** Head of Product Management (VISION) at SensoPart

Information transfer. The prerequisite for preventing information leakages and losses along the digital thread is efficient information transfer. Data collected at a specific point in the value chain might be most useful at a different point (either earlier or later) in that same value chain. To make information available at a specific point, it is crucial to share it across the value chain, for most advanced applications even in real time. Therefore, companies need to integrate disparate sources of data from different applications to create a holistic view of the end-to-end process. Also, the integration of data should not stop at the company border. For example, in the food processing industry, information on the expected quality of an ingredient might be available even before the harvesting takes place (e.g., based on data on weather conditions). This information might be relevant for adapting manufacturing processes or sourcing other ingredients.

Information processing and synthesis. Getting from data to insights requires thorough processing of the captured information. Modeling the yield sensitivity of a gold mine with advanced analytics showed, for example, that oxygen concentration is a central driver of yield. Thus, production can be optimized by adding the ideal amount of oxygen to the extraction process. Arriving at the right conclusion depends on both relying on a relevant causal relation between factors (e.g., derived from historical data points) and employing this insight to optimize the status quo. Optimization opportunities exist where either interrelations are not obvious or where insights are not yet used for optimization.

Turning information into outcomes. The last step needs to close the loop from the digital sphere back to the "real world" by translating conclusions from the data analyses into recommendations and – ultimately – actions. Many decision making processes still require human involvement, while data analyses are often already automated and performed in real time. Therefore, opportunities are associated with speeding up and potentially (partially) automating these decisions, and triggering the required actions. In the semiconductor industry, it is standard to operate advanced process control (APC) systems that translate anomalies detected by a statistical process control (SPC) system into automated adjustments of equipment parameters. This means an automated feedback loop is created that is used to ensure the manufacturing process produces the required outcome.

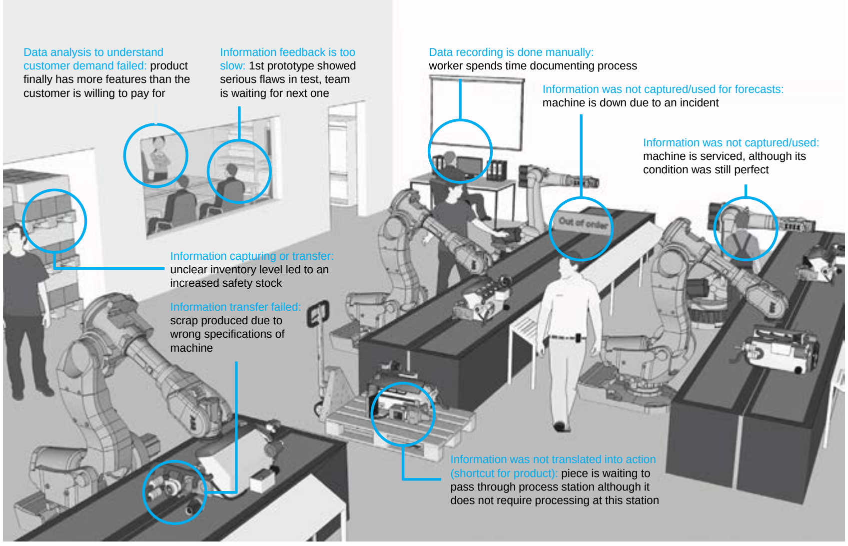
2.2 The McKinsey Digital Compass helps identify and prioritize optimization opportunities around eight value drivers

What would production look like in a world of perfect information? To answer this greenfield-related question convincingly, we should perhaps ask about the brownfield situation first: Which inefficiencies in today's manufacturing processes and value chains could be eliminated by making better use of that information? Does some of this information already exist, and if not, can it be generated?

Information itself does not have an inherent value. All data collection should be approached with the objective of maximizing value. We thus need to look out for concrete value drivers across the business (i.e., areas where inefficiencies occur due to information leakages) (Exhibits 7 and 8). For example, machinery and assets are a significant cost category for manufacturing companies; therefore, asset utilization is a value driver that might contain untapped potential due to information leakages. As described above, Industry 4.0 technologies make use of information to capture such value potential. Introducing remote monitoring and steering to decrease downtimes by making the best use of all information about the machinery can improve asset utilization and thus generate value. Other examples include using information on energy prices for the scheduling of machine times to decrease energy costs or converting the information on spare parts into an actual spare part via 3D printing to reduce machine downtimes. Use cases of Industry 4.0 levers to capture value across the entire product lifecycle are numerous.

Exhibit 7

Information leakages cause digital inefficiencies



SOURCE: McKinsey

Industry 4.0 enables a more flexible and more modular production through flexible production equipment and automation technology. This will allow manufacturing companies to react faster to changed demand, covering both production volumes and a variety of products.

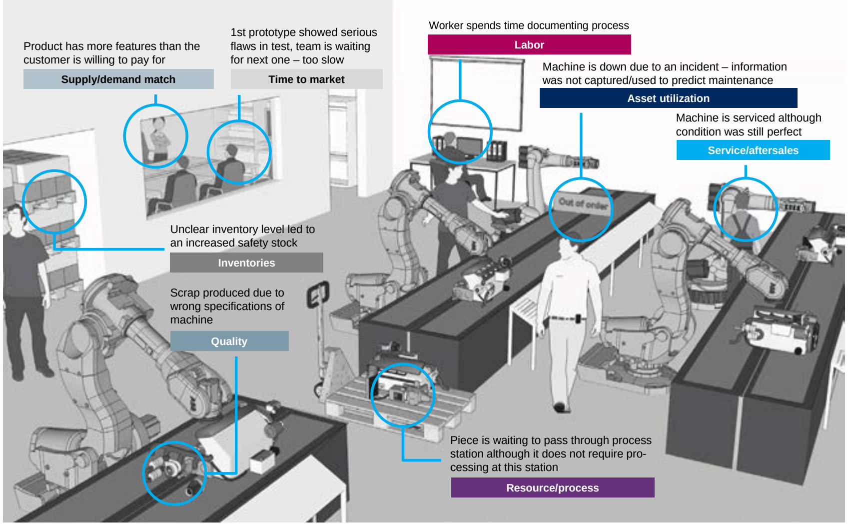
Machinery companies will extend their current competences in order to optimize their customers' businesses. This will allow them to unlock vast new potential.

Industry 4.0 requires the convergence of business IT and manufacturing IT systems. Applications and different engineering disciplines have to grow together and collaborate in an interdisciplinary way to create additional value through better usage of data.

Dr. Jan Stefan Michels, Head of Standardization and Technology Development at Weidmüller

Exhibit 8

Eliminating these digital inefficiencies could unlock potential along 8 different value drivers



SOURCE: McKinsey

In order to identify and prioritize opportunities along the digital thread, we have developed a new diagnostic framework, the McKinsey Digital Compass (Exhibit 9). The tool uses the eight value drivers that have significant impact on the performance of a typical manufacturing company (Exhibit 10). For each of these value drivers, Industry 4.0 levers exist that typically lead to improvements. The compass links the most important levers to the eight value drivers, resulting in a framework that companies can leverage to systematically identify Industry 4.0 potentials:

Resource/process. Improving a process in terms of material consumption, speed or yield drives value – in the first case via decreased material costs and via increased revenues through more output in the second and third cases. An exemplary Industry 4.0 lever to improve process/resource effectiveness is real-time yield optimization as employed in a cement kiln by ABB.[8] At this kiln, a computer-based system for controlling, stabilizing, and optimizing process variables was introduced. It mimics the actions of an "ideal" cement plant operator focused on achieving particular targets. Based on the actual measures, adjustments to the process necessary to achieve the ideal process are calculated by the system. The newly calculated values for kiln feed, fuel flow, and fan damper position are then sent automatically to the kiln control system to drive the process towards the optimized kiln targets. Typically, real-time process optimization yields an improvement in throughput of up to 5 percent.[9]

Asset utilization. Improving asset utilization drives value by making the best use of a company's machinery park. Especially in asset-heavy industries with expensive machinery, every minute a machine does not produce causes a loss in terms of capital expenditures and lost revenue. Industry 4.0 levers like predictive maintenance can thus drive value by decreasing planned machine downtime, unplanned machine downtime, or changeover times. For example, GE[10] offers predictive maintenance in which remote sensors collect and report data on the condition of the machinery. Based on the sensor data, early signs of problems are detected for timely correction at minimal costs, maintenance resources can be prioritized and optimized, and machine availability can be increased. Typically, predictive maintenance decreases the total machine downtime by 30 to 50 percent and increases machine life by 20 to 40 percent.[11]

Exhibit 9

The McKinsey Digital Compass maps Industry 4.0 levers to the 8 main value drivers

1 Maintenance, repair, and operations

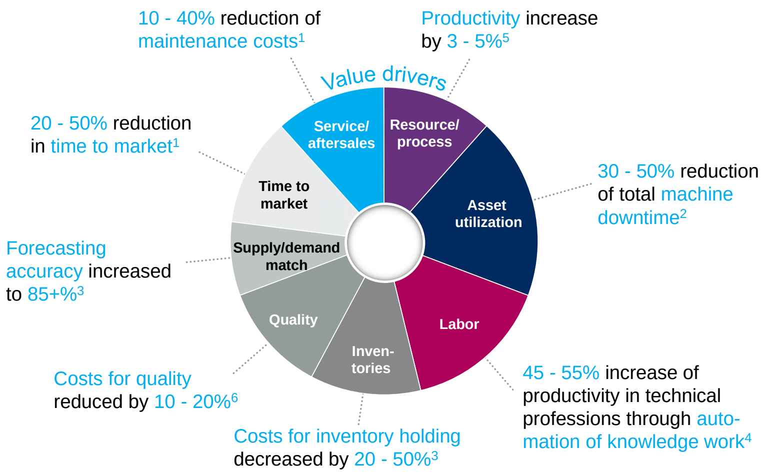
SOURCE: McKinsey

Labor. Since labor is an important cost driver in most industries, improving labor productivity can drive significant value. This value can be captured via levers that reduce waiting time (e.g., completion of previous process step in manufacturing, delayed delivery of a good in manufacturing, or a prototype in R&D) or increase the speed of workers' operations by reducing the strain or complexity of their tasks. Etalex, a Canadian manufacturer of warehouse furniture, introduced collaborative robots to increase labor productivity in their plant, as they were facing two problems: workers were manually loading press brakes with large metal parts, which is a physically straining task. Furthermore, the limited space did not lend itself to the addition of large machinery. Etalex therefore introduced human-robot collaboration, allowing humans and machines (collaborative robots from Universal Robots) to work in close proximity to each other without risking injury of the workers. Due to a built-in force control, the robot automatically reacts in case of contact with humans and slows down or even pauses its movements. Etalex was able to increase throughput, such that sales were increased by 40 percent, while maintaining the same employee base.[12] Another example of labor improvement is the case of the warehouse logistics company Knapp AG (see Text box 3).

Inventories. Too much inventory ties up capital, leading to high capital costs. Reducing excessive supply in stock can lower these. Industry 4.0 levers target the various drivers of excess inventory, such as inaccurate stock numbers that increase sludge, unreliable demand planning necessitating safety stock, or overproduction. Würth's iBins, for example, uses intelligent camera technologies to capture the actual fill level of a supply box whether it is stored on the shelf or has been moved to the production line. The box is wirelessly connected and automatically reorders supply based on accurate fill information.[13] Through levers like this real-time supply chain optimization, Industry 4.0 can typically reduce costs for inventory holding by 20 to 50 percent.[14]

Exhibit 10

Indicative quantification of value drivers



1 Cf. McKinsey Global Institute: Big data: The next frontier for innovation, competition, and productivity 2 McKinsey analysis
3 McKinsey analysis 4 Cf. McKinsey Global Institute: Disruptive Technologies 5 See, for example, ABB case study
6 Cf. T. Bauernhansl, M. ten Hompel, B. Vogel-Heuser (Hrsg.): Industrie 4.0 in Produktion/Automatisierung/Logistik (2014)

SOURCE: McKinsey

Text box 3: Knapp AG

Logistics company Knapp AG developed KiSoft Vision[15] – a paperless picking technology that uses augmented reality to optimize the picking process in a warehouse. This wearable technology resembles eyeglasses and is worn as a headset by the employee. Virtual information is shown on its see-through display, and all relevant information for the picking process is superimposed on the employee's field of vision. This information helps new employees locate items more quickly and precisely, guides them on optimal pallet building, and makes suggestions regarding the stacking of fragile items. While wearing the headset, the employee has both hands free for handling the items, since paper is not needed anymore. Furthermore, the integrated camera with image processing can also capture serial and lot ID numbers, thus enabling real-time stock tracking. The main benefits of the technology can be seen in the reduction of training time for new and seasonal workers, the acceleration of the picking process, and the reduction of the error rate by approximately 40 percent* (compared to the pick-by-paper approach).[16]

Quality. Improving quality is a value driver since scrap and products requiring rework lead to extra costs (for machine time, material and labor). These quality inefficiencies are caused by unstable processes in manufacturing, deficient packaging in the supply chain or distribution, and unskilled installation. Eliminating issues during the value creation process using Industry 4.0 levers such as SPC, advanced process control (APC), and digital performance management can create value. Toyota, for example, uses advanced analysis for real-time problem solving in the production process.[17] Real-time data analytics and APC enable real-time error corrections to minimize rework and scrap. We typically see a decrease in costs related to suboptimal quality of 10 to 20 percent[18] through Industry 4.0 quality levers.

Supply/demand match. Only a perfect understanding of the customer demand – regarding both the quantity and the product features customers are willing to pay for – maximizes the value captured from the market. Therefore, optimizing the match of supply to the actual demand with Industry 4.0 levers can seize value potential. Crowd forecasting based on advanced analytics, for example, can increase the accuracy of demand forecasting to 85+ percent[19] on a weekly basis. One automotive OEM uses the data-driven design lever by gathering information via the online configurator on its Web site and actual purchasing data to identify the product options that customers are willing to pay a premium for. As a result, the product offering could be limited to only 13,000 relevant options, thereby significantly decreasing development time and production costs.

Time to market. Reaching the market with a new product earlier creates additional value through increased revenues and potential early-mover advantages. Therefore, every Industry 4.0 lever that speeds up the development process such as concurrent engineering or rapid experimentation/prototyping (e.g., through 3D printing) will help drive this value. An extreme example is Local Motors. This manufacturer produces cars almost completely through 3D printing, with a design crowd sourced from an online community. They were able to reduce the development cycle from the industry average of six to seven years to one year and achieved a massive cost reduction in R&D.[20] Other OEMs, e.g., Vauxhall and GM, also use 3D printing and rapid prototyping. Typically, Industry 4.0 levers can reduce the time to market by 30 to 50 percent.[21]

* Even given that today's error rates are already only 0.35 percent, decreasing errors further is desirable since they usually have high follow-up costs.

Service/aftersales. Since the costs of operation are driven by service costs (e.g., maintenance, repair) and machine downtimes (e.g., due to unexpected incidents), offering solutions to decrease these to the customer can open up further value potential. One of these service levers is remote maintenance, and Secomea provides an example of its success. The company offers software solutions that allow technicians to establish a secure remote connection to industrial equipment to carry out a diagnosis without visiting the site. A customer reported that 50 percent[22] of the issues that normally require an on-site visit could be resolved remotely. Typically, we see maintenance cost reductions of 10 to 40 percent[23] through remote and predictive maintenance.

Our survey showed that participants see labor, quality, and resource/process as the biggest improvement potentials enabled by Industry 4.0. The area with the largest improvement potential will depend on the company and industry.

For example, in asset-heavy manufacturing businesses (such as those in the automotive industry), asset utilization is a big value driver. Therefore, remote monitoring and predictive maintenance will play an important role in capturing value. Both of them are levers to improve asset utilization by decreasing unscheduled downtime.

For businesses in the chemicals industry, besides asset utilization (Text box 4), the real-time process optimization lever will have a significant impact. Sensors allow close monitoring and real-time adaptation in complex chemical processes, thus resource/process effectiveness can be optimized.

In a specific company assessment, the McKinsey Digital Compass identifies the levers with the highest impact along the eight value drivers. To facilitate the prioritization, we assess how a company can leverage Industry 4.0 applications to optimize operations. In a first step, we

Text box 4: Nova Chemicals and SAP

Calgary-based Nova Chemicals was struggling to process more than 20,000 maintenance work orders per year at each of its 11 chemicals and plastics resins manufacturing facilities. To improve its maintenance scheduling, the company introduced advanced analytics and cloud computing in collaboration with SAP. Today, the SAP EAM software provides a complete and consolidated view of scheduled maintenance at Nova Chemicals. It facilitates maintenance scheduling, work execution, and material availability processes. All key stakeholders can access information relevant to them – for instance, business users can get a daily and weekly view of work scheduled, priorities, resources required, scheduling conflicts, and project status – and gain a better understanding of the wide-ranging effects of maintenance operations. The results of the improved coordination and integration of maintenance scheduling are highly visible: the number of unplanned equipment outages has been cut significantly; time spent on reactive, emergency work has been reduced by 47 percent; and the time spent on proactive, preventative maintenance has increased by 61 percent. Additionally, maintenance schedule compliance has improved by 22 percent within a year-long process that also included a pilot program.[24]

identify the value drivers that have the highest impact on the company performance based on the industry characteristics and cost structure. We then determine how value can be captured within these value drivers using Industry 4.0 levers.

2.3 Activating Industry 4.0 levers will require preparation along four dimensions

> *Industry 4.0 provides a new way of doing business and a new source of creating value, especially for traditional manufacturing companies. Large industrial companies like auto manufacturers and steelmakers could already benefit from industrial automation, but we believe that Industry 4.0 will change the manufacturing process and resource allocation of small to medium-sized manufacturers significantly.*
>
> *Even though we have all the enablers to make Industry 4.0 feasible such as connectivity technology, affordable IoT hardware, standardized communication protocol, collecting meaningful data and analyzing for implications are still the biggest challenges to driving the impact from Industry 4.0.*
>
> ***Taejin Kim,*** EVP and Head of New Business Development Team, Kolon Corporation

In addition to activating specific Industry 4.0 levers, companies have to ensure the information flow they draw upon in order to reap the full benefits of this revolution. The following recommendations aim at better managing the digital thread and will help companies get ready for operational improvements through Industry 4.0:

Manage, integrate, and analyze data across sources and companies. Moving from an analog factory to a digital thread requires businesses to transcend the traditional boundaries of functions, production sites, and companies. To enable an information flow, disparate sources of data need to be integrated, from different applications both within and from outside the company. For the short term, this might even imply that the integration needs to be carried out manually via Excel. For the long term, integrated systems with common standards should be implemented.

Share outcomes across the value chain. To fully leverage the value of data along the entire digital thread, information needs to be shared across company borders – both with customers and suppliers. This means that companies need to build structures to exchange and integrate information. Outcomes of analysis need to be shared as real-time feedback across the value chain – from design and production through service and end of life – to allow quick reactions and adaptations.

Ensure integration with physical production assets. To actually map the physical lifecycle onto the digital sphere, companies need to close the "digital gap" in production and install sensors and actuators across their production equipment. Data captured at the shop floor forms the basis for Industry 4.0 levers such as predictive maintenance and real-time process optimization. While installing sensors/actuators is the first step, they need to be connected (also with the central systems) in a second step through secure wireless networks. To best integrate the production and IT, companies need to ensure that IT process and control know-how are developed on the shop floor.

Rethink the design of classical production systems. To capture the full Industry 4.0 potential, companies need to increase the flexibility of production. This applies to production lines and systems within a company on the one hand and production networks across companies on the other hand, and involves several stages of value add. Employing dynamically programmable production technology in combination with increased flexibility of the machine itself (e.g., flexible grip hooks) has multiple benefits, among them are individualized customization, more dynamic allocation of resources/capacity, shorter changeover times, and reduced production complexity with fewer constraints. This allows for faster, cheaper, easier, and more diverse production processes.

Another driver to increase flexibility can be the decentralization of intelligence, e.g., with intelligent lots. Further optimizing the production flow for highly complex manufacturing processes with high variability (e.g., in semiconductors) at a central level might become a mission impossible at some point.

The next level of optimization may be delegating the process to smaller units (equipment, work pieces) by assigning a few simple rules to those units. The spatial decoupling of physical assets and their monitoring and steering also allows for more agility and flexibility. In cases of unplanned machine stops, for example, a quick remote analysis of the issue and potentially a remotely steered restart instead of physically walking to the machine can decrease the reaction time significantly. New forms of human-machine interaction can facilitate the interaction with complex systems (e.g., via visual interfaces on tablets instead of complex program codes) as well as with new intelligent machinery (e.g., where people and robots work at the same station within a production line).

2.4 Future, fully optimized manufacturing sites will converge towards three plant archetypes

In the long run, Industry 4.0 will not just impact current plants by improving operational effectiveness through new, disruptive technologies. It will also help manufacturers develop the next generation of plant models to address the evolution of demand.

> *The way we see our own plants in the future is being split into two categories:*
>
> — *A traditional category with large specialized and vertical plants highly optimized by some advanced process control using thousands of sensors providing online data processed by highly sophisticated decision making tools, located in large industrial basins outside of cities and strongly interconnected with their industrial neighbors. Those industrial parks or basins require a large infrastructure and perfect logistics to deliver final goods to remote places.*
>
> — *A new category with mini and micro stand-alone plants embedded into the dense urban tissue, flexible and able to provide products for consumers nearby. Those new urban plants will be very compact, energy efficient, safe, clean, esthetical, or invisible, with minimal environmental impact. They will be easily accessible for users and also for the people serving them.*
>
> ***Philippe Queille,*** Group R&D VP, Asia at Air Liquide

We see three archetypes of next-generation plant models emerging, all drawing upon various Industry 4.0 value levers but each to a different extent and with a different emphasis depending on which demand segment and needs they address (Exhibit 11):

- **Smart automated plants** address the need for mass products at low cost and are fully automated, digitized, and highly cost efficient. These plants produce large volumes and commodities.
- **Customer-centric plants** address trend markets. These are ultraresponsive plants producing highly customized products at scale and affordable cost to address the trend towards mass personalization.
- **E-plant in a box** addresses niche and remote markets. This small-scale, low-capex, mobile plant is able to produce a limited range of products at a new location and can be set up quickly to address subscale niche and remote markets.

Smart automated plants. On the mass market, 1.8 billion new consumers in the next 10 years will drive huge demand for low-cost products. To capture these opportunities, companies can leverage Industry 4.0 levers to develop a new generation of smart automated plants with innovative features. The supply chain will be integrated end to end, enabling full transparency and optimization of the digital thread, resulting in automated and mostly uninterrupted processes and end-to-end material flows (see Text box 5). In addition, robots, which already offer the potential for significant increases in labor productivity, will not only be smarter but also more collaborative and safer. Improved human-robot collaboration will thus enable operators to work more safely right next to robots on the shop floor (see labor-related example in section 2.2).

Text box 5: BMW i3 plant in Leipzig

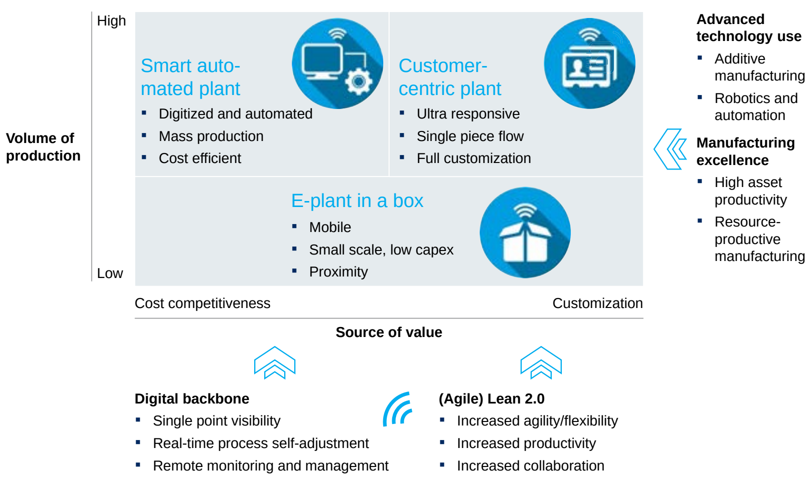
The BMW i3 plant in Leipzig can be considered an early example of the smart automated plant archetype, as it is an integrated and highly automated plant. Robots are used at each stage of production, including the body shop, the paint shop, and the assembly shop. Real-time RFID product tracking and localization is in place, and operators have mobile control tablets to monitor and access all data. Finally, plant management is centralized in one main building that acts as a "central nervous system" for the plant.[25]

The plant will provide very high productivity per machine due to the ability to use predictive maintenance to reduce unplanned downtime and high throughput from real-time yield optimization.

Systematic management of the digital thread leveraging disruptive technologies such as the IoT and M2M communication will, for example, enable full visibility of plant operations, remote monitoring and control, and real-time optimization. Based on these technologies, digital performance management will play an important role for production scheduling, control, and issue resolution. This will be feasible not just within the plant but across a global network of plants. Managing the digital thread end to end will also facilitate information sharing with suppliers and distributors, enabling further operational effectiveness through approaches such as real-time supply chain optimization and data-driven demand prediction, which will reduce inventory costs and improve service levels due to a better match between supply and demand.

Exhibit 11

For greenfield scenarios, 3 different emerging archetypes for "plant of the future" all reflect Industry 4.0 levers



SOURCE: McKinsey

Finished products from the smart automated plant will go to the mass market, while semi-finished products could be "raw material" for customer-centric plants or the e-plants in a box.

Customer-centric plants. Demand will also evolve qualitatively, driven by the powerful trend towards ever-greater mass personalization. How can so many customers be served in a segment of one? "Customer-centric plants" are likely to bridge the gap between a global, integrated supply chain already benefiting from economies of scale and a personalized approach to production and service. Leveraging Industry 4.0 levers such as digital manufacturing, 3D printing, and advanced robotics, these plants will have a range of key features (see Text box 6).

Customers will design their products online; routing flexibility means that the models will be sent directly to the most suitable factory once the order has been placed. An ultraflexible supply chain will produce in Batch Size 1 mode triggered in real time by customers' orders, leading to very short lead times. The supply of inputs and semifinished goods will be based on data-driven demand prediction.

Machines will be extremely flexible, designed to minimize changeover time to adapt to changes in demand in terms of volumes, specifications, and other parameters. Hence, despite the flexibility, the plant will still be able to provide very high productivity per machine as high utilization rates are still achievable.

Extensive use will be made of 3D printers to, for example, quickly get customized tools and molds to plug into production line machines. This will dramatically increase the range of products that the lines can make, opening up a vast catalog of combinations for customers without increasing inventories, as 3D printing can be done in situ. Based on the additional information gathered, it will furthermore become possible to proactively reach out to customers to propose highly customized products and sell services based on these customized products.

Text box 6: Stratasys – manufacturer of 3D printers and production systems

Stratasys is a manufacturer of 3D printers and 3D production systems. RedEye, a Stratasys company, has developed a rapid prototyping and 3D printing service bureau that produces complex, high-quality models and working parts in low volumes. Its large production capacity, including one large factory in the US and a network of local facilities, allows the company to reduce lead time. It has a fully integrated and optimized supply chain from online design tools to global manufacturing dispatching.[26]

E-plant in a box. Both smart automated plants and customer-centric plants imply heavy capital expenditures, which will require sufficiently high production volumes and thus large-scale demand to be profitable. But how can subscale niche and remote markets be addressed, such as growing but highly-fragmented African markets? This is why e-plant in a box will emerge, empowered by Industry 4.0 levers such as 3D printing. These small-scale, low-capex mobile plants can quickly be set up at new locations at competitive costs to produce small series of products. For this plant type, the overarching goal is not just operational effectiveness but rather also to leverage Industry 4.0 to tap into new value pools by enabling plant operations at remote locations or in markets that would normally be considered subscale. The key features of this plant type are described below.

The e-plant in a box is a prefabricated facility, agile and mobile, and potentially delivered in containers (see Text box 7). In its high-end version, the e-plant in a box could have customers stopping by to design their own products on-site with the help of specialists. They could choose structures and materials, draw on simulation tools, and later come back to pick up their product at the plant. Hence, the e-plant in a box will be highly adaptable to local trends due to its proximity to customers and local ecosystem and, what is more, time to market will also be reduced thanks to the proximity to suppliers and customers.

The plant will only be lightly automated, yet operators can leverage technology to help them in their work. Several Industry 4.0 levers can also be applied in this type of plant. An exoskeleton, leveraging human-robot collaboration, could for example relieve workers of the strain of heavy loads, as well as being light and affordable. Another example is a flexible manufacturing system with "plug-and-play" robots conducting specific tasks where the benefit is the highest. 3D printing could be used for spare and customized parts, thereby reducing inventories and at the same time also reducing freight costs and bypassing import tariffs.

End-to-end information flow will enable highly-skilled central teams to support the e-plant in a box with customer analytics, process improvement, design, and maintenance.

Finally, the e-plant in a box is fully integrated in its ecosystem, producing its own energy, for instance. Thus, it does not need to be located in an industrial area. It can be close to malls and other areas convenient to customers.

Text box 7: KUBio, an innovative off-the-shelf, modular factory by GE

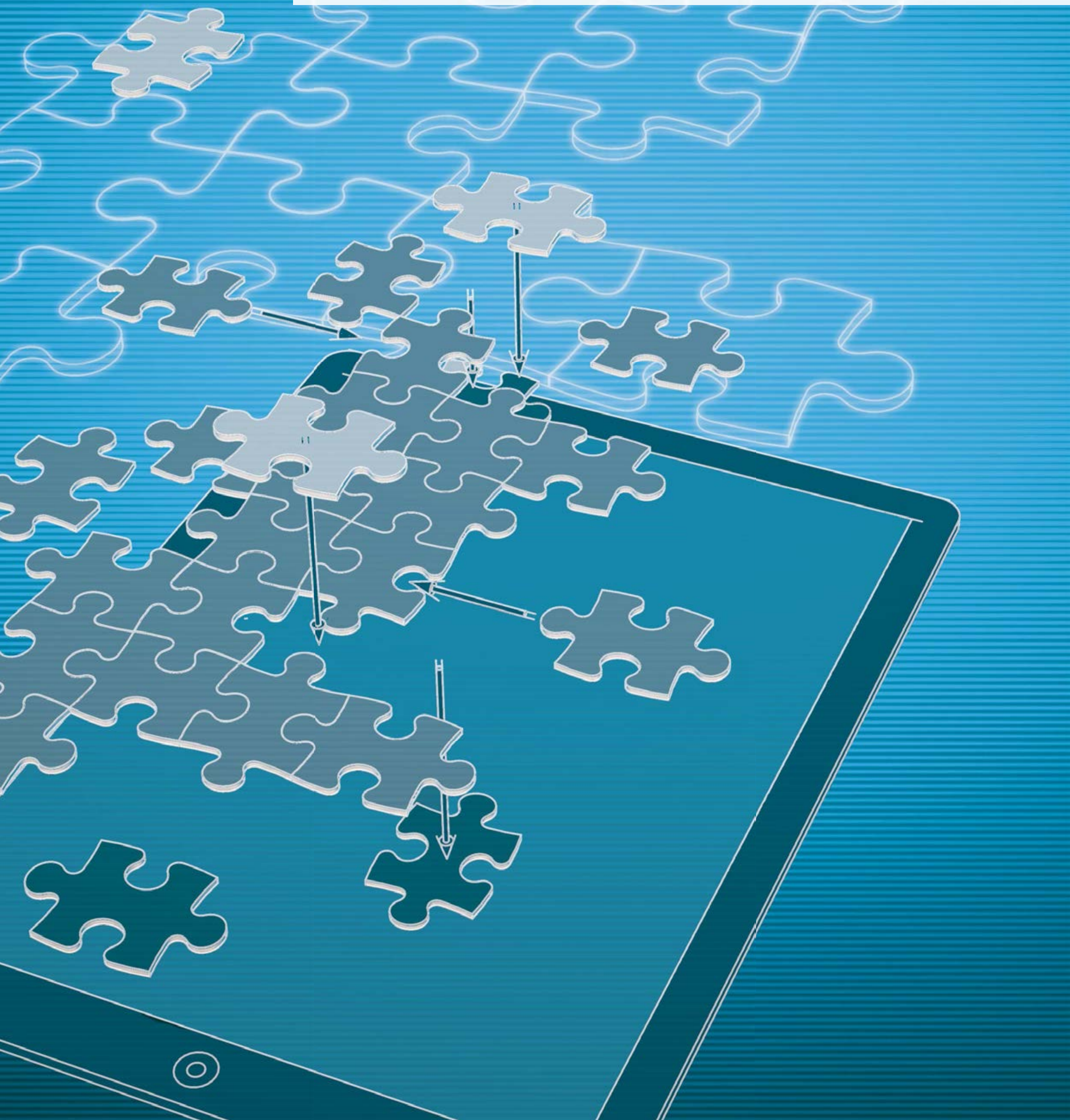
KUBio, an innovative off-the-shelf, modular factory introduced in 2012 by GE Healthcare, offers an early example of the e-plant in a box. It is a prefabricated facility and process solution designed for the scalable and cost-efficient production of monoclonal antibodies (MAbs). Prevalidated modular units and processing equipment are transported to the customer's site of choice, where they are assembled and ready to run within 14 to 18 months. Manufacturers can thus respond to local healthcare needs and bring treatments to the market more quickly. KUBio thus reduces operational costs by enabling faster deployment, accelerated production turnaround, multiproduct processing, and scalable production.[27]

The pace of adoption of these next-generation plants will be dependent on the answers to a range of key questions, such as what customers value in the future, how quickly new business models emerge, the speed of technology adoption and convergence, and how technologies change the role of plants in the value chain. Independent of the pace, it is clear that the plants of the future will differ dramatically from today's.

> *Michelin's future plants will be considerably different from those of today. But we must always – and even more and more – build them around man.*
>
> ***Dominique Foucard,*** Head of Industrial Performance at Michelin

3.

The value chain disruption will prompt players to radically rethink their way of doing business



With information at their core, the disruptive technologies of Industry 4.0 usher in new opportunities for digital integration and data-driven services. As a result, new business models are arising around novel value propositions – all heavily driven by new possibilities to collect, use, and share data. Novel business models can be built on offering solutions around integration and new services, enabling manufacturing companies to capture this emerging value. Data in this context is not associated with operational effectiveness: it should be viewed as an asset that is leveraged to generate value. Companies therefore need to ask themselves how to capitalize on existing data, and how to collect data relevant to new value propositions.

3.1 Four new types of business models are arising around new value propositions

Four new types of business models are emerging, each leveraging the disruptive technologies while providing opportunities for existing and new players (Exhibit 12).

Platforms

The first new type of business model has emerged around so-called platforms, which have in common that products, services, and information can be exchanged via predefined communication streams. Two main archetypes are crystallizing among the many different subtypes that exist.

An **interaction platform** provides a "marketplace," i.e., the technological conditions to connect multiple parties and coordinate their interactions. The provider adds value to the system by ensuring a certain quality level and ideal distribution of the goods and services offered. One example is the field of additive manufacturing, where players are typically focused on selling machinery. However, the trend is moving towards contract manufacturing, where companies specify the parts to be produced using CAD models, with the machine owners/operators performing the actual production. Platforms can act as a marketplace linking supply (operators/owners) and demand (purchaser). SLM Solutions, a 3D printer manufacturer, and Atos, a software company, are currently piloting such a marketplace. The vision is to develop an integrated production network where machines are connected via the Internet and customer orders are produced with optimal capacity utilization.[28]

Exhibit 12

There are 4 main trends regarding new business models that exploit opportunities

As-a-service business models

Pay-by-usage/subscription-based models for machinery

- New payment models transform capex into opex for manufacturers
- Perpetuation of revenue streams instead of one-off asset sale for suppliers

Platforms

Provisioning of

- Technology platforms: ecosystems for developers based on open systems
- Broker platforms: industrial spot markets that connect third parties (e.g., for excess production capacity)

IPR[1]-based business models

IPR-based services

- Recurring revenue models (e.g., licensing fees for data standards)
- Add-on services for primary products (e.g., consulting on best usage of products)

Data-driven business models

Usage of (crowd-sourced) data for

- Direct monetization of collected data instead of primary product (e.g., Google)
- Indirect monetization of insights from collected data (e.g., microsegmentation for pricing or customization)

1 Intellectual property rights

SOURCE: McKinsey

The second archetype is a **technology platform** or **ecosystem.** In this new business model, companies facilitate the further development of advanced products and applications based on their own original technologies and products. One example of this is the Nvidia Ecosystem. Nvidia is a producer of graphics processors and technologies, and visual computing software – they have also established a developer platform to increase the sales and reach of their core products. Their offerings in the so-called ecosystem can be clustered by target audience. For software developers, they provide resources for fully leveraging the underlying Nvidia technology, for instance, while programs have been established to support start-ups in building their business around Nvidia products. Many of these offerings are free of charge and easily accessible. This business model is beneficial in that many companies use Nvidia's technology as a platform for the development of their own applications and products while at the same time promoting the Nvidia product and brand.[29]

”

In order to successfully develop a platform-based business model, companies must:

- Embrace that in the future industrial platforms will become the dominant market architecture, which might disrupt the way companies do business. This creates an innovator's dilemma – hence, the topic should be placed on the CXO agenda

- Understand what it means to develop and manage a platform – and acknowledge that the development will often take place in an uncertain environment and hence requires a lab-style "trial and error approach"

- Decide in an early stage if they want to build a rather closed or an open platform, and choose the right partners to develop the platform core accordingly.

Ansgar Baums, Director Corporate Affairs at HP and author of *The DNA of Industry 4.0: Industry Platforms* (http://plattform-maerkte.de/)

As-a-service business models

Technology and automation providers may move from selling machinery to a **pay-by-usage model,** where the machine is located at the production site of the manufacturer, but payment is based on usage rather than an initial fixed total price. Instead of having high fixed costs/capex, the cost of machinery can be translated into variable costs/opex. For the supplier, this opens up interesting opportunities as well, especially considering the additional data that can be collected during operation of the machine. Furthermore, what used to be one-off revenue streams from asset sales could be perpetuated through **subscription-based** models. Another aspect might be the resulting modularization of production networks. While a machine might be located on the production site of one manufacturer, the idle time could be sold to another manufacturer that produces in the same area. As an example, we could look at the software industry, where many companies offer software or infrastructure as a service. The advantages of this – such as greater flexibility, easy scalability, or quick updatability – could also be captured when offering assets as a service: AspenTech is one example. This software supplier that optimizes process manufacturing shifted to a subscription model and increased their share of recurring revenue from some 25 percent to around 90 percent* over the course of eight years.[30]

IPR-based business models
These models may provide a new approach for recurring revenue generation in addition to or instead of a one-off asset sale. Many manufacturing companies currently lack the expertise and experience to generate value from their proprietary data. Recurring business could be based on the subscription of software, maintenance, and support. Since many companies have deep expertise on their products, this knowledge can be monetized by offering add-on services such as training courses. The consulting service SAP offers apart from their software could serve as a model for manufacturing companies. Helping customers optimize asset utilization via their equipment would be one such IPR-based revenue model. This business model is closely linked to the ever-increasing value of software and the greater importance of data as a raw material.

An example of an IPR-based business model can be seen in mobile communication standards. Qualcomm actively drove standardization efforts for 3G and was successful in shaping many standards that were advantageous for its own IP portfolio. Many technologies did not take off until an open technological standard was established, and, as a result, OEMs and competitors have to pay royalties to Qualcomm today.[31] Qualcomm now makes two-thirds of its profits (USD 3 billion in 2010) and one-third of its revenues from licensing.

Data-driven business models
New ways of collecting and using data can be leveraged through the use of data-driven business models. Two options can be observed: direct and indirect monetization of data.

For direct monetization of data, one method of collecting data is via a primary product. Google is the most prominent example of this. A search engine as primary product creates the data that is further analyzed and used for targeted advertising, which results in a natural revenue stream. Similar models can be promising in the manufacturing environment as well. A first step in this development can be observed when looking at the SCiO.[32] This is a low-cost, pocket-sized spectrometer based on near-IR spectroscopy costing only USD 249. It is aimed at consumer applications and allows customers to obtain information about the chemical composition of a product using their smartphone by simply scanning the object. Every user automatically contributes to building a large database of materials as all scans are gathered in this database. The funding for this project was obtained via a Kickstarter campaign: the financing goal was reached within one day. Another way to generate data for the direct monetization model is crowdsourcing. It allows companies to enhance their data-driven offerings with external knowledge at an affordable cost. Crowdsourcing of data means that companies obtain services, ideas, or content by receiving contributions from a large group of people and, especially, from an online community rather than from traditional employees or suppliers. An example is Kaggle,[33] which offers access to a community of over 140,000 data scientists competing against each other to create the best predictive model. Companies can generate competitions based on their challenges and choose the best solution from the data scientists' contributions.

* Fiscal year ending June. Data for 2014 is estimated based on quarters 1 - 3.

Indirect monetization refers to the use of these insights to, for example, identify and target specific customer needs and characteristics. Information on the customer allows for pricing micro-segmentation, such as tailoring insurance premiums to actual behavior patterns. Enabling very specific customization via data insight can be a business model in and of itself. Using the data collected across machinery utilized by customers can generate value-added services, for instance, such as highly specific maintenance plans that account for the actual usage patterns of a specific client.

3.2 As business models change, so will value pools

These new business models are leading to a shift away from physical product revenues towards more service-based revenues, platforms, and developer ecosystems, so this will result in a shift in value pools* for both manufacturers and suppliers (Exhibit 13). While in the manufacturing industry actual product sales have traditionally been the largest value pool in terms of the proportion of overall expenditure, this share is likely to decline in the future.

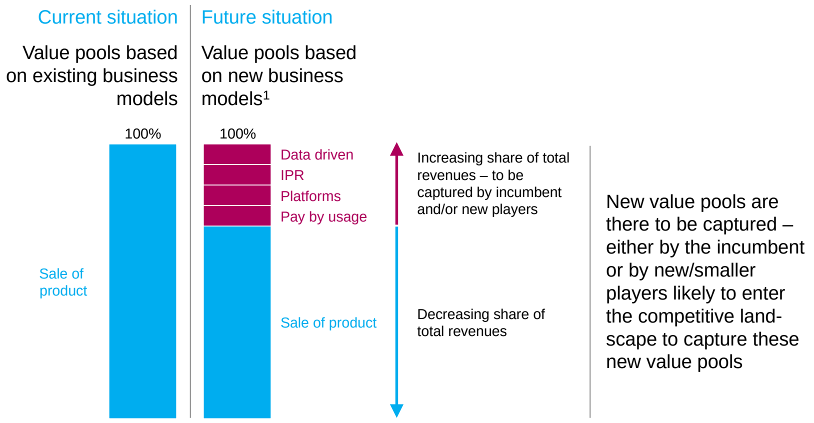
For automotive manufacturers, for example, value pools are shifting from upfront revenues to usage-based revenues derived from software and/or services. This is mainly driven by connectivity, with the potential to trigger a significant redistribution of revenues along five major automotive revenue pools: vehicle price, connectivity hardware, driver time and attention, maintenance, and insurance. Hardware will become more commoditized, lowering the barriers for new market entrants. Traditional value chains will be dismantled, creating new value pools and thus new opportunities. Being able to deliver along the new business models described above will be key to tapping this new potential.

Industry 4.0 has the potential to create additional value and redistribute existing value pools. The maintenance contract that Siemens has with various British rail operators regarding

* Value pools can be defined as sources of profit distributed along the value chain in a given industry.

Exhibit 13

Changes in business model structure will also lead to a change in value pools



1 Total may be larger/smaller than current situation, and as such can be both a win-win situation or a situation where one player captures a share from another player

SOURCE: McKinsey

their Desiro UK trains is an example of such a win-win situation: Siemens guarantees a train availability of at least 99 percent, and consistently outperforms this target via continuous monitoring and predictive maintenance. This increased availability has resulted in fewer delays and higher customer satisfaction for UK rail operators, while the maintenance contracts generate additional revenues for Siemens. The new approach to using data and expertise for value-adding services opens up new value pools for both parties involved. As this example shows, a shift in value pools does not necessarily result in shrinkage of overall value, for the "new" 100 percent value pool may well be larger than ever before.[34]

3.3 Manufacturing's competitive landscape will become more complex and uncertain

Currently, many of the disruptive technologies are driven by small, innovative companies that have specialized in a given (often rather narrow) field. These companies are frequently able to be more agile than larger, established companies – and agility is often associated with a competitive advantage in environments undergoing significant change. Smaller companies are generally able to implement new business models more easily, while larger ones need to think about how to become more agile. Should they collaborate with smaller players or develop strategic alliances? For small and new players, the disruptive technologies provide an opportunity to enter the competitive landscape and capture emerging new value pools.

This inevitably leads to transformation of the competitive landscape for the classic manufacturing value chain. The number of players is likely to increase, driving up complexity and the multiplicity of interfaces (Exhibit 14). One result is likely to be the increasing emergence of highly specialized players. Another consequence of the shifts in the value chain may be the entry of incumbents from outside the traditional manufacturing arena, such as telco companies supplying solutions for M2M connectivity or data security.

As a consequence, traditional value chains are experiencing radical transformation. Instead of one company developing and producing an entire product, a higher degree of specialization is likely to occur (disintegration of the value chain). This can already be seen in the semiconductor industry, for example, where foundries are fabricating products for other semiconductor companies – so-called fabless: the focus is on developing and marketing the technology. This is especially interesting in industries with a high level of complexity and great investment needs for production facilities. For other companies, a stronger collaboration along value chain steps (integration) could present more opportunities than disintegration. An example is the automotive aftermarket. Companies can apply condition monitoring to optimize their maintenance and repair business, reducing the cost of their services, better utilizing their workshops and improving their spare parts planning.

With such significant disruption of the value chain expected, there are still many uncharted fields – cybersecurity, for instance – where it is still open which type of company will become the dominant player. Will it be IT companies, telcos or chip providers, or will an entirely new type of provider develop around the new demand?

3.4 Three key success factors for adapting to the disrupted value chain

Our survey indicates that 92 percent of Industry 4.0 suppliers and 74 percent of manufacturers expect Industry 4.0 to have an impact on their business model.[35] The key is to be proactive and apply a three-step process to successfully implement new business models and face the changing competitive landscape.

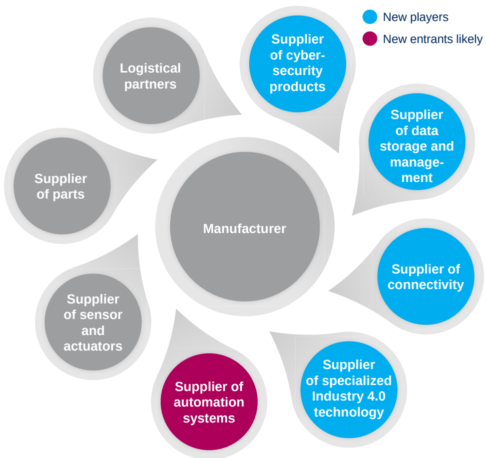
1. Begin by evaluating your current assets. Not every type of new business model is suitable for a given company, and companies should therefore think critically about their starting point. They should first reassess their current assets from a new perspective with respect to the opportunities and changes they expect from Industry 4.0. Current assets include available data, existing insights, and capabilities: a reevaluation can help understand which of these assets are truly distinctive and potentially underleveraged from an Industry 4.0 perspective. New insights that facilitate the identification of potential new business models can also be generated by first utilizing existing data.

2. Secure control points. The second step would be to identify and secure control points in the shifted value chain. A control point is an element of the full customer proposition (product, service) in a given market segment that needs to be owned/controlled by a company to sustainably create profit throughout the value chain. Examples are proprietary data as owned by Google, proprietary technology platforms as owned by Apple, or Amazon-style algorithms and experiences. Access to customers such as that of Apple via iTunes, the barrier of switching costs that keeps customers from changing their ARM architecture, and regulations that give banks the almost exclusive license to take deposits from the general public are further such control points. Companies should therefore invest time in determining control points and subsequently secure these, for instance, by building capabilities within the company, pursuing M&A activities, or strategic partnerships. It is also important to reduce efforts and investments in areas of the value chain that have become commoditized. An example would be the semiconductor industry, which transitioned from being an integrated value chain in the 1980s to today's strict division between design and manufacturing. In this case the control point was the design, while manufacturing was becoming commoditized.

Exhibit 14

Changes in the competitive landscape are likely and will probably increase complexity and uncertainty

The competitive landscape for the traditional manufacturing value chain will fundamentally change…



… towards increasing complexity and uncertainty in the short run

- Overall, the **number of players will increase,** driving up complexity and the number of interfaces
- **New players** that were not formerly part of the traditional manufacturing value chain will enter the scene (e.g., telco companies supplying connectivity)
- **Known players** – like IT companies – will provide **new products** like data storage solutions
- For **some aspects** – like cyber-security – the **dominant type of player is not yet clear** (e.g., IT company vs. telco company vs. chip provider)

SOURCE: McKinsey

3. Drive agility in a dynamic environment. Finally, companies need to anchor agility in their organization to continuously be able to adapt to a changing competitive landscape. In a dynamic environment it is important to always be in the know about competitors and new entrants. What changes are under way in the market? Who are the players trying to capture a given value pool? What is their strategy?

It is not just a company's own market environment that is relevant: other markets and industries may also provide insights into potential trends. Companies can identify business models that are transferable to their own industry by analyzing other industries (such as consumer electronics), potentially hoisting themselves into the driver's seat of new developments.

> *In the past, Enterprise IT was an efficiency driver that enabled the management of complex, global processes. Now, digital information itself is becoming the product or part of the product. We are working with many customers to establish a new strategic digital core competency to create completely new and enhanced product and service offerings. This core competency will define the next wave of productivity and competitiveness for whole economies.*
>
> ***Bernd Leukert,*** Member of the Executive Board, Products & Innovation at SAP SE

4.

Players need to establish the foundations for a digital transformation to capture the opportunities of Industry 4.0 technologies

Companies need to establish five digital pillars to support and benefit from the two sources of profit opportunity that come with Industry 4.0 technologies: falling costs and rising revenues. These pillars are key to capitalizing on opportunities, but are mostly not at the core of manufacturing companies today. This makes it more challenging but also even more crucial to focus efforts and ensure that the company quickly builds this foundation.

> *Industry 4.0 will impact the whole product lifecycle end to end – from design to production, the actual usage phase until end-of-life – and cannot be attributed to one single department of the firm. The digital transformation is a cross-functional effort that needs to be addressed by the whole company.*
>
> ***Dr. Reinhold Achatz,*** Head of Corporate Function Technology, Innovation & Sustainability at ThyssenKrupp Corporation

4.1 Build relevant digital capabilities

Industry 4.0 is a cross-cutting topic that touches all areas of the enterprise. Yet factories are generally organized in functional silos – for example, their supply chain management does not take direct customer feedback into account. In Industry 4.0, however, it will be vital to combine data, integrate systems and processes, and make decisions based on cross-functional information.

> *Industry 4.0 is a global leadership topic that should be on top of the CXO agenda. Unless top level management is involved, companies will not be able to successfully transform into a digital company. In 5 to 10 years' time digital will be the foundation of every business. Many companies are starting to understand this, but they struggle to transform while maintaining daily operations. Industry 4.0 is just as much about innovation as it is about effectiveness.*
>
> ***Lars Zimmermann,*** Executive Vice President at hyvent GmbH

Enterprises will ideally build these digital capabilities along two dimensions:

Attract digital talent. Smart companies will swiftly build a basic understanding of how to deal with Industry 4.0 technologies and adapt to shorter innovation cycles for a broad range of employees. This includes all shop-floor staff who require basic process and IT systems know-how to ensure the link from the digital world back to the physical world. New business models and operational improvements based on cross-functional information require in-depth understanding of overall processes, systems, and data. Enterprises need to seek data and process experts who can operate at the interfaces between functions and systems and are well connected to the subject matter experts (whether shop-floor managers, customer relationship managers, or supply chain managers). These experts should draw insights from the different types of information generated in all parts of the enterprise. When developing new (data-driven) business models, these experts are the hub for designing new products due to their broad knowledge of the overall production chain.

Set up cross-functional governance and steering. Breaking up silo structures requires a proper governance setup. Integration across functions needs to be reflected in the organizational structure since cross-functional teams are a key piece of the puzzle. A useful way to drive this change is to establish a task force that covers all relevant functions and reports directly to the CEO (or the Chief Digital/Transformation Officer), empowered with the authority to tap into every process flow, system, and database. Installing corporate KPI targets throughout the organization for every line manager also helps permeate traditional silos.

4.2 Facilitate collaboration in the industry ecosystem

Industry 4.0 goes beyond internal manufacturing. The increasing connection of companies with third parties along the value chain creates the need for alliances and interoperability standards. Companies thus should:

Seek alliances and strategic partnerships. One of the main impacts from Industry 4.0 on companies is the increasing need to integrate data and processes from outside the company. This applies to multiple steps in the value chain, as seen above in the context of operational efficiency when analyzing new business models. Where it is not possible for a single company to address specific revenue potential alone, partnerships with other companies that offer complementary technologies may be the solution.

Get involved in the definition of standards. To gain a competitive advantage, companies should deeply involve themselves in defining future interoperability standards and ensure readiness of their organization and technology. As soon as industry standards evolve, all players will be forced to apply them to their products. Companies will therefore ideally partner with suppliers, IT companies, connectivity providers, and/or competitors on developing industrywide standards. For those players who were not involved in shaping these standards, this could result in higher development and production costs. Involvement with associations such as the Industrial Internet Consortium (IIC) may yield an information edge on potential future industry developments[36] and provide a platform for forming strategic partnerships.

From a technological perspective, manufacturing sites as well as global supply and value chains will be highly interconnected and collaborative at a global level, enabled by a global digital backbone. The key feature of this new manufacturing paradigm will be collaborative agility, i.e., the ability to adapt almost instantly to changes in demand and setup of the industry landscape, whether of a regulatory nature, or with regard to input prices or technologies. Alliances, strategic partnerships, and cooperation in communities are therefore crucial for building up a network and maintaining a competitive edge.

4.3 Manage data as a valuable asset

As data will be the key to occupying the control points along the value chain, companies need to understand and manage data as one of their most important assets. In particular, they should take the following two approaches:

> *One of the biggest disruptions of Industry 4.0 is the ever-increasing value and importance of data. Companies need to think about data as a precious raw material. Therefore, companies will need to change the way they think about and manage large amounts of data and information. This will be one of the biggest challenges for traditional manufacturing companies.*
>
> ***William P. King,*** CTO of the Digital Manufacturing and Design Innovation Institute at the University of Illinois

Develop data as an asset. Given the importance of data and information, it is important to also treat and develop data as a central business asset. This means data needs to be actively managed at all stages of the data lifecycle (i.e., collected, stored, analyzed, shared, and archived) through defined data practices, standards, and policies. Only accurate, up-to-date, accessible, usable, and well-governed data will bring distinct value to the business. Companies should, for example, define data models and governance for data that is stored decentrally to ensure it can be leveraged across the company. Management of data must also be fully integrated with the core processes of a business model using the data.

Manage data strategically. Decisions regarding questions such as which data to share with whom are likely to grow in strategic importance. Which control points are sensitive and should be protected, and where is the added value in sharing data? If data presents a competitive advantage – e.g., because data on customer behavior helps to understand real customer needs – or an intellectual property that is crucial for the company to deliver on its value proposition, it should be protected so as not to lose this advantage to the competition. With the increasing importance of data, competitive advantages will depend on it to an even greater extent.

Finding the right balance between sharing and protecting data will be a strategic issue, while questions regarding data architecture and data protection will require an implementation focus.

4.4 Enable rapid and agile IT development via two-speed systems and data architecture

Quickly changing products and services resulting from a shift in customer expectations require agile software development methods with daily or weekly release cycles. As these short release cycles are not only often a challenge for established IT processes, but also for existing IT and data infrastructure, companies should make the following preparations:

Introduce a parallel fast-speed IT and data infrastructure. Since not all processes require quick release cycles, a parallel fast-speed architecture should be introduced alongside the transactional architecture. The latter comprises all robust and reliable services based on conventional IT systems (such as ERP, CRM, accounting, and financial reporting). This will continue to work on conventional waterfall-based release management in quarterly or semiannual cycles in self-hosted scenarios, or increasingly be sourced in software-as-a-service models (e.g., Salesforce.com). The fast-speed architecture also allows agile development, experimentation and prototyping of innovation. It usually consists of a virtual (or cloud) infrastructure offering a number of deployment environments and tailored databases.

Establish data interfaces. The fast-speed architecture requires manifold interfaces with the transactional architecture, the connected devices on the shop floor and with customers, supplier systems, and even with competitor systems. Companies should make use of emerging data and interface standards to minimize the effort required for the continuous integration of new data sources.

4.5 Ensure cybersecurity

The threat of cyberrisk is on the rise in a hyperconnected world. The Internet of Things means that physical targets such as connected machinery will become of interest to hackers. For example, systems installed for remote access will become highly susceptible to attacks with the goal of, e.g., sabotaging infrastructure or industrial facilities. Companies need to protect themselves against attacks from state- or business-sponsored entities, politically motivated hackers, and organized crime. Cybersecurity poses significant risks and needs to be a top management issue.

While systems can never be 100 percent safeguarded, four practices should be deployed to effectively manage cyberrisk:

- **Prioritize protection around key assets.** First, create a baseline of information and production assets, and assess their individual cyberrisk by attractiveness to adversaries and damage potential. Then prioritize the protection of assets according to the risk level identified.

Exhibit 15

US companies are open for outsourcing – German companies not convinced

Would you generally be willing to outsource your IT structure?
Percent

- IT outsourcing is **viable for 71% of all respondents**
- Of these 71%, **only 15%** would be prepared to outsource with **worldwide providers** and only **15% at worldwide server locations**

SOURCE: McKinsey Industry 4.0 Global Expert Survey 2015

- **Integrate cybersecurity into core processes.** Establish cyberresilience as part of the enterprisewide risk management process. Secure the core production processes by integrating cyberdefense. Have regular trainings/war games examining the possibility of cyberattacks, focusing on short reaction times.

- **Engage management and employees.** Employees need to understand the risks from cyberattacks and require proper training to help mitigate the risk of compromised security (via careful surveillance of external data and storage media, for instance). It is vital, too, that senior management act as role models for vigilance against the cyberrisk.

- **Safeguard the technology.** Develop deep integration of security into the technology for all connected technologies. Automate defense as far as possible to enable cybersecurity staff to focus on safeguarding the technology against new threats.

It is important that all four practices are employed together. While cybersecurity was solely seen as an IT topic in the early days, every part of each networked organization now needs to become involved to minimize the associated risks.

A key topic that companies should address in this context is the security of their IT sourcing strategy. Many players do this by creating "nationalized" IT solutions utilizing local cloud and storage providers, and often only trusting local technologies. Our survey shows that most companies across the globe are reluctant to outsource IT outside of their own country (Exhibit 15).

Outlook

Players should start their digital transformation today to master the transition to Industry 4.0

Industry 4.0 is driven by disruptive technologies and can impact a company in many ways – by providing an opportunity for improving operational effectiveness and challenging established business models. Realizing the benefits in these areas, however, requires that companies build a digital foundation. This is a far-reaching task that poses managerial challenges at all levels of the organization. Not just processes, strategy, and capabilities will have to change, but also mindsets. Companies need to act now, launching short-term initiatives immediately and preparing medium- to long-term initiatives that aim at transformation rather than augmentation.

A company's success in the era of Industry 4.0 depends on a digital transformation. The business model, production system, and eventually the company itself all need shaping from a digital perspective.

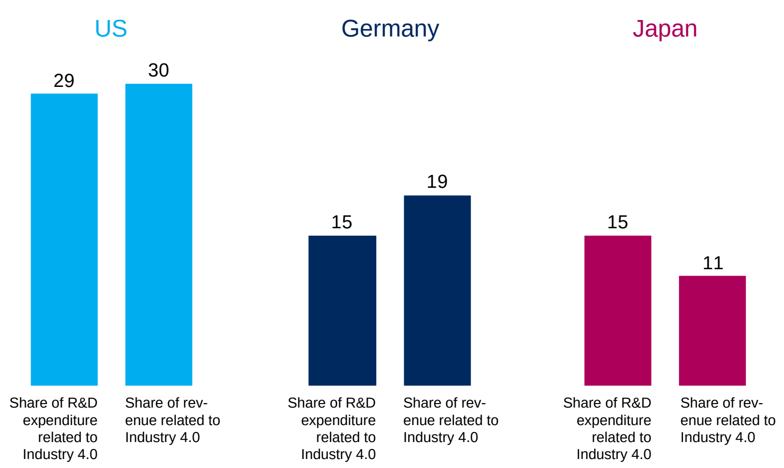
The **business model** defines a company's strategic goals, its products and service offerings, and its sources of profit. The choice of business model is dependent on company-specific knowledge, ideas, data, and algorithms and defines how these assets can be used and developed. When determining the business model, the question arises as to how these company-specific digital assets can be used to generate profit. Taking Google as an example, leveraging data for secondary services (advertising) rather than for its primary product (search engine) is most profitable. Qualcomm uses its IPR to make profits from licensing fees rather than selling its original product. The ideal scenario is to create a differentiating business model based on unique digital assets that makes the best use of all available information both to optimize physical production and to deliver additional value to the customer.

The digital thread is the starting point for designing the **production system,** not just its digital counterpart, since a growing share of the value creation is taking place in the digital rather than the physical world. The later the digital-to-physical conversion happens, the more efficient the production system can be. This means (i) digital prototyping before a physical prototype is ordered, (ii) having the model for the suppliers in a digital format instead of providing them with molds, and (iii) tracking the supply chain logistics digitally instead of using paper delivery slips.

Exhibit 16

Investment levels in Industry 4.0 vary significantly between countries

Percent



SOURCE: McKinsey Industry 4.0 Global Expert Survey 2015

In the extreme, even distribution may be digital, such as sending out all the information about a product to many microplants located in the target markets (relying heavily on 3D printing). This would open up new pockets of savings potential – avoiding import tax and logistics costs, to mention just two examples.

As digital will be at the core of the business, it needs to be considered in every major decision concerning the setup of **the company itself.** When building assets – be they machinery as physical assets, intellectual property as intangible assets, a companies' organizational structure as an organizational asset, or capabilities as human capital – the development needs to align with the digital core and digital strategy of the company. Companies should increase their efforts to ensure the right level of investment in their digital capabilities in the same way they do for other assets. Our survey reveals that many companies are still struggling to determine this level (Exhibit 16).

Using Industry 4.0 as the path to the future of manufacturing will allow companies to do more than just upgrade their equipment and eliminate inefficiencies to increase their operational effectiveness. It will also give them the freedom to make the right strategic decisions and reinvent their business model, preparing them to maintain a competitive edge in the global manufacturing market of the future.

Appendix

Further key findings from the McKinsey Industry 4.0 Global Expert Survey 2015

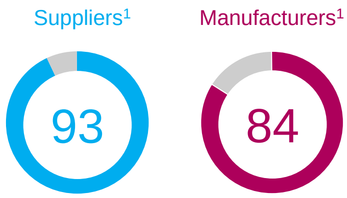
The McKinsey Global Expert Survey included 21 questions on Industry 4.0. Since not all the results could be explicitly mentioned in the report, this Appendix provides some additional detail.

SOURCE: McKinsey Industry 4.0 Global Expert Survey 2015

Exhibit 17

Technology suppliers, as well as manufacturers, generally view Industry 4.0 as an opportunity

Industry 4.0 is an opportunity rather than a risk
Percent



1 36% of respondents were suppliers, 64% were manufacturers

Exhibit 18

Most US, German, and Japanese players are optimistic about Industry 4.0 – but some regional differences do exist

Industry 4.0 is an opportunity rather than a risk
Percent

Exhibit 19

There are contrasting views between the industries as to which value drivers have the highest potential

Biggest areas of improvement based on percent of respondents assigning top 3 impact ranking

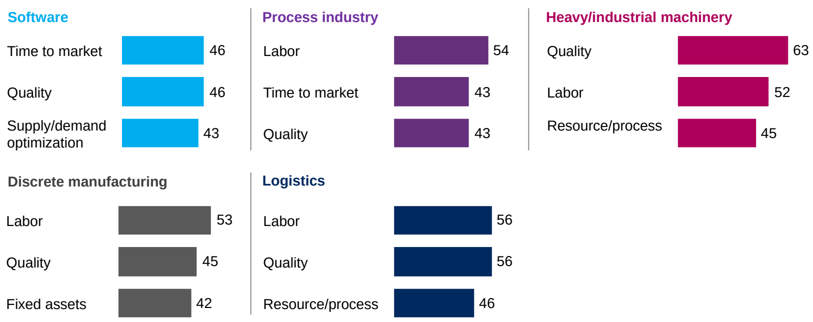


Exhibit 20

There are contrasting views between countries as to which technologies will have the greatest impact

Top 3 technologies based on percent of respondents assigning 2 highest impact scores

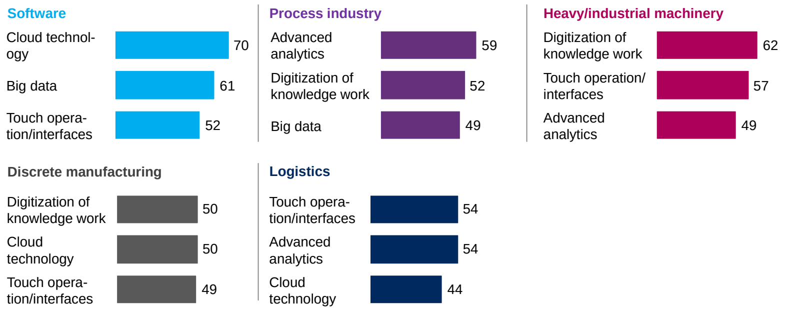


Exhibit 21

More US than German or Japanese companies expect Industry 4.0 to impact their business model

Respondents expecting Industry 4.0 to impact business model
Percent

- **US companies** seem to see **greater impact** coming from Industry 4.0
- Might explain why these companies have **already done more to prepare** themselves

Exhibit 22

The software industry sees the strongest impact on their business model

Respondents expecting Industry 4.0 to impact business model
Percent

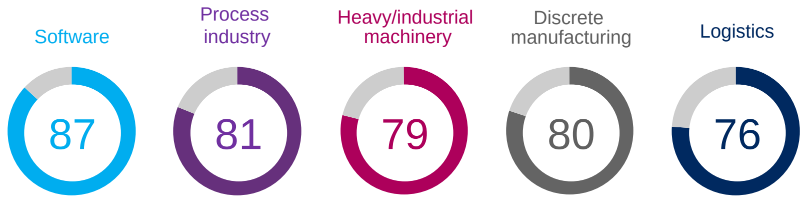
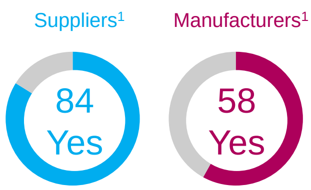


Exhibit 23

Industry 4.0 technology manufacturers are undecided whether to expect outside competitors to enter manufacturing industries

Do you expect outside competitors to use Industry 4.0 applications to attack classic industry players?
Percent



- Overall **67%** of the respondents **expect outside competitors** to enter the industry **with new business models**
- **Suppliers** expect to need to **adapt** their **business model more** than manufacturers

1 36% of respondents were suppliers, 64% were manufacturers

Exhibit 24

There is significant dissent between countries as to whether outside competitors will enter manufacturing industries

Respondents expecting outside competitors to use Industry 4.0 applications to attack classic industry players

Percent

Exhibit 25

There is significant dissent between industries as to whether outside competitors will enter their industry

Respondents expecting outside competitors to use Industry 4.0 applications to attack classic industry players

Percent

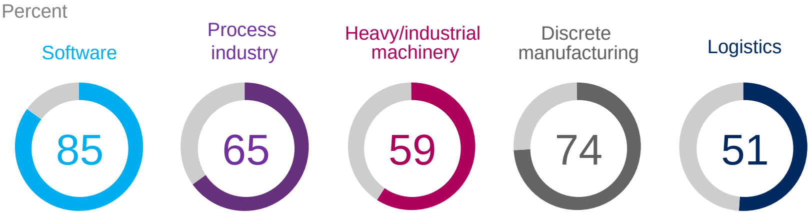
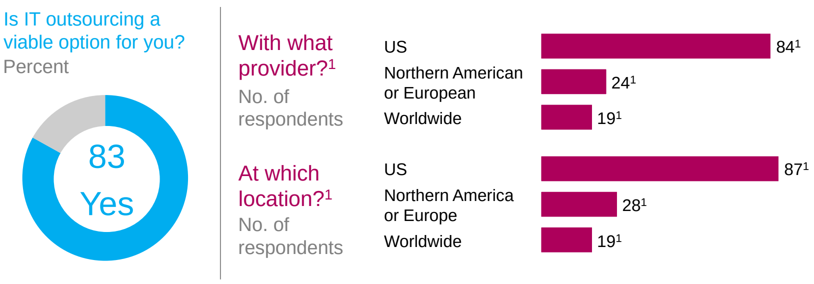


Exhibit 26

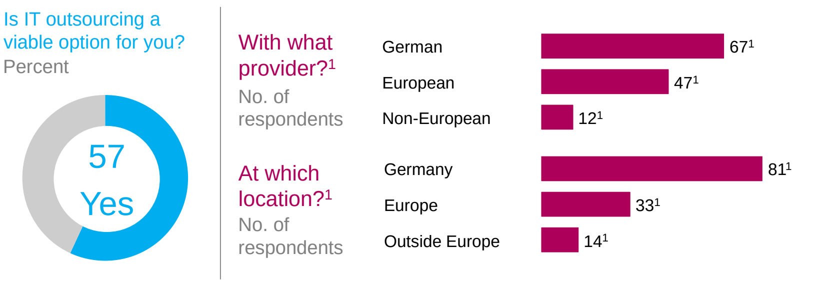
IT outsourcing is viable for 83% of American survey respondents – however, only in the US



1 Multiple answers/choices possible

Exhibit 27

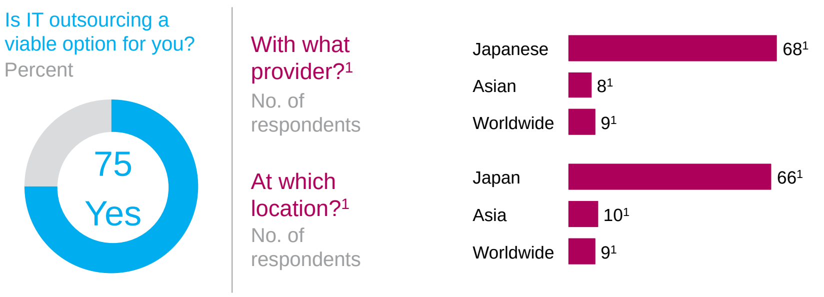
IT outsourcing is viable for 57% of German survey participants – however, only in Germany or at most in Europe



1 Multiple answers/choices possible

Exhibit 28

IT outsourcing is viable for 75% of Japanese survey respondents – however, only in Japan



1 Multiple answers/choices possible

Exhibit 29

US, German, and Japanese players are predominantly skeptical about accepting worldwide IT server locations

Percent of US companies that would be prepared to outsource and would accept worldwide server locations

Percent of German companies that would be prepared to outsource and would accept worldwide server locations

Percent of Japanese companies that would be prepared to outsource and would accept worldwide server locations

Overall, only 11% of all respondents (and 15% of the respondents that would outsource) would be prepared to outsource their IT infrastructure to worldwide locations

Exhibit 30

Viability of IT outsourcing is highly dependent on industry

Percent

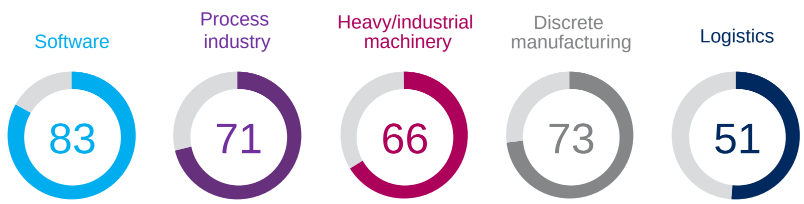
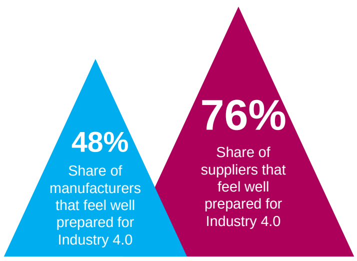


Exhibit 31

Industry 4.0 technology suppliers feel relatively well prepared, whereas manufacturers are undecided



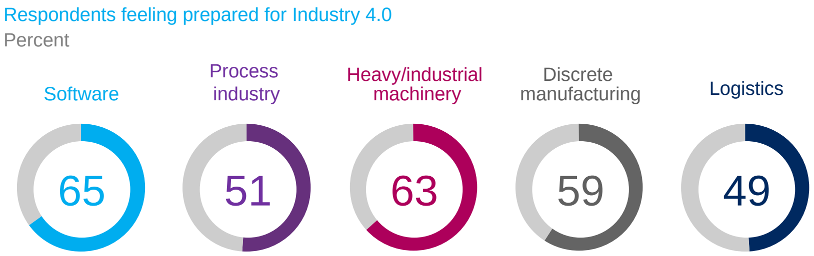
- Overall, **only 58% feel well prepared** for the challenges of Industry 4.0
- **Manufacturers** feel significantly **less prepared** than **suppliers**
- **Manufacturers might have to invest more** in Industry 4.0 technologies

Exhibit 32

US companies feel relatively well prepared, German players are undecided, and Japanese feel unready

Exhibit 33

There are contrasting levels of preparedness between the different industries



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