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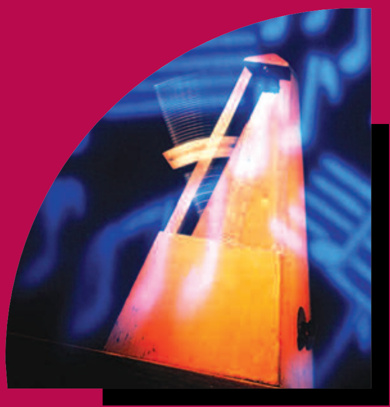

INDUSTRIE 4.0 READINESS

Foundation for mechanical engineering,
plant engineering, and information technology

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This research project was sponsored by VDMA's IMPULS-Stiftung

Aachen, Cologne, October 2015

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About this study

Industrie 4.0 is all around us today: in politics, in the media, and on the agendas of researchers and entrepreneurs. Smarter, faster, more personalized, more efficient, more integrated – those are just some of the promises of this new industrial era. The potential, especially for Germany´s mechanical engineering industry and plant engineering sector, is indeed great, both for providers and for users of technologies across the spectrum of Industrie 4.0.

But there are still many unresolved questions, uncertainties, and challenges. Our readiness study seeks to address this need and offer insight. Because Industrie 4.0 will not happen on its own. This study is intended to bring the grand vision closer to the business reality. We also highlight the challenging milestones that many companies must still pass on the road to Industrie 4.0 readiness.

The study examines where companies in the fields of mechanical and plant engineering currently stand, focusing on what motivates them and what holds them back, and on the differences that emerge between small and medium enterprises on the one hand and large enterprises on the other. The results make it possible for the first time to develop a detailed, systematic picture of Industrie 4.0 readiness in the engineering sector.

The study concludes with recommendations for action in the business community, complementing the diverse suite of programs and activities offered by VDMA's Forum Industrie 4.0. We would like to take this opportunity to thank the two sponsors of this project from the VDMA Forum, Dietmar Goericke and Dr. Christian Mosch, whose efforts played a critical role in making this study a success.

We are convinced that Industrie 4.0 can become a success story for Germany's engineering sector. May our "Industrie 4.0 Readiness" study do its part in this effort.

Frankfurt, October 2015

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Executive summary

Industrie 4.0 is at the center of many futuristic visions by business leaders, economists, and policymakers. But we need more information on the current state of preparedness in Germany´s mechanical engineering industry and plant engineering sector – a key industry for the realization of Industrie 4.0. This study examines Industrie 4.0 readiness – the willingness and capacity of companies to implement the ideas behind Industrie 4.0. The current implementation status was determined empirically and categorized using a classification scheme, the Readiness Model.

Readiness Model

The Readiness Model was used to define criteria through which companies are classified into three types: "newcomers," "learners," and "leaders." This classification is based on the following six key dimensions of Industrie 4.0: strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees.

Online Self-Check — the tool for company self-assessments

The Readiness Model is also the foundation for a self-assessment and comparison. The Online Self-Check developed for this purpose gives companies the ability to check their own Industrie 4.0 readiness in the six dimensions: strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees. The results are used to classify the companies as "newcomers," "learners," or "leaders." The Online Self-Check is available at www.industrie40-readiness.de.

Industrie 4.0 has arrived in Germany's mechanical engineering industry

More than twenty percent of German companies in the mechanical engineering industry are heavily involved in Industrie 4.0 – compared to just ten percent in the manufacturing industry[1] as a whole. For German mechanical engineers and plant engineers, the opportunities of Industrie 4.0 far outweigh the risks: Nine of ten companies heavily involved in Industrie 4.0 see it as an opportunity to differentiate themselves in the marketplace. In addition, 76.2 percent say that addressing this topic is an inherent part of being a technology leader.

Classification of surveyed companies

Despite this, only a relatively small 5.6 percent of companies are already in the group of leaders when it comes to implementing Industrie 4.0. Another 17.9 percent are learners, who are working with Industrie 4.0 concepts and taking the first steps to make it happen. The overwhelming majority of 76.5 percent have not yet taken any systematic steps to implement Industrie 4.0 and are classified as newcomers.

Size matters when it comes to readiness

There is a correlation between the size of a company and its Industrie 4.0 readiness. Large engineering enterprises are further along in implementing Industrie 4.0 than small and medium-sized enterprises. It is almost impossible for a company to reach a higher level of Industrie 4.0 readiness on its own without the help of partners, since readiness requires all the players along the value chain to implement the necessary concepts and interact in a digital network.

1 Mechanical and plant engineering is a subset of the manufacturing industry.

Four key insights

1. Industrie 4.0 must be rooted more firmly in the corporate strategy

For Industrie 4.0 to take hold, it is essential that management first embrace and above all practice such concepts. Four of ten companies do not yet have any Industrie 4.0 strategy. Size emerges here as a clear delineator: The larger the company, the more likely it is to have a strategy in place for Industrie 4.0. Small and medium-sized enterprises in particular should make an effort to explore the topic through pilot initiatives.

2. Qualified personnel is already an issue

Most companies have already recognized that a workforce with broad skill sets is a key success factor in reaching the goals of Industrie 4.0. Companies draw upon their experience in training employees when it comes to professional development and feel confident on this issue. Only 30 percent of companies report that they currently have no core competencies in house to manage the personnel demands associated with Industrie 4.0.

3. Data-driven services and smart products enable new business models

Companies across the spectrum – newcomers, learners, leaders – exhibit what is by far the lowest level of Industrie 4.0 readiness in the dimension of data-driven services. Nearly two-thirds of companies have not yet discovered the potential of data-driven services and do not offer any such portfolio. And yet, the collection and analysis of data accumulated during the product lifecycle offers tremendous potential for companies to expand their service portfolio or business model down the road. Additional product functionalities are especially helpful in developing product and solution strategies tailored to the precise needs of current and future customers. Site-specific data, which very few companies collect, can deliver a genuine added value.

4. Funding of Industrie 4.0 projects must be ensured

The leaders are well aware of the economic benefit that Industrie 4.0 brings. Uncertainty about the economic benefit of Industrie 4.0 disappears quickly when companies give up their wait-and-see attitude and actively delve into topics such as data-driven services or smart products. At that point, however, the necessary expenses become clear.

Some 63.4 percent of leaders indicated that, as ongoing Industrie 4.0 projects grow more complex, a lack of financial resources is preventing them from pursuing the subject further. This puts the funding issue ahead of calls for uniform standards, IT security, or the resolution of legal issues as an obstacle for leaders. Policymakers have a role to play here as well by proposing appropriate measures such as tax incentives to support research. In addition, businesses need to have a solid business model already in place as Industrie 4.0 is gradually rolled out internally.

1 Objective, design of study, current situation

In this initial chapter, we outline the purpose of the study, define the basic terminology, and explain the methodologies used. We also offer a brief sketch of how things stand today in the German engineering sector with regard to Industrie 4.0. In chapter 2, we introduce and explain the Readiness Model developed for this study and designed to offer a snapshot of the current state of Industrie 4.0 implementation among Germany's mechanical engineers. In chapter 3, we then present the empirical results of these measurements as obtained through a company survey based on the model. We conclude the study in chapter 4 by identifying areas where action is urgently needed. Addressing these needs can help Industrie 4.0 concepts further penetrate Germany's mechanical engineering industry.

1.1 Objective of study

Industrie 4.0 refers to the real-time digital integration of suppliers, producers, and customers along value chains and business models. This fusion of state-of-the-art information and communications technology (ICT) and traditional industrial processes offers mechanical and plant engineering companies in Germany numerous opportunities: One study predicts that Industrie 4.0 technologies will bring the sector additional potential added value of 23 billion euros and annual growth of 2.1 percent between now and 2025 (Bitkom/Fraunhofer IAO, 2014). This potential can be achieved with the help of optimized value-adding networks, efficiency gains in business processes, innovative products, and new services and business models.

Since engineering companies will grow from being just users of Industrie 4.0 concepts to providers of solutions, it is especially important for this sector to take an early, in-depth look at the underlying concepts.

The work of the Industrie 4.0 Platform and the VDMA Forum Industrie 4.0 have shown, however, that many companies in the mechanical engineering industry still have significant uncertainties and a strong need for information regarding the details of Industrie 4.0 implementation. Some companies are already very far along in implementing Industrie 4.0 processes and technologies, while others – mostly small and medium-sized businesses – are still very much taking a wait-and-see approach. That's because, for lack of information, there is still a lot of uncertainty about the risks and opportunities associated with Industrie 4.0 (Wischmann et al., 2015).

Determining Industrie 4.0 readiness in the mechanical engineering industry

The objective of this study is therefore to support Germany's mechanical and plant engineering companies as they embrace Industrie 4.0. This study examines Industrie 4.0 readiness in the companies. A concept to measure readiness was developed, and the parameters were identified empirically through a company survey.

The study essentially answers two specific questions:

1. Where do companies in Germany's mechanical engineering industry currently stand on the road to Industrie 4.0?

2. What are the conditions that must be created for the successful implementation of Industrie 4.0 in the companies, and which circumstances need to change?

Online Self-Check for Businesses

As part of the study, project partners IW Consult and FIR at RWTH Aachen University developed an online tool with which interested companies can measure their own individual Industrie 4.0 readiness. The self-check uses the same six dimensions of Industrie 4.0 cited in the study and compares this self-assessment (actual profile) with the profile of leading Industrie 4.0 companies (benchmark profile) and the profile of the target vision (target profile). This shows companies where they are already in particularly good shape and where they still need to optimize.

Online Self-Check available at:
www.industrie40-readiness.de

1.2 Terminology

The Industrie 4.0 Platform Steering Committee defined the term "Industrie 4.0" as follows:

"The term Industrie 4.0 stands for the fourth industrial revolution, a new level of organizing and controlling the entire value chain across product lifecycles. This cycle focuses on increasingly personalized customer wishes and extends from the concept to the order, development, production, and shipping of a product to the end customer and ultimately to its recycling, including all associated services.

The foundation is the real-time availability of all relevant information through the integration of all objects in the value chain and the capacity to determine the optimal value flow at any time from the data. The interconnection of people, objects, and systems produces dynamic, real-time-optimized, self-organizing, cross-enterprise value-adding networks that can be optimized according to various criteria such as cost, availability, and resource consumption." (Industrie 4.0 Platform, 2015)

Industrie 4.0 is a vision that describes the industry of the future. The specific potential lies above all in high-flexibility, high-productivity, resource-friendly production that makes it possible to manufacture highly individualized products under the economic conditions of mass production. Engineering, production, logistics, service, and marketing are ultimately interconnected in dynamic, real-time-optimized, value-adding cross-enterprise networks.

The vision of Industrie 4.0

For the mechanical engineering industry, the vision of Industrie 4.0 means achieving the following four objectives (Industrie 4.0 Platform, 2015):

1. Horizontal integration: The smart factory constantly adapts to new circumstances (such as the order volume or availability of materials) and automatically optimizes its production processes. It does this through integration with suppliers and customers in the value chain.

2. Vertical integration: People, machinery, and resources are digitally modeled in the smart factory, communicating with one another through cyber-physical systems (CPS).

3. Smart products have information about their own production process and can gather and transmit data during the manufacturing and usage phase. This makes it possible to obtain a digital model of the smart factory and offer data-driven services to customers during the usage phase.

4. Human beings as the drivers of added value.

Building such systems is not an end unto itself. It will only take place if it yields promising business models. It is possible to focus on a wide variety of issues:

Industrie 4.0 technologies are designed to make small, customer-specific batch sizes possible with an optimal use of capacities. The hallmark of this vision is the possibility of profitable production with a batch size of one and idle costs of zero.

On the input side, Industrie 4.0 promises to enhance the efficiency of invested work, capital, materials, energy, and time by 30 to 50 percent while cutting the consumption of resources by 20 to 25 percent (McKinsey, 2015).

Industrie 4.0 is designed to accelerate all processes and unleash greater innovative drive.

This delivers significantly higher revenues of up to 30 percent, especially for the mechanical engineering industry as both the supplier and user of the future smart factory (McKinsey, 2015).

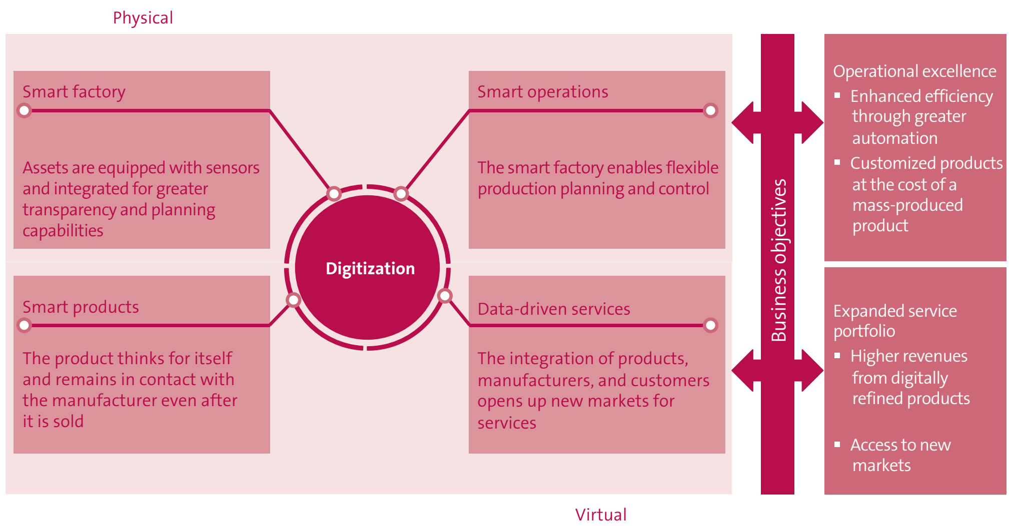
What Industrie 4.0 means to us

Although there is a general consensus on the vision and definition of Industrie 4.0 as outlined in numerous publications, this study can still benefit from a user-centric translation for the business community. A real-world definition of Industrie 4.0 is essential in order to pursue the vision and goal and develop a roadmap for the future development of mechanical and plant engineering. Because starting off in the right direction requires knowing your destination.

This means that the vision of Industrie 4.0 on which this study is based relates primarily to the areas in which there is potential. Our understanding of Industrie 4.0 encompasses the following four dimensions (Figure 1-1):

- Smart factory
- Smart products
- Smart operations
- Data-driven services

Figure 1-1: Industrie 4.0 as the fusion of the physical and virtual worlds



Original layout

A key point in this understanding is that the first two dimensions (smart factory and smart products) relate to the physical world, while the other two dimensions (smart operations and data-driven services) represent the virtual representation of physical dimensions. According to this concept, Industrie 4.0 is the fusion of the physical and virtual worlds.

Smart factory: Successful implementation of Industrie 4.0 enables distributed, highly automated production. Unlike in traditional production, smart workpieces will control and monitor the production process and, in the final expansion phase, guide themselves autonomously through production. This happens in the environment of the smart factory. The smart factory is a production environment in which the production systems and logistics systems largely organize themselves without human intervention. The smart factory relies on cyber-physical systems (CPS), which link the physical and virtual worlds by communicating through an IT infrastructure, the Internet of Things. Industrie 4.0 also involves digital modeling through the smart gathering, storage, and processing of data. In this way, the smart factory concept ensures that information is delivered and resources are used more efficiently. This requires the real-time, cross-enterprise collaboration between production systems, information systems, and people. These integrated systems produce huge amounts of data that are processed, analyzed, and integrated into decision-making models.

Smart products: Smart products are a vital component of a unified “smart factory” concept facilitating automated, flexible, efficient production. Physical products are equipped with ICT components (sensors, RFID, communications interface, etc.) to collect data on their environment and their own status. Only when products gather data, know their way through production, and communicate with the higher-level systems can production processes be improved and guided autonomously and in real time. It also becomes possible to monitor and optimize the status of the individual products. This has potential applications beyond production alone. Using smart products during the usage phase makes new services possible in the first place – through communications between customers and manufacturers, for example.

Data-driven services: The objective of data-driven services is to align future business models and enhance the benefit to the customer. The after-sales and services business will be based more and more on the evaluation and analysis of collected data and rely on enterprise-wide integration. The physical products themselves must be equipped with physical IT so they can send, receive, or process the information needed for the operational processes. This means they have a physical and digital component, which in turn are the basis for digitized services in the usage phase of the products.

Smart operations: One hallmark of Industrie 4.0 is the enterprise-wide and cross-enterprise integration of the physical and virtual worlds. The advent of digitization and the plethora of data it has brought to production and logistics have made it possible to introduce what are in some cases entirely new forms and approaches to production planning systems (PPS) and supply chain management (SCM). The technical requirements in production and production planning necessary to realize the self-controlling workpiece are known as smart operations.

1.3 Methodology

This study was conducted using a mixed methodology of an analysis of the literature, expertise, workshops, and a comprehensive company survey.

Workshop to identify Industrie 4.0—relevant indicators

The first step after thoroughly exploring the literature was to conduct a workshop with select leading companies from the mechanical engineering industry that already had experience using Industrie 4.0 technologies. In this workshop, the experts worked with the project partners (IW Consult and FIR) to systematically identify and evaluate success-related indicators for Industrie 4.0.

Design of Readiness Model

Building upon the workshop results, an analysis of the literature, and the expertise of the project partners, the next step was to design a Readiness Model that was used to define a total of six levels of Industrie 4.0 readiness (see details in chapter 2):

- Level 0: Outsider
- Level 1: Beginner
- Level 2: Intermediate
- Level 3: Experienced
- Level 4: Expert
- Level 5: Top performer

The Readiness Model was aligned closely with the four dimensions of Industrie 4.0 named in the definition. Two additional, universally applicable dimensions were also taken into account: strategy and organization, and employees. The indicators used for measuring readiness were identified through company surveys.

Design of questionnaire

Building upon the requirements of the Readiness Model, a questionnaire was developed to explore the following aspects:

- Structural attributes of the companies
- General questions on Industrie 4.0
- Degree to which companies satisfy the dimensions of Industrie 4.0
- Motivators and obstacles on the road to Industrie 4.0

In the first part of the questionnaire, respondents are asked to provide information about the structure of their companies. This information is used primarily to ensure the survey is representative and to enable projections.

The second part of the questionnaire contains general questions about Industrie 4.0, such as the extent to which the company is already involved in Industrie 4.0 and a self-assessment by the company of the status of its implementation of Industrie 4.0. The purpose of these two questions was to filter out those companies to whom Industrie 4.0 is unknown or irrelevant. At the heart of the survey was the definition of the indicators used to describe in detail the 6 dimensions and 18 fields of Industrie 4.0 (see chapter 2) and measure the extent to which these indicators were present. A total of 26 questions were formulated for this purpose. Companies provided feedback on the implementation status of their Industrie 4.0 strategy, the functionalities of their equipment infrastructure, the data they collect, autonomous production, data-driven services, and employees. They also named the main motivators for the implementation of Industrie 4.0 and the main obstacles slowing implementation.

Survey sampling pool

The heart of the empirical data collection is an online survey of VDMA members conducted from April to July 2015. VDMA sent out an e-mail to its members inviting them to participate. Companies received an extensive questionnaire, which 232 participants completed.

This random sampling did not prove adequate for a representative projection. Smaller companies in particular did not participate at a high enough rate. For this reason, the VDMA survey was expanded to include an identical survey conducted during the 26th round of the "Panel on the Future" (*Zukunftspanel*) by the Cologne Institute for Economic Research (IW). Measures were taken to rule out the double counting of companies that may have taken part in both surveys. There was also grounds to assume that the VDMA sampling could be distorted. The reason is that companies very interested in a particular topic typically take part in such lengthy and clearly themed surveys with disproportionate frequency. To expand the empirical base and counteract this effect, two additional surveys were added – one accompanying the 23rd round of the IW Entrepreneur Survey (*Unternehmervotum*), and a telephone survey we conducted ourselves. These surveys were used only to determine the percentage of companies unaware of or uninterested in Industrie 4.0, however. What's important is that all surveys were conducted during the same period and using exactly the same language. The sampling in the additional surveys was randomly selected and therefore allows for representative projections. Since the mechanical engineering industry is well represented in VDMA, it is assumed that this sampling also offers a representative picture of the industry.

The survey design is therefore based on a two-phase methodology (Tabelle 1-1):

- First, the four datasets were used to determine the percentage of Industrie 4.0–friendly companies. This drew on information from 431 companies.

- The Industrie 4.0–friendly companies were then asked further questions to measure their readiness. This included 289 responses – 199 from the VDMA member survey and 90 from the IW Panel on the Future.

The study only uses data from companies with more than 20 employees. VDMA is especially well represented among companies of this size category. Among the 6,419 entities in Germany's mechanical engineering industry with more than 20 employees listed in the companies register, about half are VDMA members. Large enterprises are over-represented in the sampling relative to the overall base. Weighting factors were used to compensate for this.

In areas where significant differences exist, the results are broken down by size using the following categories:

- Small enterprises (20 to 99 employees)
- Medium enterprises (100 to 499 employees)
- Large enterprises (500+ employees)

Table 1-1: Breakdown of the survey sampling pool				
Companies	Workforce size categories			
	20–99	100–499	500+	Overall
	Mechanical and plant engineering companies			
Companies register	4,268	1,812	339	6,419
	Random sampling to identify Industrie 4.0–friendly companies[1]			
VDMA member survey (April to July 2015)	67	86	79	232
IW Panel on the Future (26th round; July to August 2015)	66	44	16	126
IW Entrepreneur Survey (23rd round; May 2015)	8	10	7	25
Special telephone survey (July 2015)	24	19	5	48
Overall	165	159	107	431
	Core survey to measure readiness of Industrie 4.0–friendly companies[1]			
VDMA member survey (April to July 2015)	50	77	72	199
IW Panel on the Future (26th round; July to August 2015)	40	35	15	90
Overall	90	112	87	289

[1] Companies for whom Industrie 4.0 is relevant and who were familiar with the term.
Figures refer to the number of companies.
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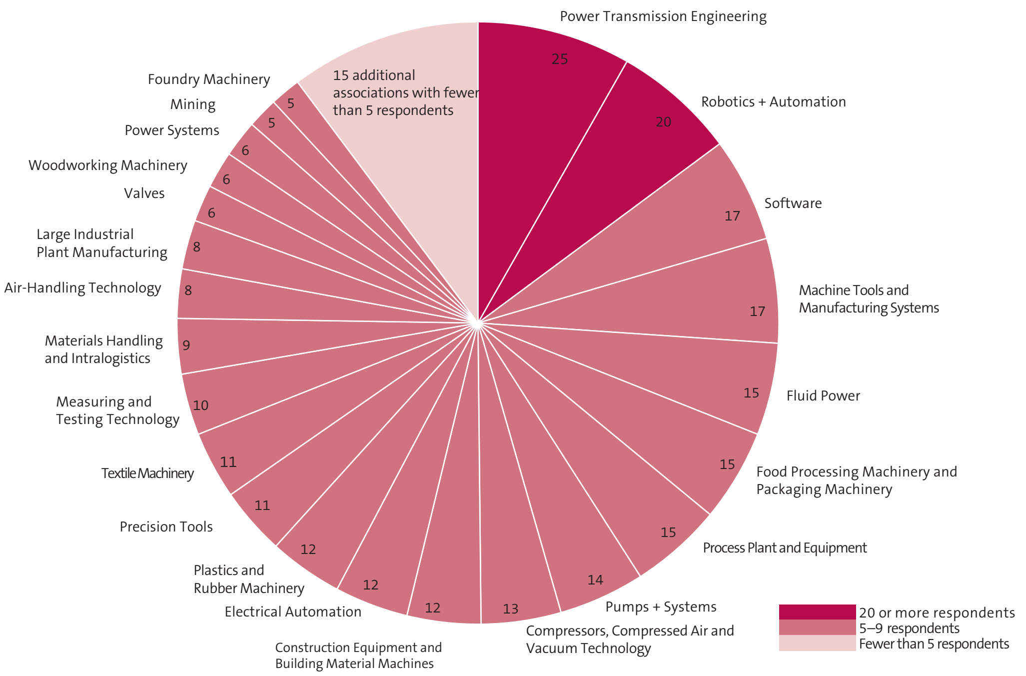
Figure 1-2 shows the VDMA associations to which the surveyed companies belong. The areas of drive technology and robotics are heavily represented.

Figure 1-2: Respondents by VDMA association



n = 214; only companies that listed an affiliation with a VDMA association
Source: VDMA member survey, 2015

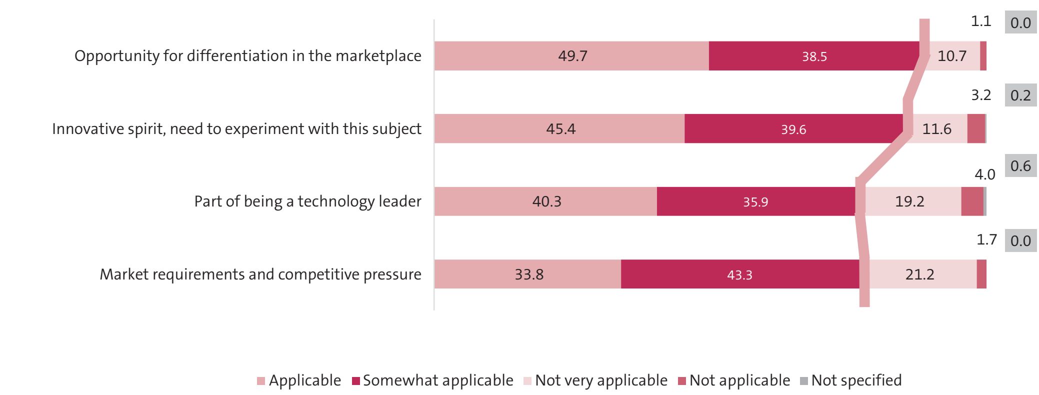
1.4 Background and motivation of companies

The company survey yields some initial findings on the general attitude of Germany's mechanical engineering industry toward Industrie 4.0 and the opportunities and risks it presents.

Engineering sector recognizes opportunities of Industrie 4.0

Germany's mechanical engineering industry sees Industrie 4.0 as something positive – the opportunities strongly outweigh the risks. The survey results (Figure 1-3) make this very clear. For nearly nine out of ten companies, the opportunity to differentiate oneself in the marketplace and generate unique selling propositions is the primary motivation for getting involved in Industrie 4.0. Industrie 4.0 awakens the innovative spirit – some 76.2 percent of companies say that addressing this topic is an inherent part of being a technology leader. Industrie 4.0 is on the agenda for some three out of four surveyed companies because market trends and competitive pressures require it. These companies assume that traditional ideas will not be enough to measure up against competitive pressures. They feel compelled to deal with the subject of Industrie 4.0. No significant differences are apparent among companies of various sizes on the question of motivation, so these results are not broken down explicitly by size category.

Figure 1-3: Motivation for Industrie 4.0



Figures indicate percentages; multiple responses allowed; n= 134
Only takes into account companies with more than 20 employees.
Source: VDMA member survey, 2015

Industrie 4.0 opens up significant revenue and efficiency potential

What goals are German engineering companies pursuing with Industrie 4.0? Are there differences based on the size of the company? The VDMA member survey shows that more than six out of ten companies see Industrie 4.0 applications as an opportunity to enhance the efficiency of their production system – by increasing flexibility, shortening manufacturing throughput times, lowering production costs, improving on-time performance, etc.

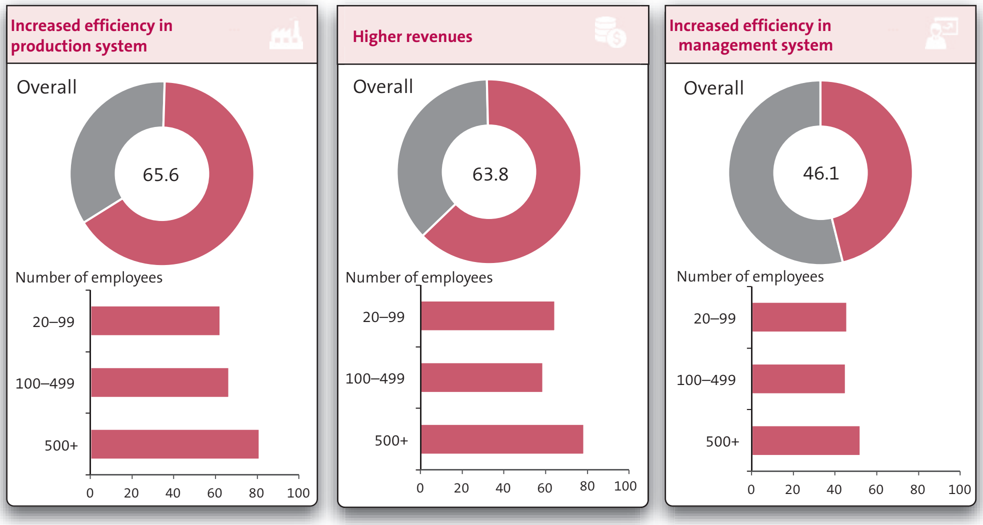
Over 60 percent of companies also expect Industrie 4.0 to boost their revenues, above all by opening up new business models through expanded product or service portfolios or higher customer retention rates.

Some 46.1 percent of companies expect greater efficiency in their management system through improvements such as optimized coordination processes or greater transparency in inventory and order processing.

The results vary greatly based on the number of employees in the company. Higher revenues are the most important for small businesses (20 to 99 employees), while medium-sized businesses (100 to 499 employees) are counting primarily on increased efficiency in the production system. For large enterprises (500+ employees), both objectives carry equal weight (Figure 1-4).

Overall, these results show that Industrie 4.0 is associated with opportunity and clear business objectives.

Figure 1-4: Objectives of Industrie 4.0



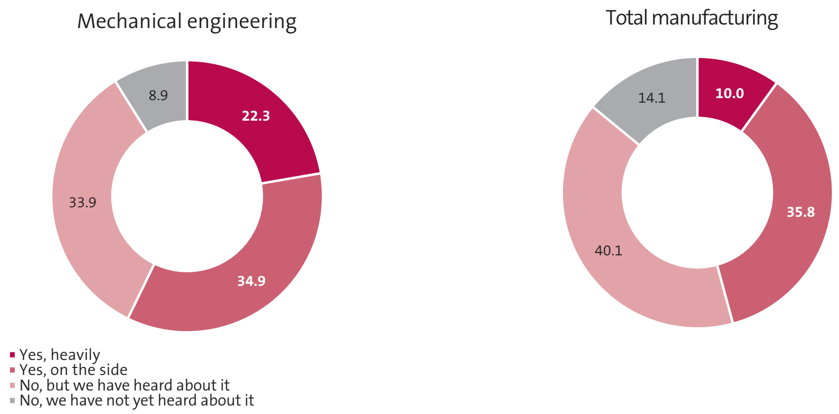
Totals for "primary and significant objectives"; figures for both overall sampling and by size of company workforce; figures indicate percentages; multiple responses allowed; n = 188; Only counts companies with more than 20 employees.
Source: VDMA member survey, 2015

One of two surveyed companies is involved in Industrie 4.0

Given this positive assessment of the opportunities, it is not surprising that the subject of Industrie 4.0 has taken hold in the engineering sector. More than half of respondents (57.2 percent) have already become involved in the issue of Industrie 4.0. Larger enterprises are addressing the subject in greater numbers than small and medium-sized businesses. About one-fifth of mechanical and plant engineering companies are heavily involved in solutions to implement Industrie 4.0. One-third admits to having heard of Industrie 4.0 but has not yet taken any action. Only about 9 percent of those surveyed are not yet familiar with Industrie 4.0 (Figure 1-5).

Companies in the mechanical engineering industry are much better informed than those in the manufacturing industry as a whole. Some 10 percent of companies in the overall manufacturing industry (including mechanical engineering) have studied Industrie 4.0 closely (Figure 1-5). The share of those that have not yet heard of Industrie 4.0 is also much higher than in the mechanical engineering industry. Overall, these results show that Industrie 4.0 is much more relevant in mechanical and plant engineering than in other sectors.

Figure1-5: Involvement in Industrie 4.0



Figures indicate percentages; n=431 mechanical engineering; n = 674 manufacturing industry
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round;
IW Entrepreneur Survey 2015, 23rd survey round; telephone survey, 2015

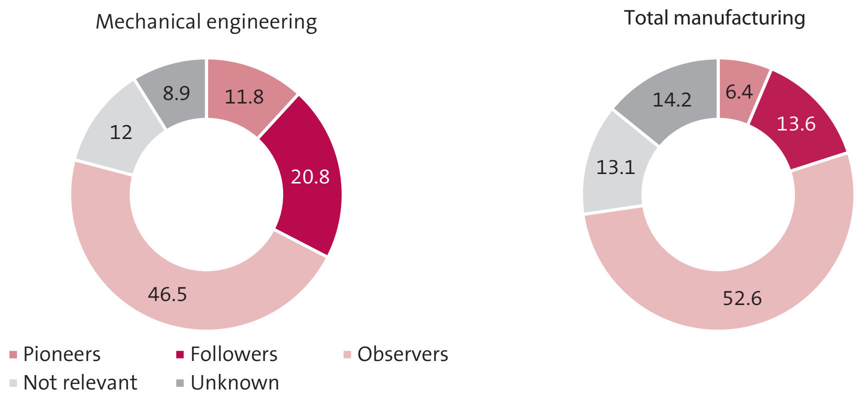
Mechanical engineering industry and plant engineering sector further along with Industrie 4.0 than manufacturing industry

In the four surveys cited above, the companies that are already involved in Industrie 4.0 were asked to complete a self-assessment on their Industrie 4.0 implementation status and their relative position. They had the opportunity to classify themselves as "pioneers," "followers," or "observers" and identify whether Industrie 4.0 was "unknown" or "not relevant" to them. The results (Figure 1-6):

- Nearly 12 percent of mechanical and plant engineering companies classify themselves as pioneers – much higher than the 6.4 percent figure in the manufacturing industry as a whole.
- About 20 percent see themselves as followers and apparently aspire to become pioneers – also much higher than in the overall manufacturing industry.
- The majority (46.5 percent) of mechanical and plant engineering companies in the survey classified themselves as observers, compared to nearly 53 percent in the overall manufacturing industry.
- Only one-fifth (20.9 percent) of surveyed companies do not know about Industrie 4.0 or consider it irrelevant, compared with nearly 28 percent in the manufacturing industry as a whole.

The one-fifth of mechanical and plant engineering companies for whom Industrie 4.0 is unknown or irrelevant are included again in the measurement of readiness in chapter 3. They are automatically assigned to the bottom level of 0 (outsiders) in the model. In analyzing the VDMA member survey, it is assumed that this sampling represents only the 79.1 percent (100 – 20.9 = 79.1) of mechanical and plant engineering companies that are familiar with this topic and consider it relevant. This corrects the self-selection effects described above that result from the disproportionate response rate of Industrie 4.0–friendly companies in the VDMA survey.

Figure 1-6: Company self-assessment of Industrie 4.0 implementation



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Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round;
IW Entrepreneur Survey 2015, 23rd survey round; telephone survey, 2015

2 Readiness Model

Companies that hope to remain competitive must assess where they stand in the digital transformation process and whether they are exploiting the full potential of Industrie 4.0. That is why this study measured Industrie 4.0 penetration. The project partners developed a model to measure readiness – the degree of sophistication on the road to Industrie 4.0 – of companies in Germany's mechanical engineering industry.

Readiness Model with 6 dimensions and 18 fields

The Readiness Model is based on the four dimensions of Industrie 4.0 as defined in section 1.2. The workshop identified two additional, universally applicable dimensions that were also taken into account: strategy and organization, and employees. All in all, the model therefore looks at six dimensions:

- Strategy and organization
- Smart factory
- Smart operations
- Smart products
- Data-driven services
- Employees

Each of these six dimensions is further delineated into fields, which in turn are operationalized with appropriate indicators. They form the basis for measuring the Industrie 4.0 readiness of the companies. The data used in this measurement was collected in a company survey (section 1.3).

Figure 2-1 provides an overview of the structure of the Readiness Model:

- The inner circle shows the six basic dimensions.

- The outer circle shows the fields associated with each of the six dimensions. A total of 18 fields are measured using the appropriate indicators.

Workshops were conducted with company representatives to identify the appropriate criteria for measuring readiness in each of these six dimensions.

The six dimensions of Industrie 4.0 are used to develop a six-level model for measuring Industrie 4.0 readiness. Each of the six readiness levels (0 to 5) includes minimum requirements that must be met in order to complete the level.

Level 0 describes the outsiders – those companies that have done nothing or very little to plan or implement Industrie 4.0 activities. Level 5 describes the top performers – those companies that have successfully implemented all Industrie 4.0 activities. Level 5 of the model also describes the state of full implementation of the target vision (target profile) – when the entire value chains are integrated in real time and can interact.

The vision of Industrie 4.0 and the path to this vision will be different for each company. Not every company has a short-term ambition to implement the full target vision of Industrie 4.0. Companies define their own interim and final goals based on their own background and status quo. For this reason, the model allows for clear differentiation by the aforementioned dimensions.

Figure 2-1: Dimensions and associated fields of Industrie 4.0

Original layout

Model defines six levels of Industrie 4.0 implementation

The six levels of the Readiness Model are illustrated in Figure 2-2 and can be described as follows.

Level 0: Outsider

A company at this level does not meet any of the requirements for Industrie 4.0. Level 0 is also automatically assigned to those companies that indicated Industrie 4.0 was either unknown or irrelevant for them (see chapter 1 and Figure 1-6).

Level 1: Beginner

A company at this level is involved in Industrie 4.0 through pilot initiatives in various departments and investments in a single area. Only a few of the production processes are supported by IT systems, and the existing equipment infrastructure only partially satisfies future integration and communications requirements. System-integrated, in-company information sharing is limited to a few areas. IT security solutions are still in the planning or implementation phase. In this production environment, a beginner is making products with the first steps toward IT-based add-on functionalities. The skills needed to expand Industrie 4.0 are found only in a few areas of the company.

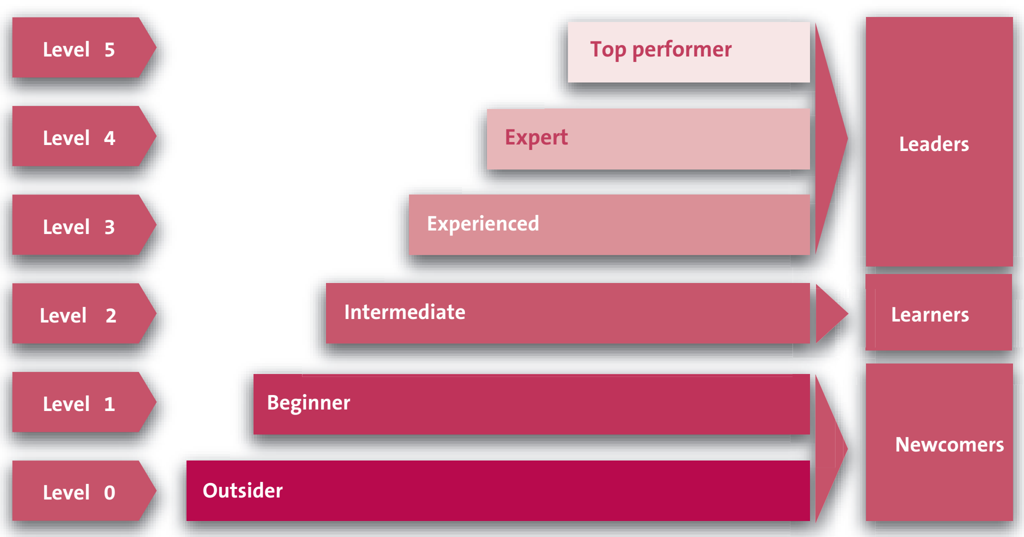
Level 2: Intermediate

An intermediate-level company incorporates Industrie 4.0 into its strategic orientation. It is developing a strategy to implement Industrie 4.0 and the appropriate indicators to measure the implementation status. Investments relevant to Industrie 4.0 are being made in a few areas. Some production data is automatically collected and being used to a limited extent. The equipment infrastructure does not satisfy all the requirements for future expansion. In-company information sharing is integrated into the system to some extent, and the first steps are being taken to integrate information sharing with business partners. Appropriate IT security solutions are already in place and are being expanded. In this production environment, the company is making products with the first IT-based add-on functionalities. In some areas, the employees possess the necessary skills to expand Industrie 4.0.

Level 3: Experienced

A company at this level has formulated an Industrie 4.0 strategy. It is making Industrie 4.0–related investments in multiple areas and promoting the introduction of Industrie 4.0 through department-oriented innovation management. The IT systems in production are linked through interfaces and support the production processes, with data in key areas automatically collected. The equipment infrastructure is upgradable to accommodate future expansion. Internal and cross-enterprise information sharing is partially integrated into the system. The necessary IT security solutions have been implemented. Cloud-based solutions are planned to accommodate further expansion. In this environment, the company is making products with several interconnected IT-based add-on functionalities. These product form the basis of the first rudimentary data-driven services, but the company is not yet integrated with its customers. Data-driven services for customers account for a small share of revenues. Extensive efforts have already been made to expand employee skill sets to achieve this.

Figure 2-2: Six levels of Industrie 4.0 Readiness Model



Original layout

Level 4: Expert

An expert is already using an Industrie 4.0 strategy and monitoring it with appropriate indicators. Investments are being made in nearly all relevant areas, and the process is supported by interdepartmental innovation management. The IT systems support most of the production processes and collect large amounts of data, which is used for optimization. Further expansion is possible, since the equipment already satisfies future integration requirements. Information sharing both internally and with business partners is largely integrated into the system. IT security solutions are used in the relevant areas, and IT is scalable through cloud-based solutions. The expert is beginning to explore autonomously guided workpieces and self-reacting processes. The workpiece and the finished product feature IT-based add-on functionalities that allow for data collection and targeted analysis during the usage phase. This in turn supports data-driven services, which the customers are already using and which account for a small share of revenues. The data-driven services feature direct integration between the customer and producer. In most of the relevant areas, the company has the necessary skills internally to achieve this status and further expand Industrie 4.0.

Level 5: Top performer

A company at this level has already implemented its Industrie 4.0 strategy and regularly monitors the implementation status of other projects. This is supported by investments throughout the company. The company has established enterprise-wide innovation management. It has implemented comprehensive IT system support in its production and automatically collects all the relevant data. The equipment infrastructure satisfies all the requirements for integration and system-integrated communications. This in turn provides for system-integrated information sharing both internally and with business partners. Comprehensive IT security solutions have been implemented, and cloud-based solutions deliver a flexible IT architecture. Some areas of production already use autonomously guided workpieces and autonomously reacting processes. The workpieces and products feature extensive IT-based add-on functionalities, and the data collected this way in the usage phase is used for functions such as product development, remote maintenance, and sales support. Data-driven services for customers already account for a significant share of revenues. The producer is integrated with the customer. The company has the in-house expertise it needs in all critical areas and can move forward with Industrie 4.0.

The six readiness levels can be grouped into three types of company, which makes it possible to better summarize the results. This grouping also makes it easier to draw conclusions about progress and conditions relating to Industrie 4.0 and identify specific action items based on the level of implementation (Figure 2-2):

- Newcomers (level 0 and 1): Newcomers include those companies that have done either nothing or very little to deal with Industrie 4.0 and are therefore assigned to levels 0 or 1 in the readiness measurement.
- Learners (level 2): Learners is the name for companies that are at level 2 and have thus already taken their first steps in implementing Industrie 4.0.
- Leaders (level 3 and up): Leaders include companies that have reached at least level 3 in the readiness model. They are already well on the way to implementing Industrie 4.0 and are therefore far ahead of most companies in Germany's mechanical engineering industry. The represent the benchmark group.

Each company was ranked with a readiness level in each dimension based on the lowest score in any single field within the given dimension: If under "smart operations," for example, a company reaches level 5 in three fields and level 1 in one field, the readiness level for this dimension is 1. The six dimension-level readiness scores were then consolidated through a weighted average to produce a total readiness score. The formula for weighting the dimension scores was determined in the survey by asking the companies to assess the relative importance of each dimension in the implementation of Industrie 4.0. From a total of 100 possible points, the dimensions are weighted as follows: strategy and organization – 25; smart factory – 14; smart products – 19; data-driven services – 14; smart operations – 10; employees – 18. These calculations were used to assign every company a readiness level of 0 to 5.

Empirical implementation

To measure readiness, criteria were defined for each area. These criteria have to be met to move up to the next readiness level. Some companies did not provide all the necessary information on the relevant criteria. This yields three possible scenarios (Figure 2-3), which are illustrated using the following example:

- In scenario A, the company has provided the necessary information and meets the criteria for level 1. The criteria for levels 2 to 5 have not been met. The company is therefore assigned to readiness level 1.
- In scenario B, it is not possible to determine whether the criteria for level 1 have been met, since the company did not provide any information on the corresponding indicators (missing values). Since the criteria to reach level 2 have been met, however, the missing values from level 1 are interpreted as meeting the criteria for level 1. The company is therefore assigned to readiness level 2.
- In scenario C, no information is available to determine whether the criteria for level 1 have been met. Since the criteria for level 2 have not been met, the missing values for level 1 are interpreted as not meeting the criteria. The company is therefore assigned to readiness level 0.

Figure 2-3: Empirical implementation of six-level readiness measurement

	Satisfaction of one or more criteria ...						
	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5	Result
A	Yes	Yes	No	No	No	No	Level 1
B	Yes	Missing values ↔	Yes	No	No	No	Level 2
C	Yes	Missing values ↔	No	No	No	No	Level 0

Original layout

3 Results of readiness measurement

This chapter presents the results of the readiness measurement. We begin by taking a look at Industrie 4.0 readiness by company, then present the readiness measurement results in the six dimensions of Industrie 4.0 as well as selected findings from the company survey.

3.1 Overview

Mechanical engineering industry is further along with industry 4.0 than manufacturing industry

The readiness measurement shows that Industrie 4.0 has already arrived in Germany's mechanical engineering industry (Figure 5-1). Nearly one-fifth of companies have already reached intermediate levels of Industrie 4.0 readiness (level 2). To date, 4.6 percent of companies have reached level 3. The "experienced" level reflects the profile of the current Industrie 4.0 leaders and serves as a benchmark for engineering companies.

Only 1 percent of companies have so far reached the level of expert (level 4). None of the companies reaches level 5 (top performer). Since level 5 is the target vision of Industrie 4.0, it is not surprising that no company has yet reached this level. Reaching this target vision is a long-term goal for most companies in the sector.

Some 37.6 percent of mechanical and plant engineering companies are beginners (level 1) and are so far involved in Industrie 4.0 only to a very small degree. Nearly 39 percent of companies stand at level 0 and are classified as outsiders. Level 0 includes not only those companies that do not meet the minimum requirements for level 1 but also those companies that were assigned to level 0 automatically because they indicated that Industrie 4.0 was either unknown or irrelevant to them (see chapter 1.4 and Figure 1-6).

The mechanical engineering industry is much more advanced in Industrie 4.0 than the manufacturing industry as a whole, however. The percentage of companies at the advanced levels of 2 to 4 is lower in the overall manufacturing industry, for example. In addition, the manufacturing industry as a whole also has a higher share of companies classified as outsiders (level 0) than the mechanical engineering industry (Table 3-1).[2]

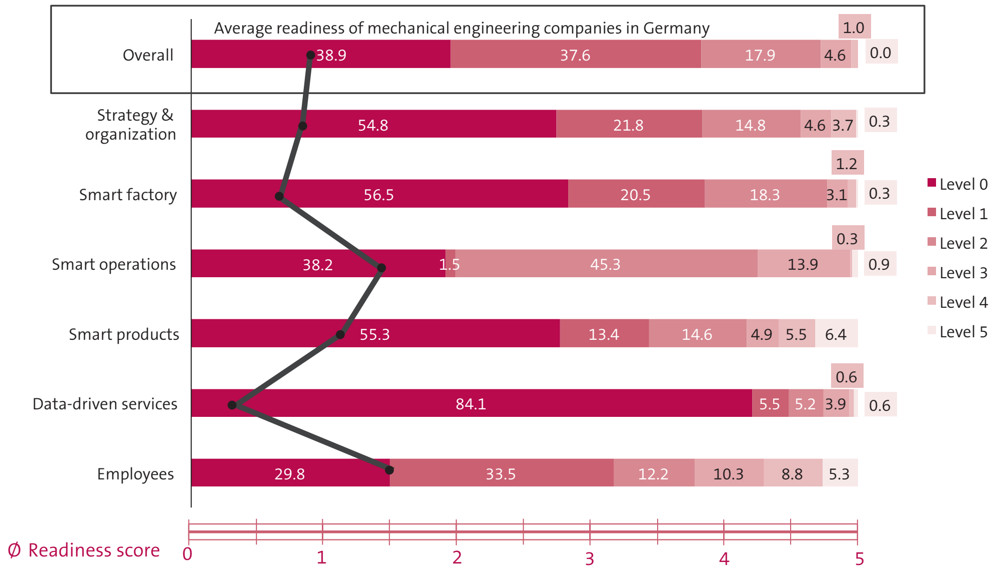
Table 3-1: Overall results for Industrie 4.0 readiness

	Mechanical and plant engineering	Manufacturing
Level 0 (outsider)	38.9	58.2
Level 1 (beginner)	37.6	30.9
Level 2 (intermediate)	17.9	8.6
Level 3 (experienced)	4.6	1.7
Level 4 (expert)	1.0	0.6
Phase 5 (top performer)	0.0	0.0
Average readiness	**0.9**	**0.6**

Information for readiness levels 0 to 5 in percent; information for average readiness: scale of 0 to 5;
n= 234 (mechanical and plant engineering); n = 602 (manufacturing industry)
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

2 This study is not designed to provide more detailed results for the manufacturing industry as a whole, so the following information is limited to the mechanical engineering industry in Germany.

Figure 3-1: Readiness measurement



Figures indicate percentages, figures for readiness levels: scale of 0 to 5; n=234-268; Only takes into account companies with more than 20 employees. Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

As outlined in chapter 2, the results from the six readiness levels can be used to group companies in the mechanical engineering industry into three types:

- Leaders (level 3 and up): The study finds that 5.6 percent of companies in Germany's mechanical engineering industry reach level 3, classifying them as Industrie 4.0 leaders.
- Learners (level 2): Nearly one-fifth of companies are classified as learners.
- Newcomers (level 0 and 1): Some three-fourths of companies only reach level 0 or 1 and are thus classified as newcomers.

The current Industrie 4.0 readiness of Germany's mechanical engineering industry, on a scale of 0 to 5, is 0.9. The score for the manufacturing industry as a whole is lower at 0.6 (Tabelle 3-1 and Figure 3-1).

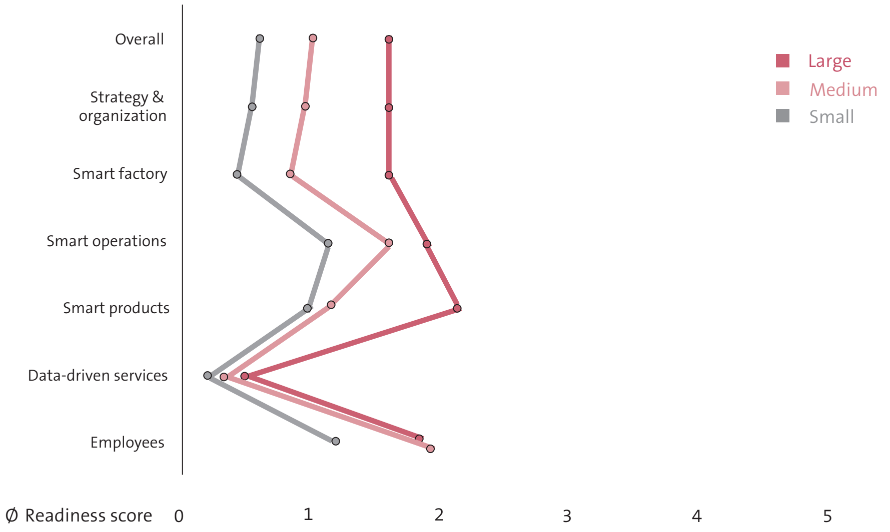
Industrie 4.0 readiness increases sharply with size of company

The survey results shows that large enterprises stand out from small and medium-sized businesses across all dimensions.

The differences by size of company are statistically significant in five of the six dimensions.[3] Only in the dimension of data-driven services was no statistically significant difference found between companies of different sizes (Figure 3-2).

3 Differences are considered statistically significant at a level of 5 percent. This means that the differences between the size categories in the random sampling are very likely attributable to corresponding differences in the overall base.

Figure 3-2: Readiness measurement by size category of company



Scale of 0 (outsider) to 5 (top performer); n=234–268
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

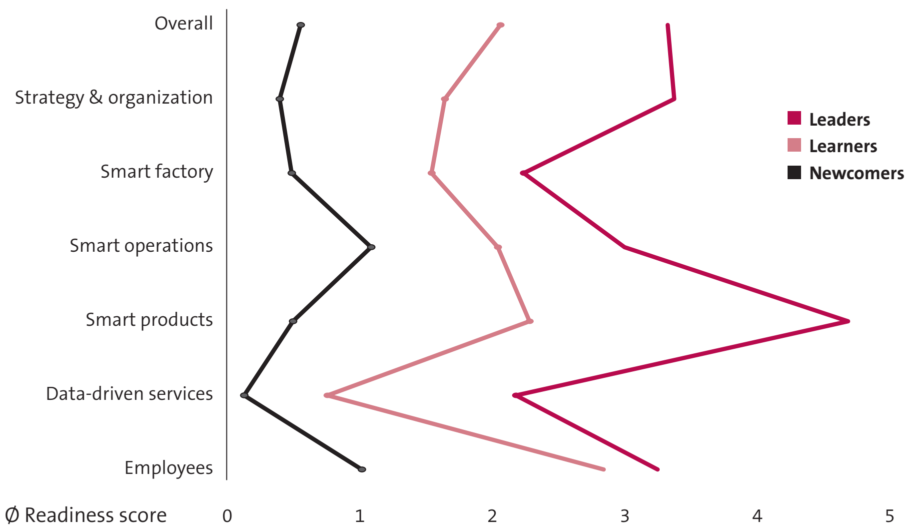
Leaders stand apart above all in smart products

The leaders are the benchmark group for the companies of Germany's mechanical engineering industry. They score an average readiness of 3.3 on a scale of 0 to 5 in the readiness measurement. In the individual dimensions, the leaders (level 3 and up) really stand out ahead of the intermediate (level 2) and newcomers (levels 0 and 1) in the dimensions of strategy and organization, smart products, and data-driven services. Action is needed in the dimension of data-driven services, however, where the leaders scored just 2.1, their lowest readiness score of all the dimensions. The leaders also need to optimize in the dimensions of smart factory and smart operations, where their readiness score is under 3.

Companies of all types are in urgent need of action when it comes to data-driven services. Like the leaders, the newcomers and learners also scored the lowest here among all six dimensions. This means that companies of all three types are still taking their first steps when it comes to digitizing their traditional business models and developing new business models with a focus on data-driven services (Figure 3-3).

In the following sections, we present the detailed results of the readiness measurement for the six dimensions of strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees. We then supplement these results with selected findings from the company survey.

Figure 3-3: Industrie 4.0 readiness by type of company



Scale of 0 (outsider) to 5 (top performer); n=234–268
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

3.2 Strategy and organization

Industrie 4.0 is a strategic issue

Industrie 4.0 is about more than just improving existing products or processes through the use of digital technologies – it actually offers the opportunity to develop entirely new business models. For this reason, its implementation is of great strategic importance. How open is Germany's mechanical engineering industry in dealing with Industrie 4.0. What is the current culture? To find answers, we look at the following four criteria:

- Implementation status of Industrie 4.0 strategy
- Operationalization and review of strategy through a system of indicators
- Investment activity relating to Industrie 4.0
- Use of technology and innovation management

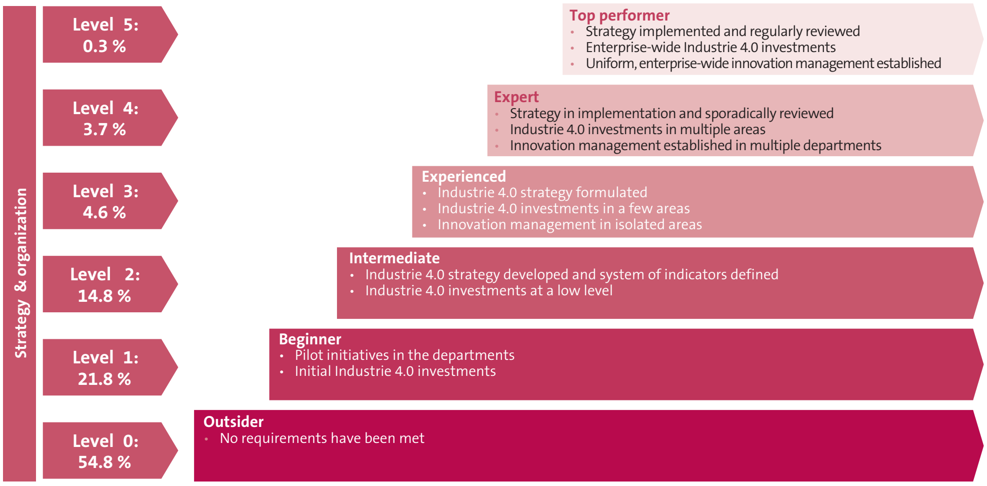
Industrie 4.0 not yet established in corporate strategy of all companies

The average readiness score in the dimension of strategy and organization among mechanical and plant engineering companies in Germany is 0.8. The leaders score an average readiness of 3.3 (Tabelle 3-2) on a scale of 0 to 5 in the readiness measurement.

One main reason for the predominantly low score in the dimension of strategy and organization is that Industrie 4.0 is not factored into the strategy of about half the surveyed companies. This means that one out of every two companies is ranked an outsider (level 0) in strategy and organization.

About one-fifth of surveyed companies can at least point to early department-level pilot initiatives, classifying them as beginners (level 1) in this dimension. They are making their first investments in Industrie 4.0, though only in one area of the company.

Figure 3-4: Readiness levels in the dimension of strategy and organization



Figures indicate percentages; n=248
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Another 15 percent are beginning to implement a strategy and system of indicators, which classifies them as intermediate (level 2). They are making small-scale investments, while innovations are still not systematically analyzed and implemented.

The Readiness Model ranks 4.6 percent of companies at level 3 (experienced). The main hurdle is inadequate implementation of the strategy they have developed, however. Those who reach level 4 (expert) have a strategy in an advanced stage of implementation that is being reviewed sporadically. They are also making Industrie 4.0 investments in several areas of the company. Guided by a principle of vertical integration, these companies in the second-highest level have implemented innovation management in multiple departments.

Only 0.3 percent of surveyed companies are classified in the highest level of 5 (top performer). Level 5 requires complete implementation of the strategy and a regular strategic review. Companies are nevertheless encouraged to invest across the company and establish an enterprise-wide system of innovation management. The survey finds fulfillment of the criterion of “implementation status” to be especially critical (Figure 3-4).

Table 3-2: Average readiness in the dimension of strategy and organization

	Overall	Newcomers	Learners	Leaders
Readiness score	0.8	0.3	1.6	3.3

Scale of 0 (outsider) to 5 (top performer); n=248
Only counts companies with more than 20 employees

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Main hurdles to reaching a higher level of readiness

Based on the results of the readiness measurement in the dimension of strategy and organization, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-5).

The following is a more detailed handling of specific findings in the dimension of strategy and organization from the company survey.

Four of ten companies still lack comprehensive strategy to implement Industrie 4.0

Most companies have already worked on Industrie 4.0 strategies, but four of ten companies surveyed (39.8 percent) still have no comprehensive strategy to promote the transition to an Industrie 4.0 company. Only 1.3 percent of companies have implemented an Industrie 4.0 strategy. One in five is working on a strategy, while one-fourth of surveyed companies have not moved beyond pilot initiatives.

The percentage of companies without a strategy is lower among large enterprises. Here, only one in five lacks an Industrie 4.0 strategy. And yet, only 1.2 percent of large enterprises have already implemented the strategy. The percentage of those who have implemented the strategy is highest among the small and medium-sized businesses. Nevertheless, the share of companies that have already implemented an Industrie 4.0 strategy is very low at 3.8 percent (Figure 3-6).

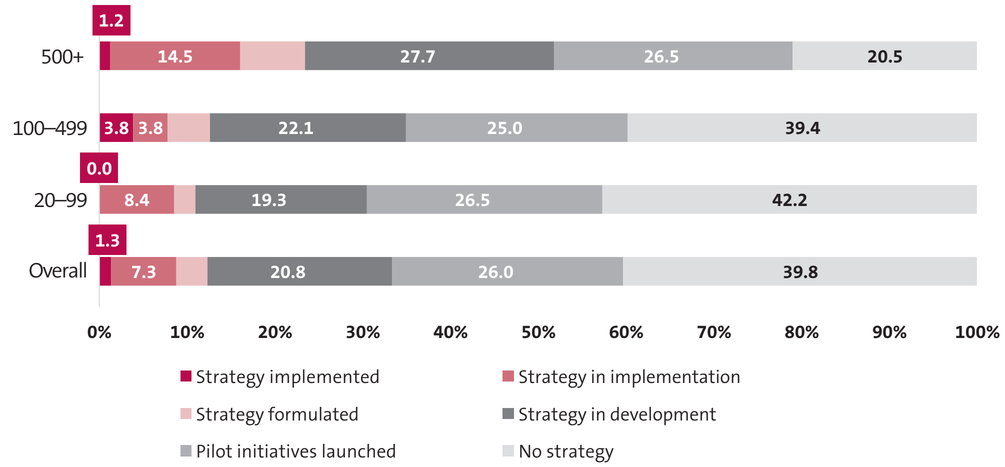
Figure 3-5: Main hurdles in the dimension of strategy and organization

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Industrie 4.0 has little or no impact on the strategic process	▪ Industrie 4.0 is part of the strategic process, but a specific strategy has not yet been defined	▪ An Industrie 4.0 strategy has not yet been implemented ▪ The strategic process does not yet include a system of indicators

n=248
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-6: Implementation status of Industrie 4.0 strategy



Figures indicate percentages; n= 270
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Three of four companies not using any system of indicators

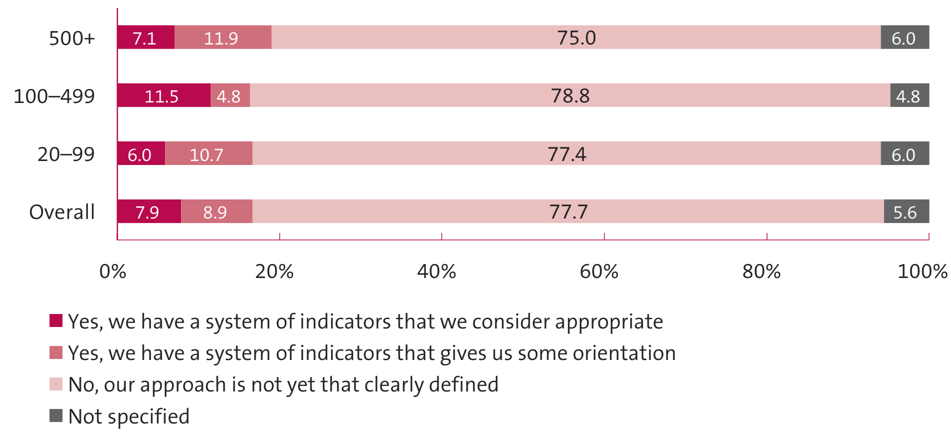
Three-fourths of all companies do not use any system of indicators to measure the implementation status of Industrie 4.0. Only 16.8 percent of companies even have such a system, but less than half of these companies consider their system of indicators to be adequate. Here, too, we see a trend based on a company's size: The larger the company, the more likely it is to use a system of indicators to measure the implementation status of Industrie 4.0 (Figure 3-7).

Three of ten companies already have enterprise-wide technology and innovation management

New and often innovative technologies are needed to further digitize production processes and equip products with the new IT-based add-on functionalities that turn them into "smart" products. A company needs an organizational structure in place for the systematic early identification, planning, and controlling of new technologies and to monitor their use. Currently, this is often done separately for product development, production technology, and IT. But as Industrie 4.0 advances, many innovations in the areas of product development and production technology are IT-driven. So to ensure that new information technologies in the product and production environment are used to optimal effect, it's a good idea to consolidate department-specific expertise and build up enterprise-wide, integrated technology and innovation management in the company.

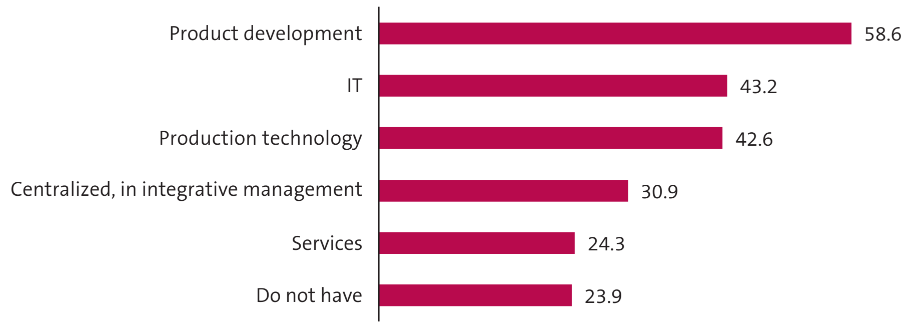
The survey shows that at least three of ten companies already have enterprise-wide technology and innovation management. Only just under one-fourth of companies in the mechanical engineering industry have no systematic technology and information management. Most of the companies surveyed do this in product development (Figure 3-8).

Figure 3-7: Use of a system of indicators



Figures indicate percentages; n= 272
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-8: Technology and innovation management

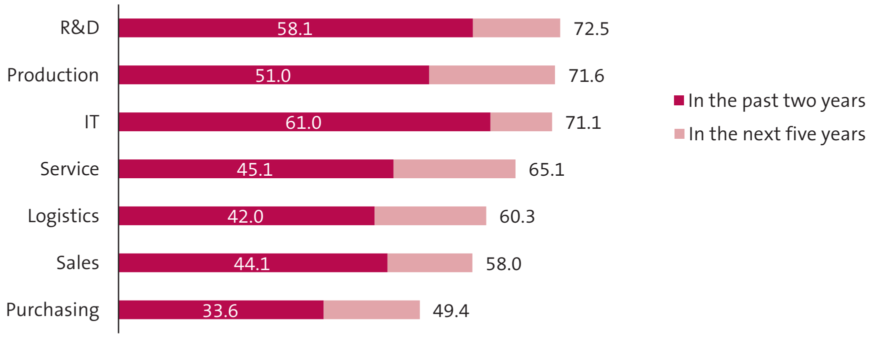


Figures indicate percentages; n= 248
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Companies currently investing only small amounts in Industrie 4.0

The companies surveyed for the study invested an average of 1.7 percent of their annual revenues from 2013 and 2014 in the implementation of Industrie 4.0 projects. This represents 15 percent of the overall investment budget for material and personnel expenses. One-fifth of companies have not yet seen any need to invest in Industrie 4.0 applications. Meanwhile, some half of those surveyed made investments throughout the company in 2013 and 2014. The main beneficiaries were research and development, IT, and production. The percentage of companies making investments in Industrie 4.0 will grow between now and 2020, according to the companies themselves (Figure 3-9). The survey also underscores that large enterprises in the sector plan to invest heavily in services and logistics.

Figure 3-9: Past and planned investments in Industrie 4.0



Figures indicate percentages; n= 223
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

3.3 Smart factory

The smart factory is the concept of an intelligent, interconnected factory in which the production systems communicate directly with the overlying IT systems (or MES, ERP, SCM systems – see also “smart operations”) and with the smart products. The smart factory achieves the highest level of digitization of the value chain through the integration and self-regulation of all processes, especially in production. A key challenge in implementing the smart factory is the high investment costs. The objective of efficient information delivery and resource use can be achieved through the synchronized interaction of production systems, information systems, and people (employees and customers).

A key feature of the smart factory is the placement of comprehensive sensor technology throughout the factory and on the machinery and systems at strategic data collection points. The aim is to capture all relevant process- and transaction-related data in real time and process it quickly to map the order processing. The big data this generates places a high burden on IT systems and infrastructure. The big data is analyzed for informational purposes using data analytics. This requires powerful computer systems.

The following four criteria are used to measure progress in Germany’s mechanical engineering industry in the dimension of the smart factory:

- Digital modeling
- Equipment infrastructure
- Data usage
- IT systems

More than half of companies yet to begin with the smart factory

In the dimension of the smart factory, the companies in Germany’s mechanical engineering industry have a readiness value of 0.7 on a scale of 0 to 5. The leaders have an average value of 2.2 (Tabelle 3-3).

More than half the companies are classified as outsiders (level 0) in the smart factory dimension, meaning they do not yet meet the criteria for level 1. About one-fifth of companies meet the criteria of level 1 and are classified as beginners. These companies already meet some of the future equipment infrastructure requirements, but they are not yet working on an integrated technical solution to upgrade their equipment infrastructure, which is a prerequisite for level 2 in the smart factory dimension. Some 18.3 percent of companies are at level 2. This means that the overwhelming majority of nearly 95 percent of companies are at levels 0 to 2. A mere 3.1 percent of companies in Germany’s mechanical engineering industry are ranked at level 3,

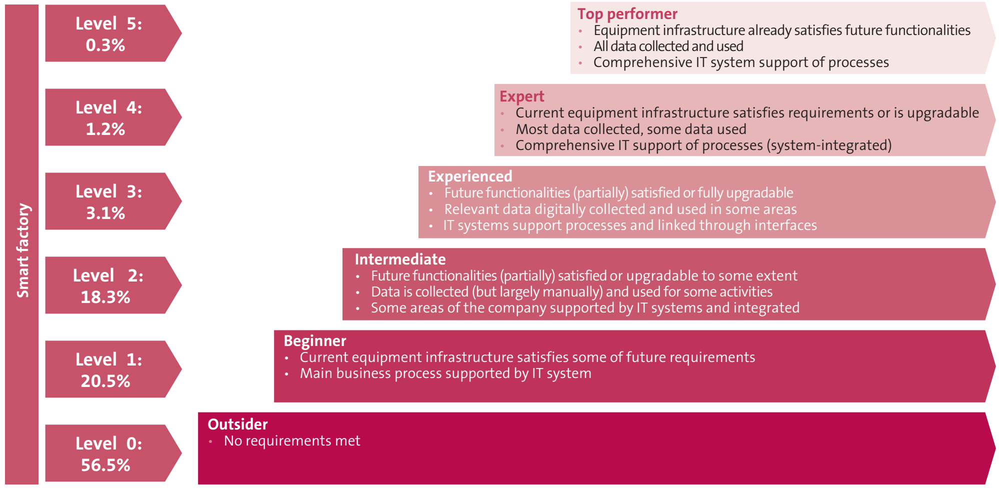
Table 3-3: Average readiness in the dimension of smart factory

	Overall	Newcomers	Learners	Leaders
Readiness score	0.7	0.4	1.5	2.2

Scale of 0 (outsider) to 5 (top performer); n=268
Only takes into account companies with more than 20 employees.

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-10: Readiness levels in the dimension of smart factory



n=268 Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

meaning they meet the equipment infrastructure requirements for criteria such as data collection and the use of IT systems.

The final level of experts accounts for the smallest share of all companies with 0.3 percent. This means that only a miniscule percentage of companies have already fully upgraded their equipment infrastructure to fully satisfy the requirements of Industrie 4.0 (Figure 3-10).

Main hurdles to reaching a higher level of readiness

Based on the results of the readiness measurement in the dimension of the smart factory, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-11).

Figure 3-11: Main hurdles in the dimension of smart factory

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Equipment infrastructure not connected to higher-level IT systems ▪ No machine and process data collected	▪ Equipment infrastructure not fully connected to IT systems ▪ Limited capacity for equipment infrastructure upgrades	▪ Machine and system infrastructure does not yet meet all future requirements ▪ Collection of machine and process data is not consistently digitized

n=268
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Some of the findings from the company survey for the smart factory dimension are presented below.

Only few companies collecting all machine and process data

The collection of machine, process, and article data is a basic prerequisite for unlocking the full potential of Industrie 4.0. The survey shows that about two-thirds of companies in the mechanical engineering industry are laying the foundation for Industrie 4.0 in this area. Of this, 10.9 percent of all companies record all their machine and process data, while another 59.9 percent record some of it. Only about one-fifth of companies do not collect any data. This figure is greatest among small businesses, where more than one-fifth of companies collect no machine or process data whatsoever, compared to only 3.6 percent among large enterprises (Figure 3-12).

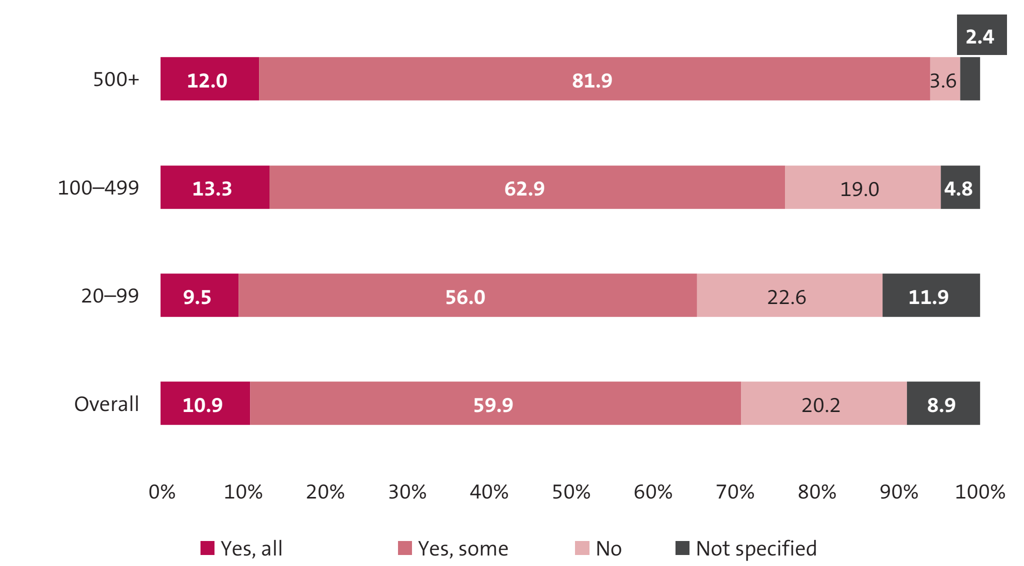
Three of ten companies use real-time data for automatic production control

The survey shows that the data collected in all companies is most frequently used to bring transparency to the production process and for quality management. Rounding off the top three uses for machine, process, and system data is optimization of the logistics process.

About half of companies do actually already use the data they collect to optimize resource consumption and conduct predictive maintenance. Three of ten companies use real-time data for automatic production control.

These results show that much potential is still going unused. Operational data alone does not yield any benefit – it must be qualified through a smart transformation to value-added data. The

Figure 3-12: Collection of machine and process data



Figures indicate percentages; n = 272
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

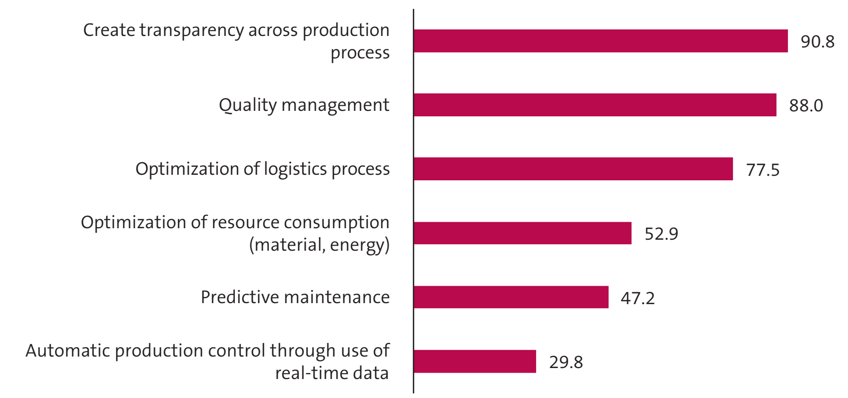
digital model of production then yields conclusions and insights that help the decision-making process. Real-time-enabled data collection, processing, and delivery brings complete transparency to the process chain, making production planning and control more accurate and above all more flexible, and enabling simulations that enhance the quality of business decisions. More hands-on, diversified uses of this data can yield forecasts with the potential to enhance planning and efficiency and cut costs for the equipment and systems infrastructure (Figure 3-13).

M2M and interoperability already in place at four of ten companies

In addition to cyber-physical systems (CPS), the smart factory relies on the elements of smart machines, smart products, and – last but not least – people as the decision-makers. Intelligence is the common theme when you look at the future of production machinery. What this means is that machines are aware of their functionalities, location, resource consumption, operating expenses, and current utilization. Enterprise-wide and cross-enterprise integration makes it possible for them to respond autonomously to changes in the order, component failure, or lapses in quality. By connecting to other product units, machines can respond autonomously, in real time, and with flexibility to irregularities, ensuring smart and optimized production.

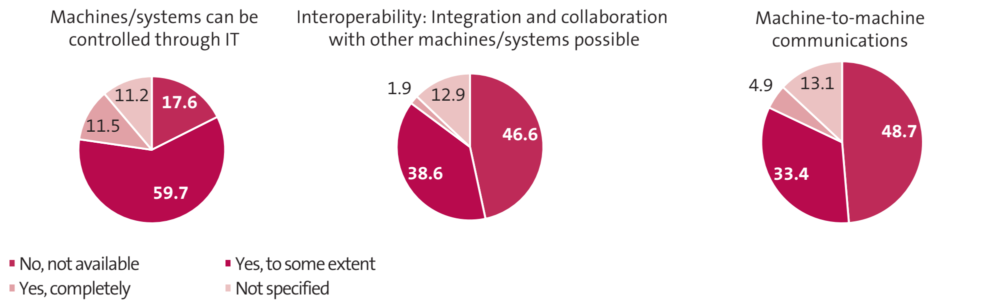
The results vary when broken down by the functionality of the companies' equipment infrastructure (Figure 3-14). While seven of ten companies can control their machinery and systems fully or somewhat through IT, only about four of ten companies say the same with regard to interoperability and machine-to-machine (M2M) communications. Complete functionality in the areas of M2M, interoperability, and IT control is correspondingly low at 4.9 percent, 1.9 percent, and 11.5 percent, respectively.

Figure 3-13: Use of data



Figures indicate percentages; n = 200
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-14: Equipment infrastructure functionalities



Figures indicate percentages; n = 270
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

3.4 Smart operations

Integration is key to Industrie 4.0

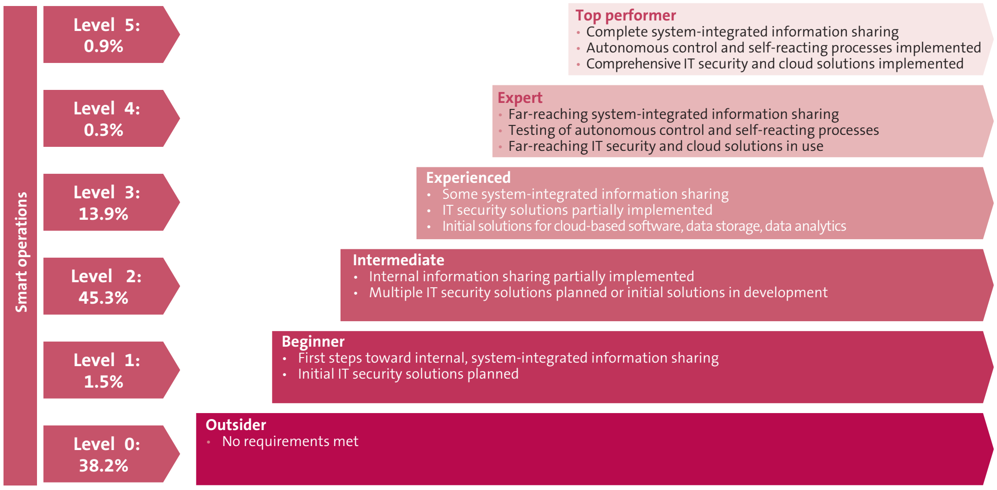
The integration of all components and systems within a plant is an essential component in the realization of Industrie 4.0 and the foundation for horizontal and vertical integration of the value chain. The core idea behind the integrated horizontal value chain is the interconnection of all internal and external value chain partners, from the supplier to the customer. The result is a network of cross-enterprise planning and control of the entire product lifecycle with a focus on fulfilling the needs of the customer. Vertical integration describes the integration within a company, from sales to product development and planning all the way to production, after-sales, and ultimately finance. This integration of production systems offers a wide range of potential to enhance productivity, quality, and flexibility (PwC, 2014).

Decisions on prioritization and implementation of order processing within the value chain are based on the analysis of data of the highest possible resolution. That's why the collection, analysis, and utilization of data is so important to Industrie 4.0 and one of the main drivers for developments in this area (Accenture, 2014). Sensor technology installed in production captures transaction and process data, which is processed and analyzed with the help of integrated smart systems. The insights this yields enable more precise forecasting (of interruptions and malfunctions, for example), which improves the flow of production. The higher the data resolution, the more relevant the insights. That explains the growing importance of data security (MHP, 2014).

Industrie 4.0 readiness in the area of smart operations is determined using the following four criteria:

- Information sharing
- Cloud usage
- IT security
- Autonomous processes

Figure 3-15: Readiness levels in the dimension of smart operations



n =234
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

One of four companies already ranked intermediate in the dimension of smart operations

The average readiness in Germany's mechanical engineering industry for the dimension of smart operations is 1.4 on a scale of 0 to 5. The leaders have an average readiness score of 2.9 (Tabelle 3-4).

Some 45 percent of surveyed mechanical and plant engineering companies are classified as level 2 (intermediate). For most companies, the main hurdle in the attempt to reach a higher readiness level is the lack of system-integrated external information sharing. Those at level 2 have implemented some of the necessary system-integrated internal information sharing. Multiple solutions for IT security are either planned or have already been developed.

Nearly four of ten companies (38.2 percent) are outsiders (level 0). The few companies classified as beginners (level 1) are developing early system-integrated external information sharing and IT security solutions. Some 13.9 percent of companies have reached level 3. These intermediate companies have partially implemented system-integrated information sharing – both internally and externally with business partners – as well as IT security solutions. They are also working on deploying cloud solutions. The main thing they lack to advance to level 4 is tests with self-guiding workpieces in production and autonomously reacting processes. Only very few companies have crossed this threshold. The experts (level 4) account for just 0.3 percent and the top performers (level 5) for just 0.9 percent of surveyed companies (Figure 3-15).

Table 3-4: Average readiness in the dimension of smart operations

	Overall	Newcomers	Learners	Leaders
Readiness score	1.4	1.0	2.0	2.9

Scale of 0 (outsider) to 5 (top performer); n=234
Only takes into account companies with more than 20 employees.

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-16: Main hurdles in the dimension of smart operations

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Little or no system-integrated, in-company information sharing	▪ No initial steps toward system-integrated information sharing with external partners	▪ Autonomously guided workpieces not yet in use ▪ Self-reacting processes not yet in use

n=234
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Main hurdles to reaching a higher level of readiness

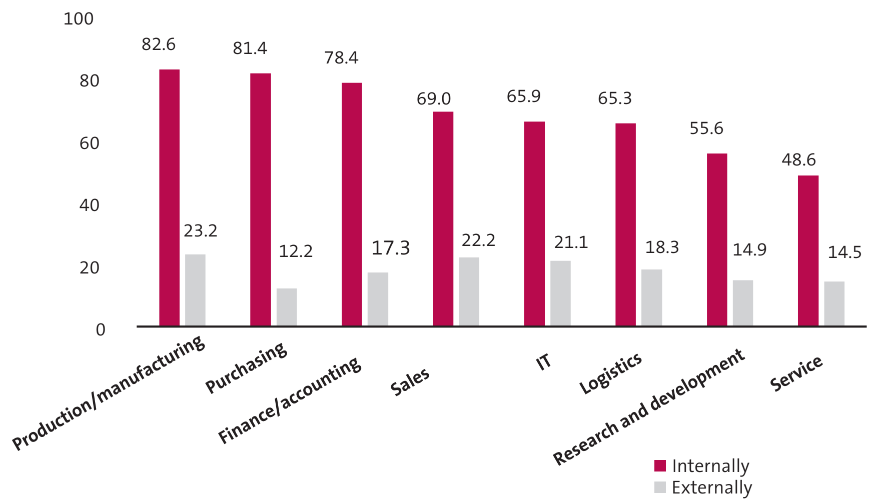
Based on the results of the readiness measurement in the dimension of smart operations, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-16).

The key findings in the dimension of smart operations are outlined below.

Low level of external integration

Companies are very strongly integrated internally, but there is still much unrealized potential in the area of external integration. Streamlined communication channels and automatic integration of purchasing and sales into the various processes can lower costs and enhance efficiency.

Figure 3-17: System-integrated information sharing by area



Figures indicate percentages; n = 234 (internal), 221 (external)
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

External integration is especially weak in the areas of purchasing, service, and research and development (R&D)[4] (Figure 3-17). The larger the company, the greater the level of both internal and external integration. For internal integration, the reason can be found in the widespread use of enterprise resource planning systems to support in-house business processes.

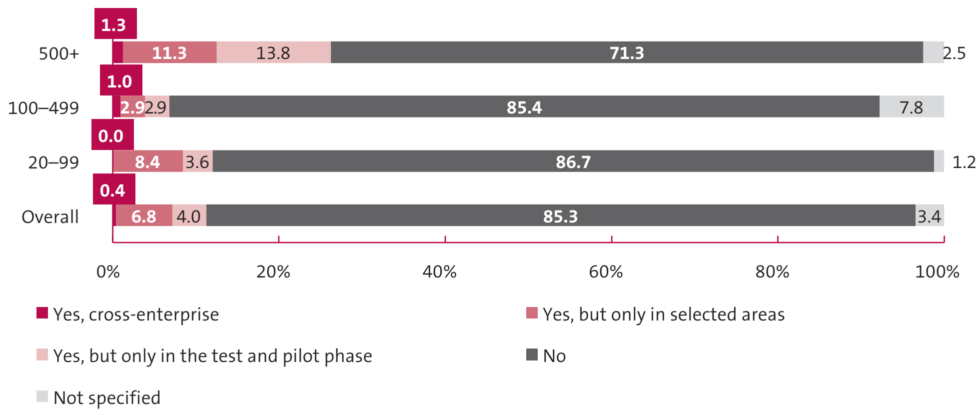
Only few companies offering autonomous control

One of the grand visions of Industrie 4.0 is self-guided production: Workpieces move by themselves to the next processing station, determine routes and sequences on their own, and communicate the necessary production parameters to the equipment.

The survey polled Germany's mechanical engineering industry about the degree to which they have implemented this kind of autonomous control in their companies.

The survey reveals that on average, 85.3 percent of the surveyed companies have no autonomous control systems. The large enterprises were the most advanced, with one in four citing autonomous control in development or already in use. Surprisingly, smaller companies embraced this technology more strongly (12 percent) than medium-sized companies (6.8 percent). The percentage of companies with cross-enterprise autonomous control is miniscule at 0.4 percent (Figure 3-18).

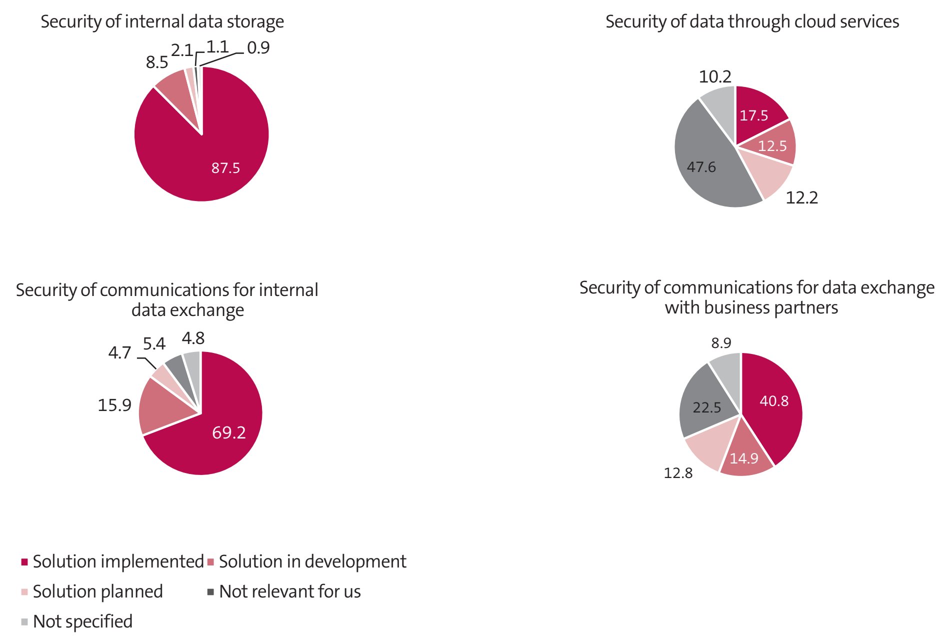
Figure 3-18: Autonomous control of workpiece in production



Figures indicate percentages; n = 266
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

4 External integration in the area of R&D refers to system-integrated information sharing with development partners or research institutions. An example of this kind of integration is a product lifecycle management system that provides multiple partners with the construction data of a product, enabling collaboration on the product.

Figure 3-19: IT security solutions



Figures indicate percentages; n = 260
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

IT security measures implemented primarily for internal purposes

As explained at the outset, it is not enough to ensure the availability of high-resolution data and the systems to analyze and utilize this data – you also need to ensure the security of this data. German companies in particular are careful with data and place a high premium on data protection and security. The survey results confirm this:

Companies have already implemented solutions for internal data and communication channels but are more restrained when it comes to external protections and communication channels. Nearly half indicate that they do not regard the security of data through cloud services to be relevant (48.1 percent).

The general trend is evident here as well: Large enterprises are more likely to have implemented solutions in the various categories than smaller businesses, who do not see the topic of cloud services in particular and communications with external partners as relevant for themselves (Figure 3-19).

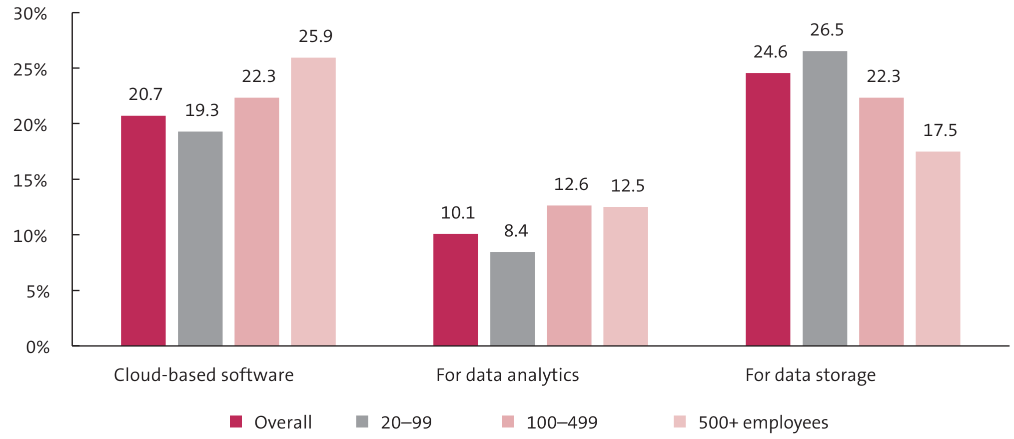
Penetration of cloud solutions remains low

The use of cloud solutions was the last aspect of Industrie 4.0 implementation in the dimension of smart operations to be examined. The term cloud solutions includes cloud storage (data storage), cloud computing (data analytics), and cloud-based software. The primary subject of interest is whether and for what purpose companies are using cloud solutions. Companies often use cloud solutions to outsource computing and storage capacities and license software more efficiently. The scalability combined with a growing number of integrated devices and growing volumes of data is a key IT-driven solution for the success of Industrie 4.0 (Figure 3-20).

The survey shows that the penetration of cloud solutions is still quite low in the mechanical engineering industry. This often involves significant transformations of the IT environment, however, and companies tend to show restraint when it comes to cloud computing in particular.

The frequently observed trend that large enterprises are more active in pursuing Industrie 4.0 than small businesses is evident in the areas of cloud-based software and cloud-based data analytics as well but not in the area of cloud-based

Figure 3-20: Use of cloud services



Figures indicate percentages; n = 266
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

data storage, where small businesses are more active. The outsourcing of storage capacities and the associated reduction in administrative overhead and hardware procurement costs seems to be especially attractive to small businesses. The switch from internal storage solutions to cloud storage is a classic outsourcing process that brings greater flexibility to availability and storage capacity, but the user experience adheres closely to local concepts. The use of cloud-based software is not much more than a change in licensing models – from the user perspective, the only difference is the addition of a few new functionalities. Cloud computing for data analytics gives companies access to entirely new areas of activity that must first be explored. The flexible access to immense computing capacities enables complex simulations without the high expenses associated with upgrading one's local IT infrastructure.

3.5 Smart products

Smart products are the foundation for the smart factory and smart operations

Many features of the smart factory and potential benefits of data-driven services rely on the availability of comprehensive information about a particular product. The smart factory needs to know which product is at which location in production in order to communicate the order status in real time. Equipment manufacturers need extensive information about how long and how intensively a piece of equipment is used in order to offer customers a predictive maintenance plan based on actual usage. These scenarios require the use of smart products – physical objects equipped with ICT. This makes them uniquely identifiable, so they can interact with their environment, record their environment and status through sensors, and offer various add-on functionalities in operation (Deindl, 2013).

In the vision of Industrie 4.0, a self-guiding workpiece in production tells a machine which worksteps need to be carried out. To do this, the product needs information about itself and about planned and previously implemented worksteps.

This information can be gathered through the functionalities of object information, monitoring, and product memory. The product functionalities of integration and self-reporting make it possible for products to communicate worksteps to the machine. To enable monitoring of the overall order progress, products must be able to automatically identify and locate themselves.

In the usage phase, these same functionalities open the door to data-driven services such as telemaintenance or the ability to offer equipment parameter settings for processing certain materials. The manufacturer also gains the opportunity to support product development by collecting all the vital usage and production data. The use conditions can be analyzed in much greater detail and the product further developed accordingly, making it possible for companies to develop products and solutions fine-tuned to potential users or customers.

Readiness in the area of smart products is determined by looking at the ICT add-on functionalities of products and the extent to which data from the usage phase is analyzed.

One in six companies using data from usage phase

In the dimension of smart products, Germany's mechanical engineering industry has an average readiness score of 1.1. Among the group of leaders, the average score is much higher at 4.6 (Tabelle 3-5).

Over half of companies have no products with IT-based add-on functionalities, so they collect no data during the usage phase that could be used for product development, sales support, or telemaintenance. These companies are classified as outsiders (level 0). Some 13.4 percent of companies are classified as beginners (level 1). These companies' products have the first signs of add-on functionality in the areas of product memory, self-reporting, integration, localization, assistance systems[5], monitoring, object information, or automatic identification. Companies at level 2 (14.6 percent) are equipping their products with the first functionalities. They are also collecting data but are not yet using or analyzing it. Companies at level 3 (experienced, 4.9 percent) have products with multiple interconnected add-on functionalities, and data from the usage phase is used in part for the aforementioned tasks. At level 4 (5.5 percent) and level 5 (6.4 percent), data usage and the number of add-on functionalities rises toward a comprehensive package of functionalities from various areas (Figure 3-21).

Table 3-5: Average readiness in the dimension of smart products

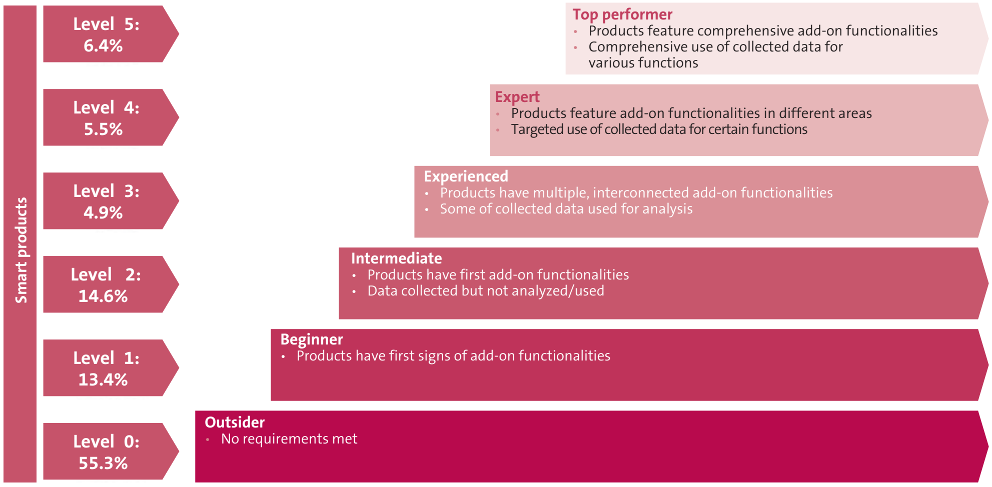
	Overall	Newcomers	Learners	Leaders
Readiness score	1.1	0.4	2.2	4.6

Scale of 0 (outsider) to 5 (top performer); n=243
Only takes into account companies with more than 20 employees.

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

5 Example from the consumer sector: The Amazon app generates suggestions for new purchases based on previous purchases, and the Spotify app uses the same concept to suggest new tunes.
Example from the mechanical engineering industry: Machines could suggest setting parameters based on previous processing orders, and head-mounted displays can help in the picking process.

Figure 3-21: Readiness levels in the dimension of smart products



Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Main hurdles to reaching a higher level of readiness

Based on the results of the readiness measurement in the dimension of smart products, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-22).

The company survey asked companies to evaluate the add-on functionalities of their products. The results offer insight into the most common product add-on functionalities and are outlined in the following.

One in four companies offers integrated products

Product add-on functionalities are most often used for object information, monitoring, and integration. The familiar trend by company size is evident here as well: The larger the company, the greater the percentage that has implemented product add-on functionalities. Anyone hoping to realize the vision of the smart factory cannot get around the issue of localization of products. And yet, a mere 7.4 percent of companies have so far integrated this feature into their products. Companies that wish to offer their customers additional services must create the necessary foundation for monitoring or integration. Small and medium-sized businesses in particular need to make up for lost time on this front (Figure 3-23).

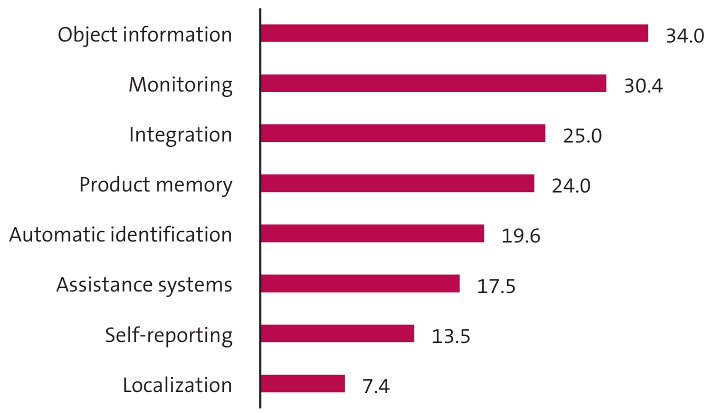
Figure 3-22: Main hurdles in the dimension of smart products

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Products offer no ICT add-on functionalities or initial attempts only	▪ No analysis or use of collected data to optimize products or processes (product development, sales support, after-sales)	▪ Products offer ICT add-on functionalities limited to just a few areas

n=243
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-23: ICT add-on functionalities of products



Figures indicate percentages; n = 243
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

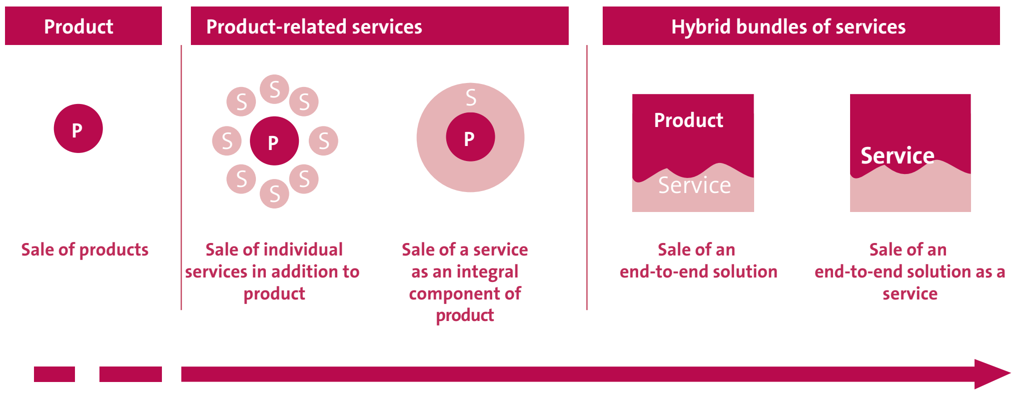
3.6 Data-driven services

Companies evolving from selling products to providing solutions

Another hallmark of Industrie 4.0 alongside the use of ICT is a fundamental rethinking of existing business models with a focus on enhancing the benefit to the customer. Companies have the opportunity to both digitize conventional business models and develop entirely new business models whose added value derives from data collection and analysis.

Disruptive, innovative business models under Industrie 4.0 go even further, with the express aim of forcing open existing value chains and tapping into new potential. In the mechanical engineering industry, the trend in recent years has been for manufacturers to move beyond simply selling machinery to providing hybrid bundles of services – combining products and services for increased added value to the customer. The classic example of this is coupling the sale of a machine with a maintenance contract that includes a contractually defined commitment of system availability. This in turn is linked to an analysis of equipment data collected to enable predictive maintenance (Figure 3-24).

Figure 3-24: Data-driven services



Source: Based on Hildenbrand et al., 2006

Readiness in the area of data-driven services is determined using the following three criteria:

- Availability of data-driven services
- Share of revenues derived from data-driven services
- Share of data used

Readiness is lowest in data-driven services

Germany's mechanical engineering industry scores its lowest readiness in the dimension of data-driven services, just 0.3 on a scale of 0 to 5. Even the leaders earn their lowest marks here among all the dimensions in the study, with an average readiness score of 2.1 (Tabelle 3-6).

The objective of data-driven services is to align future business models in order to enhance the benefit to the customer. The after-sales and services business will be based more and more on the evaluation and analysis of collected data. The results of the survey show that most companies (84.1 percent) have not yet dealt with the subject of Industrie 4.0 as it relates to data-driven services and are therefore at level 0. Among all the dimensions studied in this model, progress in Industrie 4.0 is lowest in data-driven services, with only 5.5 percent of companies reaching level 1 (Figure 3-25).

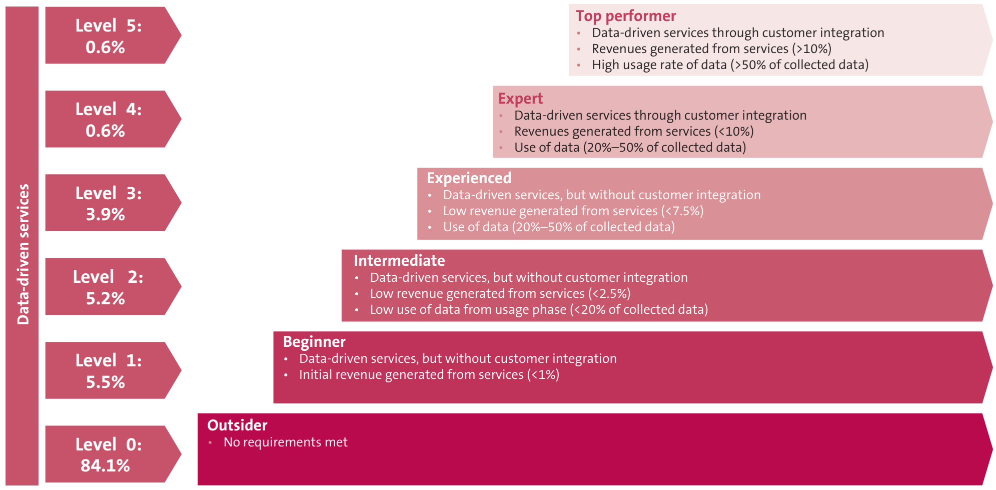
Table 3-6: Average readiness in the dimension of data-driven services

	Overall	Newcomers	Learners	Leaders
Readiness score	0.3	0.1	0.7	2.1

Scale of 0 (outsider) to 5 (top performer); n=259
Only takes into account companies with more than 20 employees.

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-25: Readiness levels in the dimension of data-driven services



n=259 Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Main hurdles to reaching a higher level of readiness

Based on the results of the readiness measurement in the dimension of data-driven services, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-26).

Readiness is determined on the basis of the survey results, which are presented on the following pages.

Figure 3-26: Main hurdles in the dimension of data-driven services

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Focus on traditional products; data-driven services not offered or not integrated with the customers	▪ Data usage of 20–50% not yet achieved	▪ Data-driven services not yet digitally integrated with customers ▪ Data-driven services do not yet account for a significant share of revenues (>7.5%)

n=259
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Hardly any data-driven services available

The results show that some two-thirds of companies (64.6 percent) have not yet discovered the potential of data-driven services and do not offer any such services.

We also see that about one-third of companies offer data-driven services but only about half of them are integrated with their customers. Small and medium-sized businesses lag behind large enterprises when it comes to offering such customer-integrated services. Nearly double as many small businesses (19.3 percent) as medium-sized businesses (10.7 percent) offer data-driven services and are also integrated with their customers (Figure 3-27).

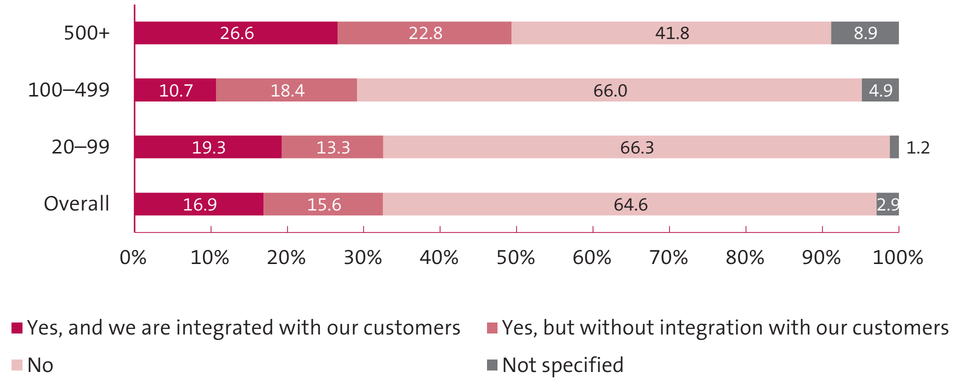
Among the companies that collect process data during the production and usage phase, only 14.7 percent do not make any further use of this data. Among the companies that gather such data, about half report that they make further use of up to 20 percent of the data. One-fifth of companies even use 20 to 50 percent of the data. These results do not vary significantly by the size of the company (Figure 3-28).

Main purpose of analysis is product development

Besides the disproportionately sharp rise in the use of sensor technology, integration is the main basic precondition for providing new services and gaining insights from the usage phase.

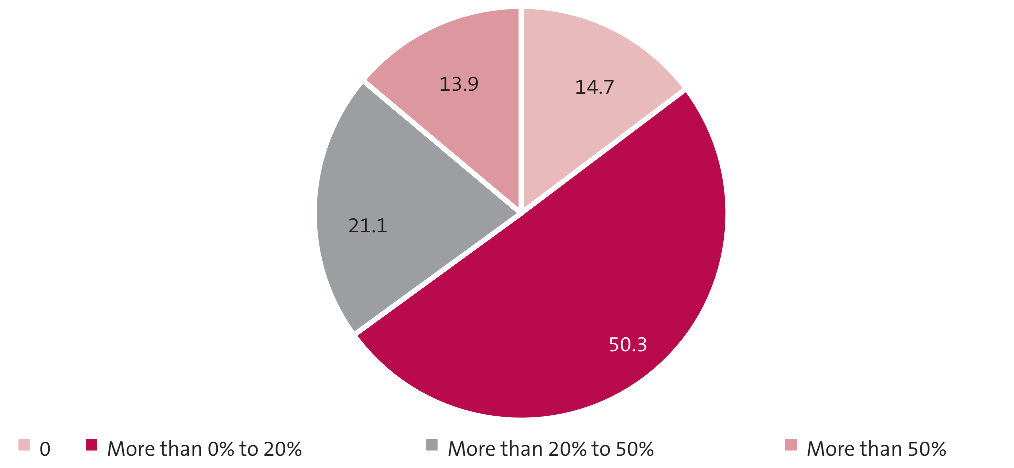
Data can be collected directly as a product is used. This makes is possible to observe and analyze user behavior, for example. This in turn makes is possible for manufacturers to learn about potentially incorrect use of the product and find way to optimize it. Data can also be used to support the sales team, offer after-sales services such as telemaintenance, and offer additional services.

Figure 3-27: Portfolio of data-driven services



Figures indicate percentages; n = 265
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

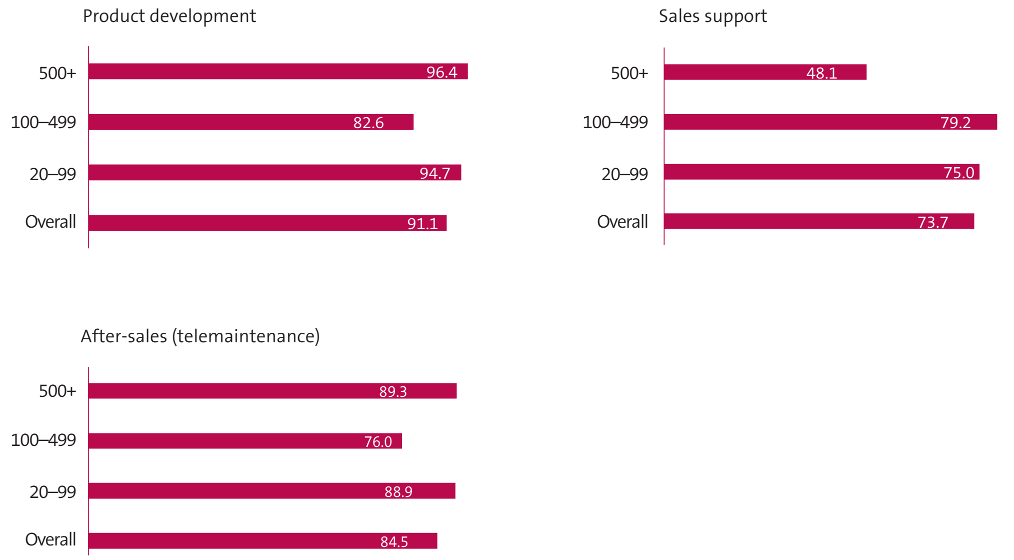
Figure 3-28: Share of data used in company



Figures indicate percentages; n = 92
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

The survey shows that nearly one-third of companies (30 percent) do not collect the data generated during the product usage phase. Another one-fourth (25 percent) collect the data but do not use it. The remaining 45 percent of companies analyze data from the usage phase. The survey shows that nearly all companies use the data they collect for product development and telemaintenance (Figure 3-29).

Figure 3-29: Analysis of data from usage phase



Figures indicate percentages, share of yes responses ; n = 67
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

3.7 Employees

Employees help companies realize their digital transformation

Employees are the ones most affected by the changes in the digital workplace. Their direct working environment is altered, requiring them to acquire new skills and qualifications. This makes it more and more critical that companies prepare their employees for these changes through appropriate training and continuing education.

The key role that employees play in change processes has already been examined in multiple studies (Spath et al., 2013; PwC, 2014; DIHK, 2015). The studies often focus on changes in qualifications and the extent to which companies can teach the necessary qualifications. The study by the Fraunhofer Institute for Industrial Engineering is devoted to exploring the anticipated effects on how work is designed and organized. The study polls 518 production engineers to offer a portrait of the status of Industrie 4.0 implementation in German industrial enterprises. The results show that the requirements of production workers will evolve as digitization progresses. A willingness for lifelong learning is seen as paramount among these changes. Higher IT skills rank third in importance among the skills asked about in the study, behind strong interdisciplinary thinking and acting (Spath et al., 2013).

Readiness in the dimension of employees is determined by analyzing employees skills in various areas and the company's efforts to acquire new skill sets.

Only one-third of companies lack necessary skills

In the dimension of employee skills, the average company in the mechanical engineering industry scores 1.5. One possible explanation for the relatively high readiness score compared to the other dimensions is that companies have more experience when it comes to the professional development of their employees, so they feel more confident here than in other Industrie 4.0 dimensions such as data-driven services, smart factory, Industrie 4.0 strategy implementation. The leaders have an average readiness score here of 3.2 (Tabelle 3-7).

About one-third of companies have a readiness level of 1 (beginners), meaning the employees have the necessary skills in one relevant area (IT infrastructure, automation technology, data analytics, data security / communications security, development or application of assistance systems, collaboration software, non-technical skills such as systems thinking or process understanding) but not at an adequate level. Another third of surveyed companies did not make it over this hurdle, however, and could not demonstrate any of the cited skills (level 0). The percentage of companies is lower and lower at each higher level. Even so, 5.3 percent of those surveyed are classified as experts in this dimension (level 4), meaning they have adequate skills in several relevant areas (Figure 3-30).

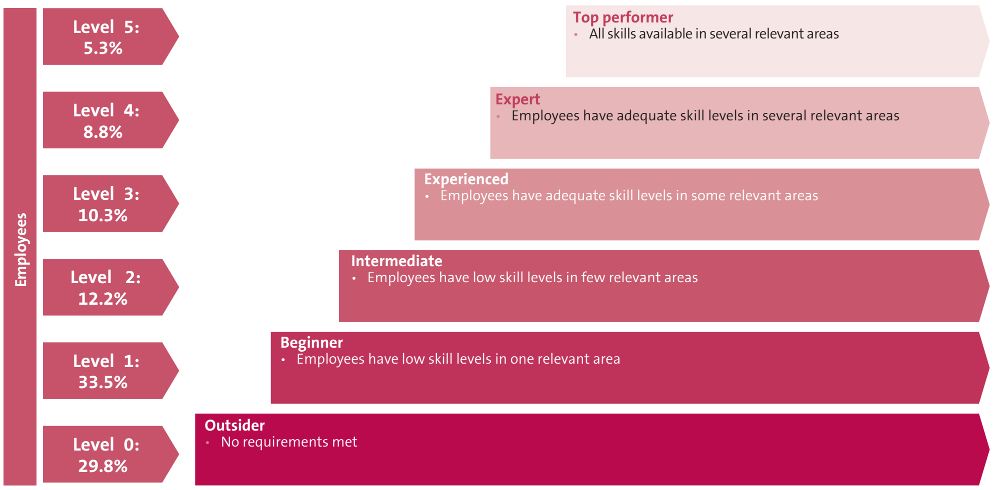
Table 3-7: Average readiness in the dimension of employees

	Overall	Newcomers	Learners	Leaders
Readiness score	1.5	1.0	2.8	3.2

Scale of 0 (outsider) to 5 (top performer); n=250
Only takes into account companies with more than 20 employees.

Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Figure 3-30: Readiness levels in the dimension of employees



n=250 Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

Main hurdles to reaching a higher level of readiness

Based on the results of the readiness measurement in the dimension of employees, the main obstacles to achieving a higher level of readiness for the three types of company (newcomers, learners, leaders) can be summarized as follows (Figure 3-31).

Figure 3-31: Main hurdles in the dimension of employees

Main hurdles to reaching a higher level of Industrie 4.0 readiness

	Newcomers (levels 0 and 1)	Learners (level 2)	Leaders (level 3+)
Main hurdles	▪ Industrie 4.0–specific employee skill sets either absent or insignificant	▪ Skill sets not yet adequate in some key areas	▪ Industrie 4.0–specific skill sets not yet fully present in all areas

n=250
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

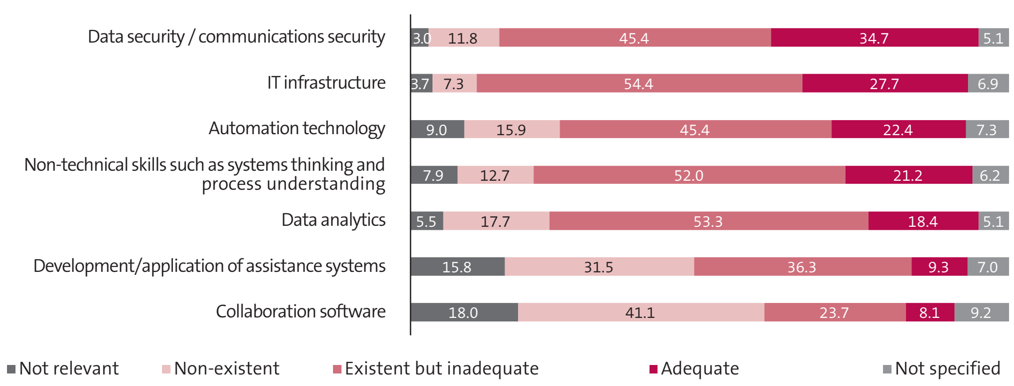
The results of this readiness measurement are based on the following findings:

Expert skills in many areas inadequate

Employees in the mechanical engineering industry have diverse skill sets, but often not to the extent necessary for a detailed implementation of Industrie 4.0 concepts. Only one-tenth to one-third of companies, depending on the area of expertise, rate their employee qualifications as up to the task of Industrie 4.0. The biggest problems are in the development and application of assistance systems, where only 9.3 percent of companies rank their employee qualifications as adequate and 31.5 percent cite no such skills whatsoever, and in collaboration software, where only 8.1 percent rank themselves adequate and 41.1 percent cite no skills (Figure 3-32).

Most companies have already addressed the lack of Industrie 4.0 skills and launched professional development programs. Nearly two-thirds of surveyed companies in the mechanical engineering industry offer special training seminars, knowledge transfer systems, and coaching to prepare their employees for Industrie 4.0, teaching them the skills they'll need to keep up with the evolution toward digitized production. In addition to basic knowledge of IT and control processes, employees learn how to exchange information with machinery and integrated systems.

Figure 3-32: Employee skill sets for Industrie 4.0



Figures indicate percentages; n = 250
Only takes into account companies with more than 20 employees.
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

4 Industrie 4.0 action items

A look at how the surveyed companies are classified in the readiness model shows that most companies in Germany's mechanical engineering industry are still just beginning their journey toward Industrie 4.0. More than three out of four companies are newcomers at level 0 or 1. This core finding can be seen across all six dimensions of the readiness model (Figure 4-1). The engineering companies are much further in implementing Industrie 4.0 ideas than the manufacturing industry as a whole, however, with nearly a quarter at level 2 or above compared to only 11 percent in the manufacturing industry overall. That clearly illustrates how open the engineering sector is to the subject of Industrie 4.0.

To ensure that Industrie 4.0 develops quickly, it is paramount that newcomers and learners emulate the example of the leaders – some 6 percent of all mechanical and plant engineering companies in Germany. But there is also much to do for today's leaders. The analysis shows that they still have far to go to fulfill the vision of Industrie 4.0 (level 5 of the Readiness Model).

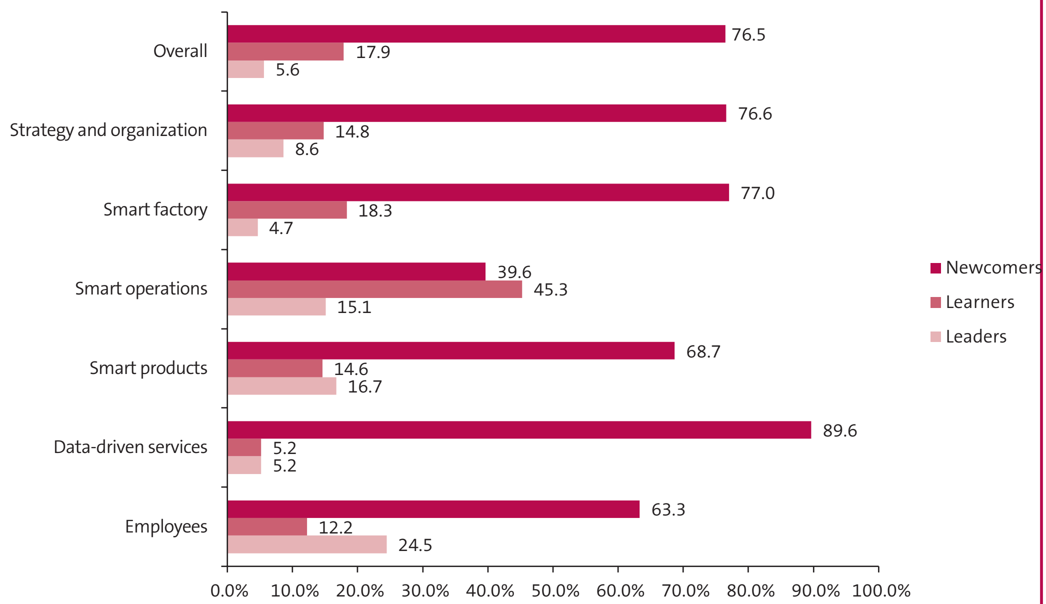
This yields two central questions for the action items:

- How can the newcomers and learners in Germany's mechanical engineering industry elevate themselves to the level of the leaders when it comes to Industrie 4.0?
- What must today's leaders still do to improve?

To answer these questions, we turn to two key results of the empirical survey:

- The factors that the companies themselves rank as obstacles on their road to Industrie 4.0.
- The reasons for not reaching the next readiness level.

Figure 4-1: Breakdown of company types by dimension



Figures indicate percentages, n = 234
Sources: VDMA member survey, 2015; IW Panel on the Future 2015, 26th survey round

In the survey, the companies were asked to name what they felt were the greatest obstacles to implementing Industrie 4.0. Figure 4-2 shows these obstacles, broken down by type of company (newcomers, learners, leaders). It is apparent that the obstacles are ranked differently depending on the type of company. Action items have been defined by type of company based on the obstacles cited and the hurdles identified through the Readiness Model.

- The main hurdles standing in the way of the next level of readiness have been identified for each type of company.

- Two factors were taken into account when assessing the obstacles. First, the obstacles most prominent for each type of company were identified. Next, the prominence of the various obstacles among the newcomers and learners was compared to their prominence among the leaders, then the results were sorted according to how big the gap to the newcomers and learners was. This makes it possible to see which obstacles had the biggest perception gap between the newcomers and learners on the one hand and the leaders on the other.

- The third step was to use this information to identify the most urgent action items for each type of company to move up to a higher readiness level.

The key findings of this analysis are summarized in Figure 4-3 through Figure 4-5.

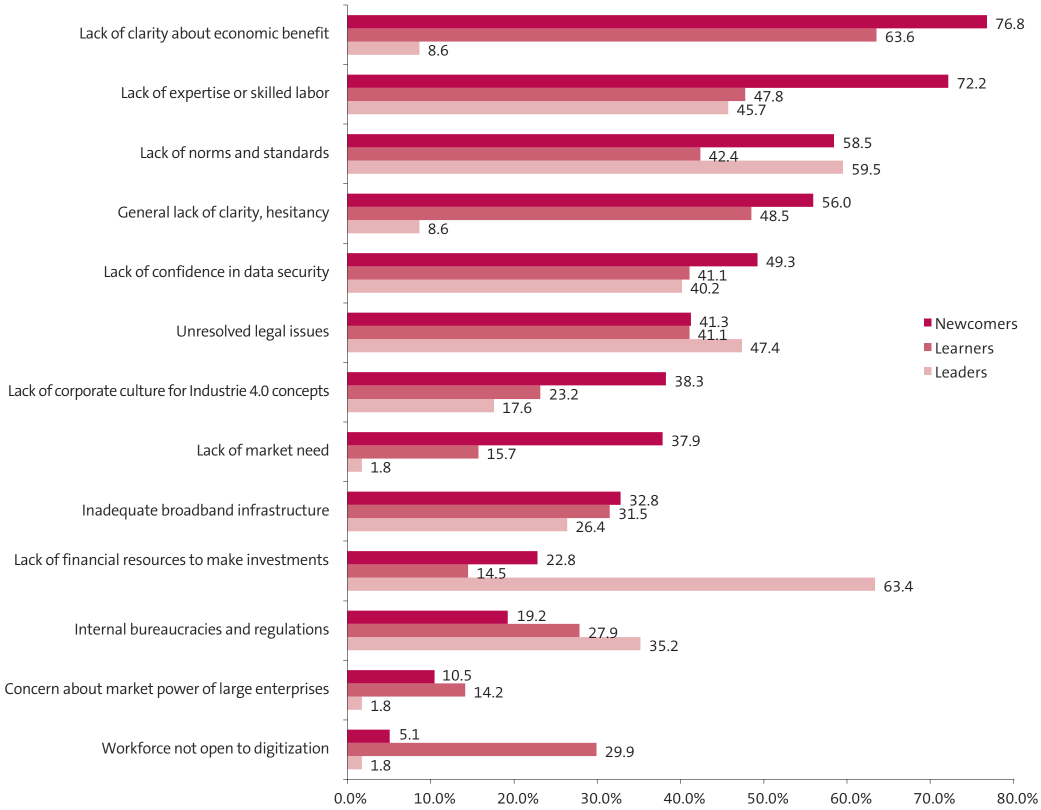
Figure 4-2 below offers an overview of the key obstacles for each section outlining action items by type of company:

- Germany's mechanical engineering industry should put aside its wait-and-see attitude toward Industrie 4.0 in favor of a hands-on approach in order to recognize the potential.

- An examination of Industrie 4.0 reveals its economic benefits and the market requirements.

- Industrie 4.0 is a highly complex topic. There is no one-size-fits-all solution for companies. The leaders, who have already gone far down this road, face a particular challenge in funding Industrie 4.0 projects.

Figure 4-2: Obstacles by company type



Figures indicate percentages, n = 167
Source: VDMA member survey, 2015

4.1 Action items for newcomers

The newcomers to Industrie 4.0, those ranked at levels 0 and 1 in the Readiness Model, need to find the courage to take the first steps. Rather than looking at the target profile as embodied by the vision of Industrie 4.0 at level 5 of the Readiness Model, they should focus on the benchmark profile of the companies ranked as leaders. The newcomers need to overcome the following serious obstacles to reach the level of the industry 4.0 leaders:

- Lack of clarity about economic benefit of Industrie 4.0 concepts
- General lack of clarity about Industrie 4.0 and hesitancy
- Lack of market need for Industrie 4.0 concepts
- Lack of expertise and skilled workers for Industrie 4.0
- Lack of a corporate culture for Industrie 4.0 concepts

The most serious obstacles for newcomers are a lack of clarity about the economic benefit of Industrie 4.0 concepts (77 percent), followed by a general lack of clarity about Industrie 4.0 (56 percent). Because of this, these companies fail to see any market need for dealing with this topic (38 percent). This is likely due in part to the fact that the subject of Industrie 4.0 is not yet firmly rooted in the corporate culture (38 percent). In addition, more than 72 percent of companies are aware that they lack the necessary expertise and skilled workers in this field. With all the obstacles cited above, the differences are most pronounced when newcomers are compared to leaders. This highlights the key themes that newcomers must work on to reduce their gap to the benchmark companies (leaders). The lack of severity with which leaders perceive the obstacles seen as most intimidating by newcomers shows that the newcomers really have good opportunities to get a handle of these problems.

But the newcomers also cite external obstacles, and here, it is primarily the government and policymakers who are called to create an environment more conducive to the success of the digital transformation in Industrie 4.0. Nearly 59 percent of newcomers cite the lack of norms and standards, for example, while 49 percent point to inadequate data security, and 41 percent to unresolved legal issues.

From an internal perspective, several hurdles are preventing newcomers from advancing to a higher level of readiness (Figure 4-3).

These findings help define several action items intended to help newcomers achieve a higher level of readiness:

Create awareness for Industrie 4.0 within the company

Industrie 4.0 is about innovation, and newcomers in particular need more clarity about the significance, potential, and benefit to their company. Companies must become aware of the significance of this topic before they can define an effective strategy and take other appropriate measures. This includes educating the workforce about the overall significance of Industrie 4.0 for the future and the initial steps the company will take toward implementation. But policymakers and industry associations can also provide valuable input and help companies develop an understanding of Industrie 4.0.

Figure 4-3: Action items for newcomers (readiness levels 0 and 1)

I4.0 dimensions	Strategy & organization	Smart factory	Smart operations	Smart products	Data-driven services	Employees
Current main hurdles (from Readiness Model)	▪ Industrie 4.0 plays little or no role in the strategic orientation	▪ Equipment infrastructure not connected to higher-level IT systems ▪ Machine and process data not collected	▪ Little or no in-company, system-integrated information sharing	▪ Products feature little or no ICT add-on functionalities	▪ Focus on traditional products; data-driven services either not offered or not integrated with customers	▪ Little or no Industrie 4.0–specific employee skill sets
Obstacles	▪ Uncertainty about economic benefit ▪ General uncertainty about I4.0			▪ No market need ▪ Lack of skills		
Action items	▪ Create awareness for I4.0 ▪ Define strategies	▪ Gradually connect equipment infrastructure to higher-level IT systems	▪ Plan initial steps for in-company and external system-integrated information sharing	▪ Analyze potential of ICT add-on functionalities	▪ Realign product portfolio ▪ Define data-driven services	▪ Run systematic needs assessment ▪ Adapt training and professional development programs

Original layout

Establish Industrie 4.0 in the corporate strategy and culture

Despite understanding the potential of Industrie 4.0, newcomers often lack a concrete strategy for developing and implementing Industrie 4.0 concepts. Exploiting the full potential of Industrie 4.0 requires a targeted corporate strategy and organizational structure set up and established by the company management.

Changing a culture is a long and slow process that is greatly influenced by the people driving and living the change. Studies indicate that innovative themes of this nature need to be firmly and clearly anchored throughout the company, the management, the organizational structure, and above all the in the value system. This is the only way to get everyone on board with the issue and tap into the potential that exists among the employees and thus within the organization. Small and medium-sized businesses in particular manage to generate enthusiasm for this topic among their employees and provide long-lasting motivation by personally demonstrating the importance of innovative themes such as Industrie 4.0 and innovative practices (IW Consult/Santiago, 2015). The corporate culture must reflect in practice what the strategy is to establish in theory. In other words: The company management must emphasize the importance of the cultural shift toward Industrie 4.0 – by creating identifying figures and role models, for example, but also by filling the key position of an Industrie 4.0 Officer. Such measures require strong, innovation-friendly leadership to be successfully implemented. Managers in the innovative environment of Industrie 4.0 are the people who need to embody the cultural shift, structure how the teams work together, and organize the individual free environments for employees.

Create the technical foundation to build a smart factory

Pilot initiatives give newcomers the opportunity to gather their first experience with applications of sensor technology and highly integrated IT systems. At the same time, it is important to ensure that the equipment infrastructure can be upgraded to connect to higher-level IT systems. The next step is to increase transparency across current production workflows.

Begin integrating components and systems

First, the company's processes should be adapted to gradually expand information sharing among the individual systems. Focus on both standardized interfaces and the use of appropriate middleware[6]. These are also a basic prerequisite for initiating data-driven services.

Expand the product portfolio

Analyze the product portfolio for a potential expansion to include ICT add-on functionalities that enhance the benefit to the customer. After the add-on functionalities are identified, you can test the first data-driven services.

Build up basic skills

Before starting down the road to Industrie 4.0, it is critical to build up basic skills within the company on the subjects of IT infrastructure, automation technology, and data analytics.

A company must often first define its own approach to determine which specific skills are needed. Companies should first conduct a systematic assessment of what their employees need and then adapt their training and professional development program to these needs.

6 Middleware represents one level in a complex software system, working as a "service provider" to enable the exchange of data with other software components that would otherwise be unconnected.

4.2 Action items for learners

Learners in Industrie 4.0, who are at level 2 of the Readiness Model, have to overcome similar obstacles as those facing newcomers:

- Lack of clarity about economic benefit of Industrie 4.0 concepts
- General lack of clarity about Industrie 4.0 and hesitancy
- Lack of expertise and skilled workers for Industrie 4.0
- Workforce not open to digitization
- Concerns about market power of large enterprises

Here, too, the most serious obstacles are a lack of clarity about the economic benefit of Industrie 4.0 concepts (64 percent), followed by a general lack of clarity about Industrie 4.0 (49 percent). In addition, nearly 48 percent of companies complain of a lack of expertise and a shortage of skilled labor for Industrie 4.0. Some 30 percent of companies fear that their employees are not open enough to digitization issues, while 14 percent of learners are also concerned about the market power of large enterprises. The results for the obstacles cited here differ the most from the results of the leaders, and learners should prioritize these obstacles in order to bridge the gap to the benchmark companies as quickly as possible.

Among the external obstacles, 42 percent of learners cite the lack of norms and standards, and 41 percent cite inadequate data security and unresolved legal issues; nearly one-third complain about inadequate broadband infrastructure.

Figure 4-4: Action items for learners (readiness level 2)

I4.0 dimensions	Strategy & organization	Smart factory	Smart operations	Smart products	Data-driven services	Employees
Current main hurdles (from Readiness Model)	▪ Industrie 4.0 is part of the strategic process, but a specific strategy has not yet been defined	▪ Equipment infrastructure not fully linked to IT systems ▪ Limited capacity to upgrade equipment infrastructure	▪ No initial steps toward system-integrated information sharing with external partners	▪ Collected data not analyzed or used to optimize products or processes (product development, sales support, after-sales)	▪ Data usage level of 20–50% not yet achieved	▪ Industrie 4.0–specific skill sets not yet adequate in some key areas
Obstacles	▪ Uncertainty about economic benefit ▪ General uncertainty about I4.0			▪ No market need ▪ Lack of skills		
Action items	▪ Define and implement a strategy	▪ Plan and install IT-integrated equipment infrastructure	▪ Expand system-integrated information sharing both in-company and externally	▪ Systematically analyze potential uses of collected data	▪ Increase level of data usage ▪ Create more data-driven services	▪ Run systematic needs assessment ▪ Adapt training and professional development programs

Original layout

From an internal perspective, learners fail to advance to a higher level of readiness because they have not yet overcome the status quo outlined in Figure 4-4.

The action items for learners are similar to those for newcomers with the exceptions of the following additions:

Use indicators to monitor strategy implementation

An appropriate indicator dashboard must be developed to monitor strategy formulation and implementation. The dashboard contains target-specific indicators – to monitor progress or the degree to which the Industrie 4.0 strategy is fulfilled, etc. – and is used to track implementation. Traditional methods such as the balanced scorecard – a tool for tracking the development of the business vision – can also be used.

Expand technical foundation

Take Industrie 4.0 requirements into account, especially those relating to the integration into IT systems and M2M communications, when drafting product requirements documents for the procurement of new machinery and systems. Also, expand internal, system-integrated information sharing by standardizing the system environment. To bring about collaboration and horizontal integration, companies should take the first steps toward system-integrated information sharing with external customers and suppliers.

Increase data analysis capacities

Companies at this level should conduct more in-depth analyses to see whether the large amounts of data they collect has greater potential uses. Increasing the level of data usage and related ICT add-on functionalities offers the opportunity to further digitize products and more closely integrate customer data into the internal processes.

Expand basic skills

To advance Industrie 4.0 efforts, it is important to continue building up basic skills within the company on the subjects of IT infrastructure, automation technology, and data analytics. Systematically assessing the needs of the workforce and responding with the appropriate training and professional development programs is an ongoing task.

4.3 Action items for leaders

The Industrie 4.0 leaders, who are ranked at levels 3 to 5 on the Readiness Model, mostly face different obstacles than those of the newcomers and learners (see Figure 4-2). The leaders are guided by the Industrie 4.0 target profile (level 5 of Readiness Model). Currently, just under 6 percent of German mechanical and plant engineering companies are in this benchmark group. To make further progress toward Industrie 4.0, the leaders need to focus on overcoming the following obstacles:

- Lack of financial resources to make investments in Industrie 4.0
- Lack of norms and standards
- Unresolved legal issues
- Lack of expertise and skilled workers for Industrie 4.0
- Lack of confidence in data security
- Internal bureaucracies and regulations

For 63 percent of leaders, the greatest obstacles are in the lack of financial resources to make investments in Industrie 4.0. Nearly 60 percent see a problem in the lack of norms and standards. But unresolved legal issues relating to Industrie 4.0 (47 percent) and the topic of skilled labor (46 percent) also represent major challenges for the leaders. In addition, 40 percent of companies have little confidence in data security, and 35 percent need to devote more attention to internal bureaucracies and regulations relating to the implementation of Industrie 4.0 concepts. The obstacles cited here show that the leaders, in contrast to the newcomers and learners, are concerned much more with external factors. Overcoming these obstacles also requires policymakers who can develop the appropriate solutions. Companies reach the limits of their powers trying to overcome obstacles such as those relating to norms and standards, unresolved legal issues, and a lack of data security.

From an internal perspective, leaders fail to advance to a higher level of readiness because they have not yet overcome the status quo outlined in Figure 4-5.

Leaders have limited autonomy on these action items – first, because the necessary external conditions are lacking for Industrie 4.0 to succeed, and second, because there are not enough potential networking partners at a similar level of readiness. The networking effect in particular is a core issue for the implementation of Industrie 4.0 concepts. This yields the following action items for leaders:

Secure financing for Industrie 4.0 projects

As our understanding grows through the implementation of Industrie 4.0 programs, the complexity of the task of integration and thus the level of investment required to implement Industrie 4.0 projects also grows. Currently, these costs are difficult for businesses to estimate. For this reason, Industrie 4.0 concepts cannot be fully implemented from the outset, they must be implemented one area at a time.

Investment-friendly conditions should be created to overcome the financial obstacles. Another incentive would be a tax deduction for part of the research and development expenses associated with Industrie 4.0 concepts. Basic tax incentives for R&D spending are already common practice in many industrialized nations.

Germany's federal and state governments could establish targeted incentive programs for Industrie 4.0. But the programs should be designed with simple administrative processes and little bureaucracy. The common restriction to small and medium-sized businesses should be questioned, given the results of the study.

Figure 4-5: Action items for current leaders (readiness levels 3+)

I4.0 dimensions	Strategy & organization	Smart factory	Smart operations	Smart products	Data-driven services	Employees
Current main hurdles (from Readiness Model)	▪ A defined Industrie 4.0 strategy has not yet been implemented ▪ System of indicators has not yet been integrated into the strategic process	▪ Equipment infrastructure does not yet meet all future requirements ▪ Collection of machine and process data not consistently digitized	▪ Autonomously guided workpieces and self-reacting processes not yet in use	▪ ICT add-on functionalities of products limited to a few areas	▪ Data-driven services do not include digital customer integration ▪ Data-driven services do not account for a significant share of revenues (>7.5%)	▪ Industrie 4.0–specific skills not yet fully available in all areas
Obstacles	▪ Lack of financial resources ▪ Lack of norms and standards			▪ Lack of skills ▪ Lack of legal framework		
Action items	▪ Fully implement strategy ▪ Regularly review strategy implementation	▪ Align equipment infrastructure to future requirements ▪ Expand digital data collection	▪ Use autonomously guided workpieces and self-reacting processes	▪ Expand scope of ICT add-on functionalities	▪ Expand service portfolio to include offerings digitally integrated with customers	▪ Development ▪ Training ▪ Recruitment

Original layout

Germany has relatively little venture capital compared with other nations. Venture capital is a form of funding especially common with start-ups that – despite the great risk borne by the investor – is not given adequate legal and financial incentives in Germany. This makes funding German companies less attractive, especially for foreign venture capitalists.

Extend the smart factory

The interoperability of M2M communications and cross-enterprise integration require the clearest possible semantics, which enables data interchange and is key to creating a common understanding of the data and being able to interpret and analyze the data correctly and uniformly. The use of additional sensor technology to increase the resolution of data capture should be examined.

Strive to fully digitize processes

With an eye on expanding the smart factory concept, pilot projects should be identified where self-guiding workpieces and self-reacting processes can be tested and developed. The first cloud-based software, data storage, and data analytics solutions should also be deployed.

Develop data-driven business models based on smart products

Companies should broaden the scope of data-driven services tailored to customer needs and adapt their business models accordingly. This requires integration with the customer – that is the only way to collect data continuously and ensure product-based services. This will greatly enhance the quality of after-sales and services. This approach makes it possible to develop a business model with clear targets, responsibilities, and processes – giving small and medium-sized businesses in particular the opportunity to increase their profitability.

Continue to expand Industrie 4.0 skills

Employees help companies realize their digital transformation. The diverse skill sets of employees are often not as extensive as necessary for a detailed implementation of Industrie 4.0 concepts, however. The more the company progresses, the more comprehensive and diversified the skills it needs. Knowledge gaps exist, especially when it comes to collaboration software and the establishment of assistance systems. Professional development and new hires are necessary to close these gaps.

Highly educated skilled labor is needed to establish Industrie 4.0 concepts. The shortage of skilled labor disproportionately affects small and medium-sized businesses, for whom it is increasingly difficult to find researchers and highly qualified specialists. To ensure that the mechanical engineering industry of tomorrow has enough employees for the transformation of Industrie 4.0 concepts, the German educational system must focus more closely on science and math. The aim must be to strengthen science, technology, engineering, and mathematics (STEM) and establish the importance of Industrie 4.0–relevant technologies in unbroken education chains from preschools to universities. One education policy the government could pursue would be to mandate science- and technology-oriented general education in primary schools. Secondary schools should consistently allot one-third of the study day for teaching STEM subjects. The immigration of highly qualified skilled workers should also be simplified and incentivized.

Create a new legal framework

The transition to an integrated industry can succeed only if a new legal framework is created that resolves the still-open legal issues regarding personal and computer-generated data.

The increase in cross-enterprise autonomous and quasi-autonomous communications between machines (M2M communications) requires clarification of the issue of liability and risk-sharing for erroneous data transmission and connectivity outages. Under current laws, no potential ownership rights to such data exist.

Ensure data security

It is important that companies surmount the initial hurdles to tap into the potential of solutions, including those already implemented. The implementation of an end-to-end security strategy is of fundamental importance for the system-wide use of collected data. This step must be taken both internally and externally in communications with business partners.

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6 Glossary

Big data – Big data refers to datasets that are too large or complex to analyze with conventional data processing procedures or methods and are subject to rapid, continuous change. Big data inverts IT priorities: Since the data is too big, the programs must now become flexible and agile. (Dumbill, 2012).

Cloud – The cloud is not a single computer but a virtual "computing cloud" consisting of many interconnected computers. Users do not need to be on site to access cloud-based computers.

Cloud computing – Cloud computing refers to the provision of IT infrastructure in the form of a cloud and IT services such as data storage, data analytics, and software. This saves users the trouble of purchasing and installing costly server solutions in their own companies.

Cyber-physical systems – CPS link the physical and virtual worlds by communicating through a data infrastructure, the Internet of Things. They are the framework that make it possible to generate a virtual model of real production, analyze all the datastreams that arise from sensors and other IT systems, and map their interrelationships.

Data analytics – Data analytics describes the process of analyzing a company's big data and finding useful interrelationships that support the company's activities. Given the enormous volumes of data in businesses today, data can only yield an added value if it can be placed in context and consolidated under larger categories.

Data-driven services – Data-driven services as defined here include telemaintenance; optimized resource consumption of machinery; availability, performance, and quality enhancements through optimized parameter settings; etc.

Digital modeling – A digital model is composed of product-related data supplemented by transaction data, geopositioning data, and other data.

Real-time requirement – The real-time requirement is a core concept of Industrie 4.0 that refers to decision-making support from data analytics in which data must be available at the time it is needed. This does not necessarily mean "now" without any delay.

ERP systems – ERP systems offer integrated software solutions for administering, planning, and controlling a company's value-adding processes, thereby providing the foundation for information processing in the company. Today's ERP systems focus on extending functionalities by integrating various functionally specialized systems through advanced planning and scheduling (APS).

Horizontal integration – Horizontal integration in production and automation technology describes the consolidation of various IT systems into an end-to-end solution. It involves the various process steps of production and corporate planning between which material, energy, and information flows. Horizontal integration takes place both within a company and across various companies.

Industrie 4.0 – The term Industrie 4.0 stands for the fourth industrial revolution, a new level of organizing and controlling the entire value chain across product lifecycles. This cycle focuses on increasingly personalized customer wishes and extends from the concept to the order, development, production, and shipping of a product to the end customer and ultimately to its recycling, including all associated services.

Information and communications technology (ICT) – Information and communications technology refers to all technical devices and systems that can digitize, process, store, and transmit information of any kind.

System of indicators – Display of aggregated information to support management.

M2M – Machine-to-machine communications. M2M stands for the automated exchange of information among technical systems or between systems and a central unit. Typical applications include remote monitoring and control. M2M links information and communications technology and forms the Internet of Things.

MES – A manufacturing execution system (MES) constitutes the process-oriented operating level of a multilayer production management system. It is directly linked to the process automation systems. MES, in contrast to ERP systems, features integrated APS logic, which allows more precise and detailed fine-tuning and control as well as better real-time capability.

Middleware – Middleware represents one level in a complex software system, working as a "service provider" to enable the exchange of data with other software components that would otherwise be unconnected.

Predictive maintenance – Predictive maintenance systems are designed to detect machine errors such as interruptions or outages before they happen. The aim is to prevents errors through maintenance and proactive repairs.

RFID – Radio frequency identification can be used for monitoring, quality control, automatic adaptation of the production process, and to identify and share information on an item itself and its environment.

SCM system – Supply chain management systems create cross-enterprise transparency relating to needs, capacities, and inventory along the value chain to support individual companies in their decision-making processes or operational workflows in real time.

Smart factory – Smart factory refers to an intelligent, interconnected factory.

Smart operations – Smart operations refer to the horizontal and vertical integration of the company, which enables flexible production planning and control.

Smart products – Smart products are physical objects equipped with ICT so they are uniquely identifiable and can interact with their environment. They use sensor technology to record their environment and their own status and offer various add-on functionalities in operation.

Smart services – Smart services are packages of products and services individually configured over the Internet (acatech, 2014). The services include predictive remote services and new business models such as the trade in production capacities and production data.

Telemaintenance – Telemaintenance refers to computer-controlled remote maintenance of machinery and machine parameters.

Vertical integration – Vertical integration in production and automation technology refers to the integration of various IT systems and various hierarchical levels of production and corporate planning into a single end-to-end solution. Examples of such hierarchical levels include the actor and sensor level, the control level, or the production control level.

7 Appendix

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Readiness Model for the dimension of strategy and organization – minimum requirements

Strategy and organization: Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Degree of strategy implementation	Industrie 4.0 is not part of the strategic process	Industrie 4.0 is an issue at the departmental level but is not integrated into the strategy	Industrie 4.0 is part of the strategic process, and a strategy is being developed	An Industrie 4.0 strategy has been defined	An Industrie 4.0 strategy is in implementation	An Industrie 4.0 strategy has been implemented enterprise-wide
Definition of indicators	No indicators exist to determine the status of Industrie 4.0 implementation	No indicators exist to determine the status of Industrie 4.0 implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place and integrated into the strategic process
Investments	No Industrie 4.0 investments	Initial Industrie 4.0 investments in one area	Low level of Industrie 4.0 investments	Industrie 4.0 investments in a few areas	Industrie 4.0 investments in several areas	Industrie 4.0 investments enterprise-wide
Innovation management	No innovation management	No innovation management	No innovation management	Innovation management in isolated areas	Innovation management implemented in several departments	Uniform, inter-departmental innovation management has been established

Figure 7-1

Readiness Model for the dimension of smart factory – minimum requirements

	Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Smart factory	Equipment infrastructure (current)	Machine and system infrastructure cannot be controlled through IT, no integration (M2M)	Some machines can be controlled through IT, are interoperable, or have M2M capability	Machine and system infrastructure can be controlled to some extent through IT, is interoperable or integrated	Machine and system infrastructure can be controlled through IT and is partially integrated	Machinery can be controlled completedly through IT, is partially integrated (M2M) or interoperable	Machines and systems can be controlled almost completely through IT and are fully integrated (M2M)
	Equipment infrastructure (target)	Machines and systems cannot be upgraded	Future requirements for machines and systems are relevant	Some machines and systems can be upgraded	All machines and systems can be upgraded	Machines already meet some of the requirements or can be upgraded	Machines and systems already meet all future requirements
	Digital modeling	No digital modeling	No digital modeling	Some digital modeling	Some digital modeling	Some digital modeling	Complete digital modeling possible
	Data collection	No data is collected	No data is collected	Data is collected but for the most part manually	The relevant data is collected digitally in certain areas	Comprehensive digital data collection in multiple areas	Comprehensive, automated, digital data collection in all areas
	Data usage	No data available for further use	No data available for further use	Data is used for a few select purposes (greater transparency, etc.)	Some data used to optimize processes (predictive maintenance, etc.)	Data used in several areas for optimization	Data used for comprehensive process optimization
	IT systems	No support through IT systems	Main business process supported by IT systems	Some areas of the business are supported by IT systems and integrated	Some areas of the business are supported by IT systems and integrated with one another	Complete IT support of processes, full integration	IT systems support all company processes and are integrated

Figure 7-2

Readiness Model for the dimension of smart operations – minimum requirements

	Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Smart operations	System-integrated information sharing	No system-integrated information sharing	Beginnings of in-company, system-integrated information sharing	In-company information sharing partially system-integrated	Some in-company and beginnings of external system-integrated information sharing	Predominantly in-company and partially external system-integrated information sharing	Comprehensive in-company and partially external system-integrated information sharing
	Autonomously guided workpieces	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
	Self-reacting processes	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
	IT security	No IT security solutions in development or implemented	Initial IT security solutions planned	Multiple IT security solutions are planned or initial solutions are in development	IT security solutions have been partially implemented	Comprehensive IT security solutions have been implemented, existing gaps are being closed	IT security solutions have been implemented for all relevant areas
	Cloud usage	Cloud solutions not in use	Cloud solutions not in use	Cloud solutions not in use	Initial solutions planned for cloud-based software, data storage, and data analysis	Initial solutions implemented	Multiple solutions implemented

Figure 7-3

Readiness Model for the dimension of smart products – minimum requirements

	Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Smart products	ICT add-on functionalities [1]	No add-on functionalities	Products show first signs of add-on functionalities	Products feature initial add-on functionalities	Products feature multiple, interrelated add-on functionalities	Products feature add-on functionalities in different areas	Products feature extensive add-on functionalities
Smart products	Use of data [2]	No data collected	No data collected	Data collected but not analyzed/used	Data analyzed/used	Data analyzed/used	Data analyzed/used

[1] Product memory, self-reporting, integration, localization, assistance systems, monitoring, object information, or automatic identification
[2] Use of data for product development, sales support, after-sales (such as telemaintenance)

Figure 7-4

Readiness Model for the dimension of data-driven services – minimum requirements

	Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Data-driven services	Data-driven services	No data-driven services offered	Data-driven services are offered, but without customer integration	Data-driven services are offered, but without customer integration	Data-driven services are offered, but without customer integration	Data-driven services are offered with customer integration	Data-driven services are fully integrated into the business model (integration with the customers)
	Share of revenues	No share of revenues	Data-driven services account for an initial share of revenues (< 1%)	Data-driven services account for an initial share of revenues (< 2.5%)	Data-driven services account for an initial share of revenues (< 7.5%)	The share of revenues is significant (<10%)	Data-driven services play an important role in revenues (>10 %)
	Level of data usage	Data not used	Data not used	0–20% of collected data is used	20–50% of collected data is used	20–50% of collected data is used	More than 50% of collected data is used

Figure 7-5

Readiness Model for the dimension of employees – minimum requirements

	Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Employees	Employee skills	No skills	Employees have low skill levels in one relevant area	Employees have low skill levels in a few relevant areas	Employees have adequate skill levels in some relevant areas	Employees have adequate skill levels in several relevant areas	Employees possess all necessary skills in several relevant areas

Figure 7-6

Acknowledgments

This study was commissioned by the VDMA´s IMPULS-Stiftung and conducted by IW Consult (a subsidiary of the Cologne Institute for Economic Research) and the Institute for Industrial Management (FIR) at RWTH Aachen University. We wish to express our gratitude to the companies who made this study possible in the first place. A series of expert workshops was also held to discuss and validate the theories and results. Our gratitude extends as well to the employees of VDMA, IW Consult, and FIR at RWTH Aachen University, who helped analyze the data and develop the content.

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