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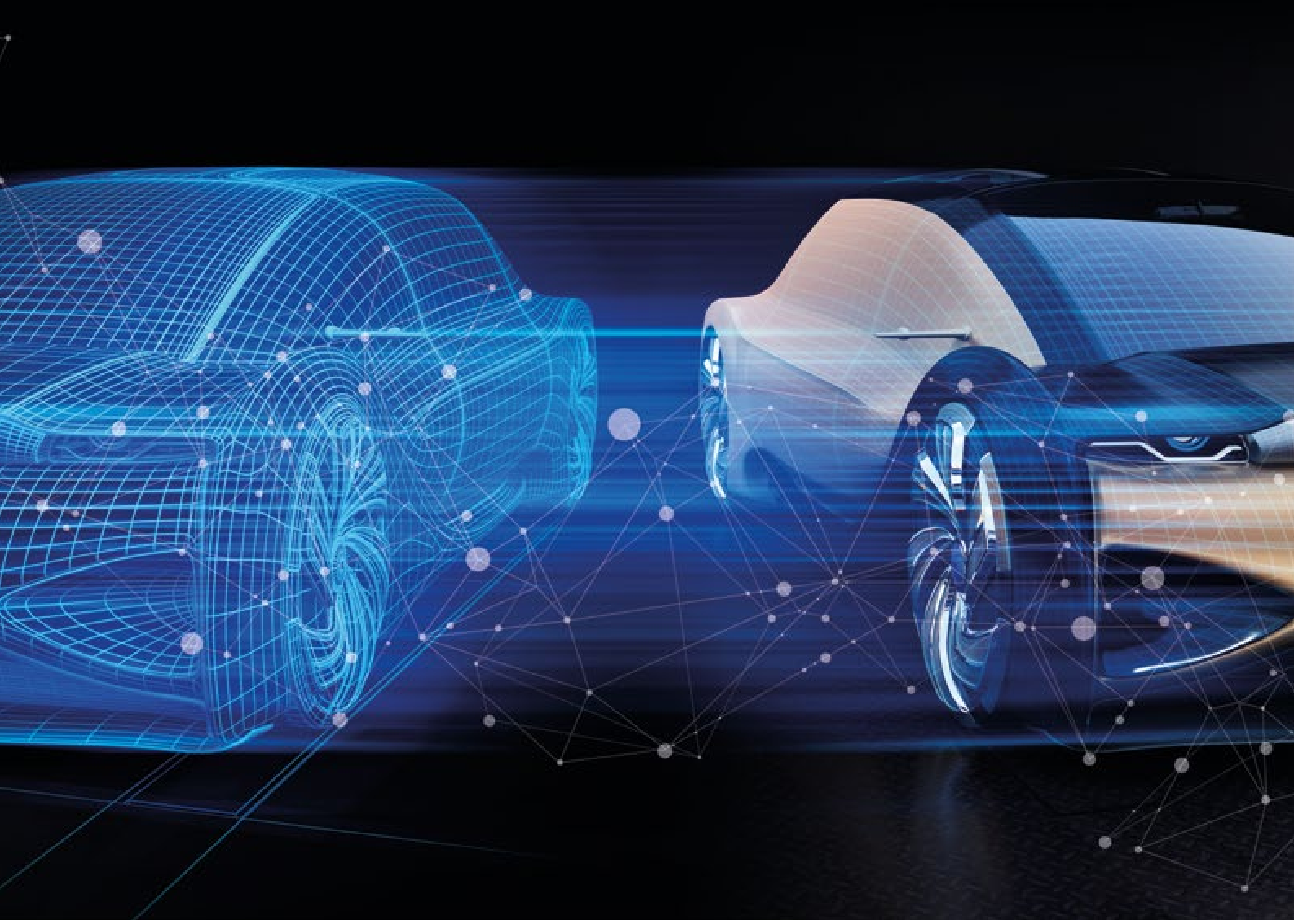
DIGITAL TWIN READINESS ASSESSMENT

A STUDY ON THE USE OF DIGITAL TWINS IN THE MANUFACTURING INDUSTRY

Authors: Theresa Riedelsheimer, Pascal Lünnemann, Sebastian Wehking, Lisa Dorfhuber



A collaborative study by: Fraunhofer IPK | msg

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We would also like to thankall the study participants from companies in the manufacturing industry. Without their willingness to be interviewed and to offer an insight into their activities regarding Digital Twin technology, it would have been impossible to carry out this Digital Twin Readiness Assessment.

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Foreword by the editors

"How far along are you and your company in the development and introduction of Digital Twin technology?" This was the key question we asked as part of this study. Following almost 18 months of work and numerous **interviews with experts and senior managers in industrial manufacturing**, we are delighted to be able to present the results of our first Digital Twin Readiness Assessment. This study is the result of a creative partnership between msg and the Fraunhofer Institute for Production Systems and Design Technology IPK.

The idea for this study formed in mid-2018. It evolved in the course of meetings with customers and workshops on the use of Digital Twins in the automotive industry. It soon became apparent that many companies have, at best, only a very rudimentary concept of Digital Twin technology, which in turn means that **potential benefits** are being wasted. Frequently, such concepts are based on data available from a specific area rather than data collected over the product life cycle. Moreover, it is generally the case that the use of a Digital Twin is limited to one **specific area** of the company, and there is no company-wide – let alone cross-company – focus on the **application** of Digital Twins. Our aim was to take a holistic approach to Digital Twins in terms of the potential they offer and, at the same time, to assess the readiness of companies for an implementation of this technology. With this in mind, we opted to develop a model to characterize their readiness level. In doing so, we faced the challenge of combining our experience from industry with that gained in research and education in order to create a pragmatic model with which to carry out our **Digital Twin Readiness Assessment**. A further challenge was to ensure that this standardized model did indeed cover the many different possible applications of Digital Twin technology over the product life cycle. In our opinion, we have succeeded in both areas.

Our Digital Twin Readiness Assessment study is also addressed at companies that have so far had little experience with Digital Twins – either on a technological level or in connection with new business models. The study offers an initial overview of requirements and use cases for implementation, and is intended to serve as an incentive to engage with this topic. At the same time, it should be of interest to companies that already have experience in the use of Digital Twins. The readiness assessment is designed to show companies where they stand compared to the rest of the industrial sector.

Most of all, the study has shown that **the potential of Digital Twin technology can only be fully tapped when the relevant information from the entire product life cycle is made available** on a continuous basis. In other words, companies must **open up their internal data silos** and facilitate the flow of information between user and supplier. This is one of the key challenges that companies in Europe will face if they wish to remain competitive and viable with the help of Digital Twin technology. In short, there is a need to establish a new attitude towards data provision, both in business and in society.

What are the next steps with regard to Digital Twin Readiness Assessment? On the one hand, we are considering conducting the study again after a certain period of time so as to chart the progress of Digital Twin Technology. On the other, we are planning to offer our **Digital Twin Readiness Assessment as a consulting service**. For companies unable to take part in the study, this will be an ideal opportunity to carry out their very own Digital Twin Readiness Assessment. Might this offer be of interest to you?

We look forward to hearing your thoughts. Please get in touch with us!

msg is an independent, internationally operating group of companies with a global workforce of more than 8000 employees and an annual revenue of one billion euros.

In the 2020 Lünendonk list of the leading IT consulting and system integration companies in Germany, msg ranked sixth. The group offers a comprehensive range of services comprising creative strategic consulting along with intelligent and sustainable value-creating IT solutions in the following sectors: automotive, banking, food, insurance, life sciences, health care, manufacturing, public sector, telecommunications, travel, logistics and utilities. In the course of 40 years, it has built up an outstanding reputation as an industry specialist.

The **Fraunhofer IPK** is part of the Fraunhofer-Gesellschaft - the world's leading applied research organization based in Germany. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. The Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of € 2.9 billion.

Update 2022: English version of the study

Due to the very positive perception of the study in the designated DACH region (Germany, Austria, Switzerland) and the high international demand for the publication, we decided to translate the entire document to English language.
We are pleased to see, that our predictions regarding the next level of evolution for Digital Twins comes true. Multiple initiatives such as e.g., CATENA-X and GAIA-X drive to define data ecosystems and standardize the data management across industries. This will further drive the application of Digital Twins. The key findings of this study are still valid and more relevant than ever.

In particular, the cross-company networking of Digital Twins must succeed while taking data sovereignty into account. The necessary functionalities are reflected in large data ecosystem projects and are developing accordingly within companies.
In our opinion there are two main reasons, why companies will contribute to a data ecosystem. Firstly, sharing the data creates a significant benefit / value for the participant. Secondly, trust in the data sovereignty of the data ecosystems regarding control and transparency. If both constraints are fulfilled, this will boost the vision and benefit of the Digital Twins.

Editors

Markus Samarajiwa is responsible for the domain Digital Twin at the msg automotive & manufacturing business unit. He develop the initial idea for the study and was a key source of ideas for its conception and design. Markus was substantially involved in conducting the expert interviews and compiling the conclusions of the study.
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Dr. Kai Lindow is head of the division Virtual Product Creation at the Fraunhofer Institute for Production Systems and Design Technology, Berlin, Germany, with focus on Digital Twin technologies and sustainable engineering. He helped developing the study and the readiness assessment and was a key source of ideas during its design and evaluation.
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Management summary

With this study on Digital Twin technology, we present a novel and innovative way of assessing a company's readiness in the areas of "understanding and use," "strategic goal and concept," and "implementation." For the purpose of this study, msg and Fraunhofer IPK developed the Digital Twin Readiness Assessment and combined it with interviews with industry experts.

The idea for the study evolved in the course of meetings with customers and Digital Twin workshops and grew out of a desire to provide companies with a quick and transparent assessment of their current state of readiness for – and the potential benefits of – the implementation of this technology.

For the study, a total of 26 interviews, each lasting 90 minutes, were conducted with experts and senior managers from the manufacturing industry in the DACH (Germany, Austria and Switzerland) region. Of the companies interviewed, 42% are suppliers in the mobility sector. Almost 60% of the companies have more than 50,000 employees. A total of 35% of the interviewees state that they work in IT and 27% in product development. The study investigated how far the manufacturing industry in the DACH region has progressed in the use of Digital Twin technology and which use cases are being pursued and to what purpose. Specifically, the study sought to answer the following **key questions**:

- "How will Digital Twins impact business models?"
- "What added value will Digital Twins create?"
- "What defines today's Digital Twin concepts?"
- "What measures are required for the implementation of Digital Twins?"
- "What skills and capabilities are required for the implementation of Digital Twins?"

A three-step approach was employed for the study. In the first step, expert interviews were conducted and evaluated in the context of the Digital Twin Readiness Assessment. These results were subsequently anonymized, consolidated and, for the purposes of the study, analyzed and described. This was followed by a second discussion with the companies interviewed in order to discuss their individual readiness level.

The study yielded the following **key insights**:

- According to the concepts submitted, Digital Twins are mainly used as a data-providing system or for the purposes of validation and fault analysis. However, this is at odds with the more ambitious expectations formulated at the level of strategic goals.
- To date, very few Digital Twin concepts feature the provision of automated value-added services. Similarly, few are designed as autonomous or adaptive systems. Yet it is only through cross-company collaboration and by networking Digital Twins that the full potential of this approach can be tapped into. This in turn requires a standardization of platforms and communication interfaces.
- The introduction of Digital Twin Technology can only succeed when a company has attained a high level of readiness in all three areas of "understanding and use," "strategic goal and concept," and "implementation."
- At the same time, it will require employees in future company organizations to display greater agility and to think holistically

- An interesting view of the division of responsibilities emerged during the interviews: IT believes that responsibility lies with development, whereas development thinks it lies with IT.

In detail, this means the following for each of the individual areas of the Digital Twin Readiness Assessment, "understanding and use," "strategic goal and concept," and "implementation":

Readiness in the area of "understanding and use"

Although all participants have prior knowledge of Digital Twins, and **85%** of the interviewees have already developed Digital Twin concepts, only **54%** have a coherent Digital Twin strategy. This is also reflected in the finding that **20%** have not yet established a unified definition of what constitutes a Digital Twin in their companies. For 46% of the interviewees, their definition features a digital shadow. Only **8%** are already making full use of Digital Twins, but more than one-third have already begun implementation of their Digital Twin concept.

Readiness in the area of "strategic goal and concept"

At the strategic level, the objectives, changes made to business models and physical products or systems, and the resulting added value were examined in relation to concrete Digital Twin concepts. According to the interviewees, Digital Twin technology will partially revolutionize existing business models. Indeed, **35%** intend to use Digital Twins to modify their business model. These will be used primarily for validation and fault analysis. According to **31%** of the interviewees, Digital Twins will make existing processes faster and more efficient.

As part of the discussion on Digital Twin concepts, the type of system represented by the Digital Twin, the relevant life cycle phases, the key functions and tasks performed by the Digital Twin, the exchange of data, and relevant laws and guidelines were examined. These concepts can be clearly divided into product-related and production-related. The majority – **73%** – of these Digital Twin concepts are product-related. Of the tasks currently performed by Digital Twins, **64%** focus on data provision. For **36%** of those interviewed, the technological requirements for this – e.g., information exchange – have yet to be resolved. **Tasks that are more complex, such as autonomous decision-making and forecasting, are only featured in very few of the concepts examined for the study.**

Readiness in the area of "implementation"

The study also examined which measures are needed – or have already been implemented – in order to design the new processes, forms of organization, IT systems and data and information models required for Digital Twins. **The findings of the study show that for a successful implementation and use of Digital Twins, companies will require greater agility as well as holistic thinking from all their employees.** At the organizational level, **44%** of the interviewees express uncertainty as to who is responsible for driving change in business and development processes. In order to pave the way for Digital Twins, **85%** anticipate a need for changes in company organization. At **24%** of the companies, the IT solutions required for an implementation of Digital Twins are being developed in-house. For this purpose, **72%** of the companies say they require additional IT skills. The skills essential for implementation are IT skills, technical skills, holistic thinking and data analytics capabilities.

The outlook for Digital Twin technology

The concluding part of this study investigates the **future outlook** for Digital Twins and their potential from a sustainability perspective. For **63%** of the interviewees, there is major potential for a future use of Digital

Twins to perform end-to-end sustainability assessments of products. Of the companies interviewed, **38%** hope to use Digital Twins and accompanying services with a **focus on sustainability**. It is noteworthy that only **4%** of the interviewees say their goal is to sell Digital Twin models. **By 2040, companies expect to be operating their own Digital Twin systems largely on an in-house basis or in close cooperation with partners.** At the same time, it is clear that business models based on Digital Twins have not yet been worked out in detail and that a lot of undiscovered potential remains to be tapped.

Findings of the Digital Twin Readiness Assessment

The aggregated evaluation of the readiness assessment allows conclusions to be drawn on the current use of Digital Twins in industrial manufacturing.

The consolidated **overall readiness** of all companies is **51%**. This was determined on the basis of the mean value for each of the individual areas assessed, which varied considerably. On average, the companies interviewed are still in the conception phase of implementing Digital Twins.

Readiness in the **understanding and use** of Digital Twins is **66%** across all the companies interviewed. This reflects the fact that understanding is already widespread in companies as a whole. Likewise, many companies have been able to acquire solid practical knowledge through their own isolated uses of Digital Twins and through dialogue with other companies and interest groups. In a comparison of the company departments surveyed, staff units have a clear advantage. In this form of organization, the requisite know-how is more readily available, meaning that companies display a higher level of readiness in terms of their strategy, concept and approaches to implementation.

On average, the readiness level in the areas of **strategic goal and concept** is **66%** across all the companies interviewed. Both OEMs and suppliers alike have a great interest in improved data consistency and data availability. An analysis of all the concepts reveals that most companies are still working on individual solutions.

The third readiness level – **implementation** – comprises three separate areas: processes and organization, data and information models, and IT systems. Here, the readiness level is **39%** across all the companies interviewed. Implementation is furthest advanced in processes and organization as well as requisite skills, with mean readiness at **45%**. In the main, however, only concepts were available for the purposes of this study. In other words, actual implementation has yet to start. The other two areas – IT systems, and data and information models – display lower levels of readiness of **39%** and **40%** respectively.

Conclusion

The study shows that Digital Twins and their use should always be connected to a specific purpose. In summary, it must be emphasized that the introduction of Digital Twins will only succeed when a high level of readiness is achieved across all evaluated areas, from understanding to strategy and concepts to implementation. It is only then that Digital Twins can reliably generate the benefits that companies envisage.

Content

INTRODUCTION

Statement of purpose

There are various reasons why Digital Twins are of great interest to the manufacturing industry. For many companies, Digital Twins provide an opportunity to gather direct information on how their products are used in the field. This knowledge can help manufacturers enhance follow-up products and the benefits they offer or even establish new business models. Analyzing data from production enables individual assessment of components or systems, and allows for an increasingly precise forecast of the length of their service life or likelihood of failure. Similarly, Digital Twins can also be used to represent specific parts of the supply chain in order to optimize production and supply processes. Among other things, this leads to products that can be used in a more sustainable way.

Usually, companies have a clear vision of where Digital Twins should take them. But how does their actual development and introduction match up to this vision?

One of the key reasons for conducting this study was to discover how far along the road the manufacturing industry in the DACH region is to using Digital Twins. In order to gauge this progress, msg and Fraunhofer IPK developed a Digital Twin Readiness Assessment, which enables companies to quickly and clearly determine where they stand in the areas of "understanding and use," "strategic goal and concept," and "implementation". This provides companies with a valuable tool to determine where they stand. The readiness assessment serves to evaluate a company's current state of readiness and to infer recommendations for further action.

The Digital Twin Readiness Assessment is based on the following five key questions, which also provide the structure for the study:

- "How do Digital Twins impact business models?"
- "What added value do Digital Twins create?"
- "What defines today's Digital Twin concepts?"
- "What measures are required for the implementation of Digital Twins?"
- "What skills and capabilities are required for the implementation of Digital Twins?"

Based on the study results, msg and Fraunhofer IPK are able to identify both proven and new methods and technologies that can help companies advance towards an actual use of Digital Twins. At the same time, the study results provide participating companies with an opportunity to evaluate their own capabilities regarding the development and operation of Digital Twins. These results therefore establish an important starting point from which companies can start realizing their vision.

An introduction to Digital Twins

The availability of necessary data and information is essential for the digitized development and the offer of digitized product systems is a fundamental prerequisite. Moreover, given the dynamic development of the IT landscape, companies are having to constantly adapt their systems to new sources of information, new protocols and new formats *(Lünnemann et al. 2019)*. At the same time, product systems are continuously changing, as innovations from information and communications technology enrich the conventional functionality of physical products through the addition of new digital features. The mechanical, electronic and communications components of these products ensure a direct connection to their environment or the cyber world.

In this context, Digital Twins provide a means of exploiting the connectivity of product systems to extract, evaluate and aggregate data from across the entire product life cycle. A Digital Twin is an exact digital representation of an individual physical product, system, process or service, which is characterized in terms of its specific properties or specific status.

The concept stems from the idea of an exemplary product life cycle management system that is able to supply and manage data related to different product instances. In combination with other technological advances, the ability to collect reliable data and information at each phase of the product life cycle creates a host of opportunities to enhance the development, production, use and recycling of products, systems and/or services; and to define new business models and design processes that are more efficient. In other words, Digital Twins are not an end in themselves. Rather, they are a technological means that enable the innovative design of product systems, processes and business models and the creation of added value within the company and beyond.

The use of Digital Twins generates concrete added value that can be firmly established along the product life cycle. In the early phases of the product life cycle, feedback-to-design concepts can be used to make actual product behavior and system usage more transparent. This can influence the design of subsequent product generations.

In the development process, feedback data from the field can be used to continuously optimize the quality of product simulations. In principle, a wide range of data can be used to generate knowledge about actual product behavior – for example, to assess sustainability factors.

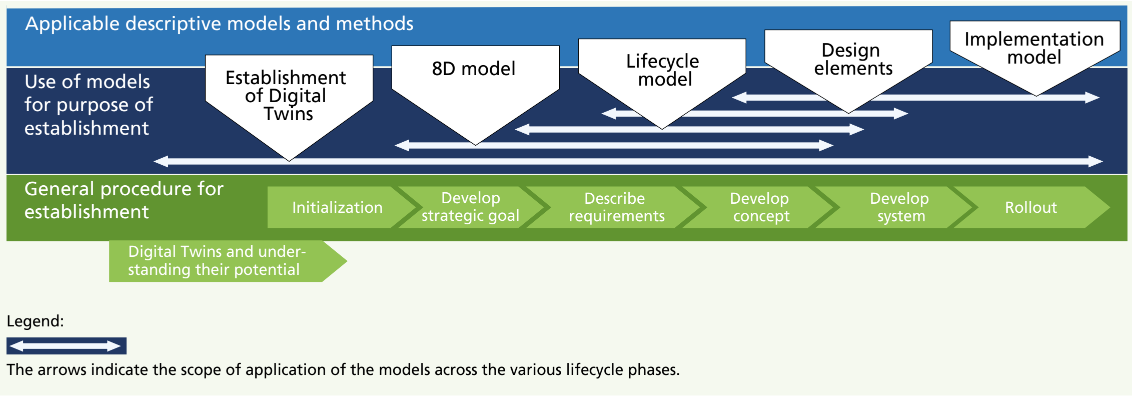
In the production phase, Digital Twins can provide a uniform platform for the purposes of production management and quality assurance.

In the use phase, Digital Twins can provide the basis for a provision of smart services. In this case, Digital Twins of different stakeholders involved in the product can create greater added value for customers than the sole product offering of an OEM.

Digital Twins also support the monitoring and maintenance of systems and can be used as a platform for product-related and production-related services. A Digital Twin can also generate added value in later life cycle phases – for example, in the recycling or reuse of components.

Companies need to consider whether, and to what degree, they should use Digital Twins. Figure 1 illustrates a generalized procedure for the introduction of Digital Twins at a company, as followed by this study.

Figure 1: General procedure for the introduction and establishment of Digital Twins



Before employing this approach, companies first need to have a proper understanding of the concept of the Digital Twin *(see "Scientific definition" on page 20)*, so as to be able to determine the potential benefits it can offer the company. The initialization phase marks the point at which the project begins to take concrete shape. Two tasks are important here: to develop necessary support within the company and to secure company-wide understanding. In addition, exemplary use cases should be identified at this stage to illustrate the concept's potential.

Once support has been secured, the second phase begins – the formulation of a strategic goal. This phase is used to determine what concrete value a Digital Twin can bring to the company. Given its wide-ranging applicability, this technology can also bring about comprehensive changes at the strategic level, such as the creation of new business models, products and services *(see "Business models" on page 21)*.

Once there is clarity as to the purpose of a Digital Twin within a specific company context, the next step is to commence its design. For the purposes of producing an initial, generic design, the 8-dimension model can be used. This provides the basic specifications for the concept *(see "Design with the 8D model" on page 22)*. This also involves a comparison with the life cycle model of existing or planned product offerings. It thus allows for the proactive involvement of relevant stakeholders in further development steps.

The actual implementation of the concept takes place in the development phase. This process is assisted by the use of design elements. These supplement existing product and system developments with the requisite elements for Digital Twins and map out the general dimensions of the 8D model in the product and its operating environment *(see "Design elements" on page 23)*.

In line with the scope of the proposed Digital Twin, it is also necessary to redesign the existing company environment in preparation for implementation *(see "Implementation in the company – the implementation model" on page 24)*. This involves more than merely coordinating the new design elements of the development process. It is also essential to ensure that functions from the operating environment and feedback-to-design are used effectively. This is where the implementation model comes into play. The areas of application of the Digital Twin are not restricted to the product or service itself. They also cover the production phase, the use phase and the end phase of the product life cycle.

Below, we describe in more detail the steps and the models presented here. We also present any current legislation and regulations that must be met during the development and the use of Digital Twins.

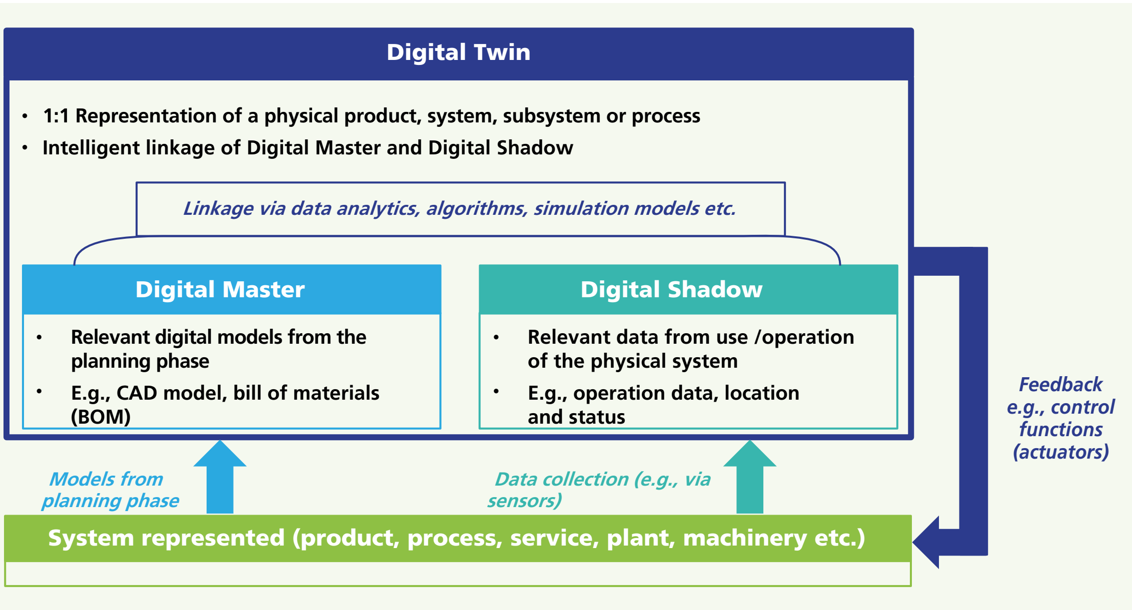
Definition

There are numerous ways of defining a Digital Twin. A recent summary *(Stark and Damerau 2019)* shows that the basic concept initially described by Grieves *(Grieves 2005)* now features a variety of elements. This includes simulation-, system-, application-, content- and domain-oriented descriptions. The present study is based upon the definitions provided by Stark and Damerau *(Stark and Damerau 2019)* and by Samarajiwa and Salamon *(Samarajiwa and Salamon 2019)*. These are presented below. According to the definition developed for the present study, a Digital Twin comprises three basic components (see fig. 2).

The first component is the digital master, which contains all the relevant models from the planning phase of the physical system under consideration. These models are derived from authoring systems such as a CAD system (CAD model) or a PLM system (bill of materials). The second component is the digital shadow. This consists of data collected (by means of, for example, sensors) across the life cycle (e.g., ordering, production, use, service) of the system represented by the Digital Twin. This can be operating data, status data or process data. The intelligent linking of these two components constitutes the third and central component of the Digital Twin – i.e., the actual analyses and optimization algorithms – and forms the basis of the knowledge generated by the Digital Twin. This in turn can be used to influence the represented system through feedback in the form of, for example, control commands or the addition of new features to the system. In a Digital Twin, the digital master data is linked with the specific digital shadow data in order to create a unique Digital Twin of the physical system. The information contained in this Digital Twin evolves over the life cycle of the system.

Figure 3 presents the life cycle of a Digital Twin and the feedback loops between the individual phases. In the initial phase, product characteristics (product specifications, architectures, simulations) are described in models and then further used in the digital master. These are then turned into concrete designs in the draft stage. The Digital Twin is developed in parallel to the development of the actual system in a separate life cycle. Data from production planning, production,

Figure 2: Schematic representation of the components of a Digital Twin



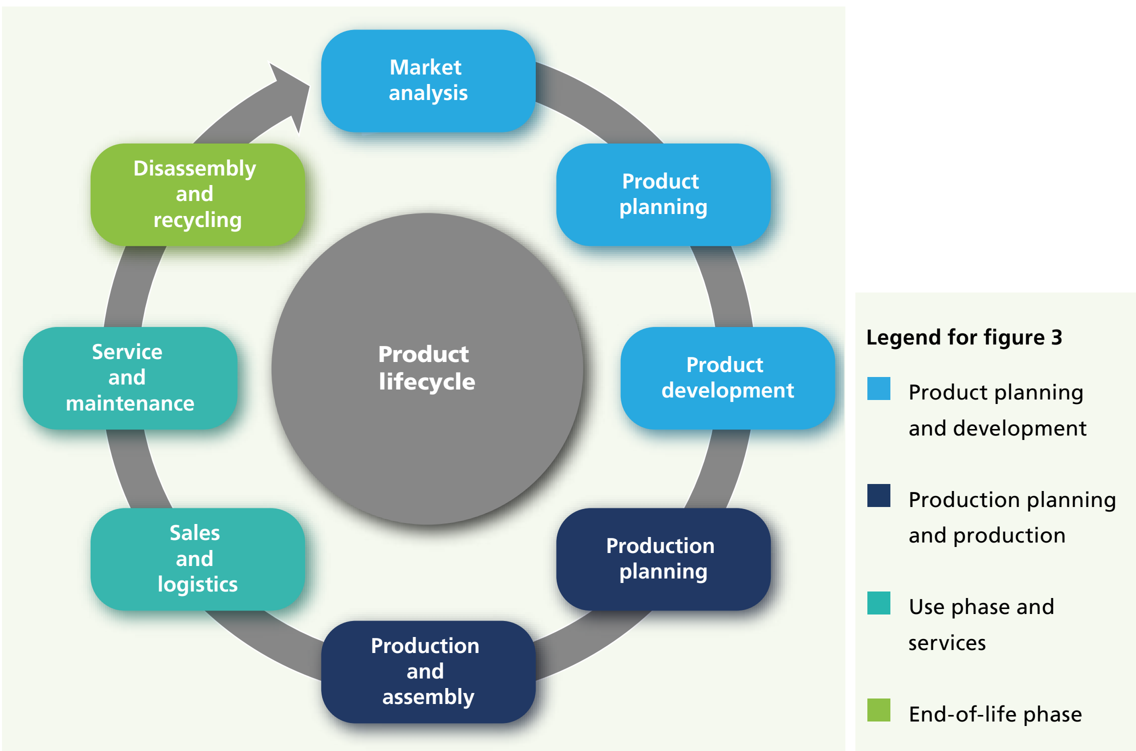
use and all the way up to recycling is collected from the physical system and mapped in the digital shadow. The simulation and analysis features of the Digital Twin combine data from the digital master and the digital shadow, thereby unleashing the full power of the Digital Twin. Potential applications lie in the areas of feedback-to-design, predictive maintenance and sustainability assessment *(Halstenberg and Stark 2018; Riedelsheimer et al.; Samarajiwa and Salamon 2020)*.

Business models

The use of Digital Twins is driven primarily by the growth in digitalization and the changing economy. The resilient new business models of the future are not the sales-oriented models of the past. Instead, they will focus increasingly on, for example, services and use-based models. They will radically change all aspects of the business, including relations to customer and supply companies, as well as income structures *(Exner et al. 2017)*. In particular, this will pose a challenge to manufacturing companies and their traditional markets *(Keskin and Kennedy 2015)*. These companies will require new methods and technologies in order to enable an integrated development of new products and services. In turn, this will necessitate not only the creation of new structures for the generation, storage and analysis of data related to products and their patterns of use but also a continuous digital flow of information throughout the entire company and along the value chain.

The ability to enrich physical products with new functions, customized features and extra services will become a critical success factor in value creation. Established business models typically have no access to product-specific information in the use phase *(Abramovici et al. 2009)*. To change this, companies require infrastructural, organizational, technological and process-related innovations, as offered by Digital Twins *(acatech - Deutsche Akademie der Technikwissenschaften 2011; Porter and Heppelmann 2015)*.

Figure 3: Product life cycle of the Digital Twin



The use of Digital Twins can transform a flow of information into tangible value. In this instance, a Digital Twin combines a life cycle focus with the service focus of smart products. The use of cross-company product models and highly individual product instances will create hitherto unknown value creation opportunities for companies *(Wang et al. 2018)*.

By analyzing and leveraging the data collected during the use phase, companies will gain insights on how a product actually behaves while in use. This in turn creates the basis for optimizing products, while in use – through updates and upgrades as well as proactively enabling product innovations for coming product generations *(Schuh and Blum 2016)*. This newly created data basis can then be used to optimize quality, use of materials, and costs. In new revenue models, partners along the value chain who have access to the data and models can profit from the insights they generate *(Wang et al. 2018)*.

Furthermore, this data allows conclusions to be drawn about how customers are using different product features. These findings offer an opportunity to develop new types of smart services to be offered during product use *(Exner et al. 2019)*. Customizing a product more closely to individual consumer requirements increases their satisfaction with that product. This enhanced level of customer support results in stronger customer loyalty *(Igba et al. 2015)*. In B2C or B2B sectors, mass products can be better adapted to niche markets and individual customer requirements. As a result, it will become more difficult for customers to switch between formerly interchangeable products, as alternative products will not be able to offer the same services *(Wang et al. 2018)*.

Reliable proof as to the sustainability of companies and their products is becoming a basic requirement of both consumers and legislators. Digital Twin technology can help companies comply with this demand. By making Digital Twins part of the value network, it is then possible to carry out a comprehensive life cycle assessment (LCA) and to make decisions that take sustainability into account *(Barni et al. 2018; Riedelsheimer et al. 2020)*.

Design (8D model)

Digital Twins have numerous purposes and areas of application. These are what determine the concept of a specific Digital Twin. This concept comprises the dimensions of the Digital Twin and defines its capabilities. In other words, these dimensions must be selected according to the desired requirements.

The 8-dimension model (cf. fig. 4) from Stark et al. can be used for the precise classification and development of a Digital Twin (Stark et al. 2019). It forms the basis for the classification of the concepts examined in the present study. The 8D model provided orientation for the Digital Twin Readiness Assessment, and individual aspects of it were used for the questionnaire.

The eight dimensions – which have a varying focus – can be clustered in three groups:

- The first three dimensions – breadth of integration, mode of connection, and update frequency – focus on the environment of the Digital Twin.
- The second group comprises dimensions four to seven: CPS intelligence, simulation capability, depth of detail of digital model, and human interaction. These describe the behavior of the Digital Twin and its range of capabilities.
- The final dimension focuses on the product life cycle and describes the life cycle context of a Digital Twin.

Figure 4 shows these eight dimensions. Each individual dimension has three or four levels of realization. It should be noted that a higher level is not necessarily an improvement on a lower one, but it does represent a distinct solution. In other words, the most appropriate solution is not necessarily the one at the highest level. Rather, it is the one that has been designed to be as lean as possible – i.e., simple and economical – in accordance with the specific purpose of the Digital Twin.

Components

(Design elements)

Digital Twins offer new ways of improving the functionality of products, processes, services and production facilities. Based on the eight dimensions of the 8D model, six design elements can be derived.

These six design elements provided orientation for the Digital Twin readiness assessment, and individual elements were used for the questionnaire.

The basic requirement for the creation of a Digital Twin is an IT infrastructure with suitable storage capacity and calculation properties. Figure 5 shows the design elements and their interaction.

Design element 1 – "Hardware of physical systems/components" – covers the hardware components that deliver the analytical capability (sensors), control functionality (actuators) and network connectivity of the Digital Twin by means of special or entire subsystems.

Design element 2 – "Software in the ECUs of physical system/components" – covers algorithms and software that perform tasks directly within the product system.

Design element 3 – "Data storage and elements of the information factory" – enables the description of computing environments, corresponding data repositories, analytical toolbox sets, and information technologies connected by networks.

Design element 4 – "Digital master and digital prototype models" – covers all relevant digital models that provide the basis for Digital Twin capabilities.
Design element 5 – "Digital shadow and information assets" – enables integration of features pertaining to operation of the physical product or service.

Figure 4: 8D model for customized planning of Digital Twins (Stark and Damerau 2019)

The eight dimensions of the Digital Twin							
Environment			Behavior & depth of detail				Context
1. Breadth of integration	2. Mode of connection	3. Update frequency	4. CPS intelligence	5. Simulation capability	6. Depth of detail: digital model	7. Human interaction	8. Product lifecycle
Level 0 Product / machine	Level 0 Uni-directional	Level 0 Weekly	Level 0 Triggered by humans	Level 0 Static	Level 0 Geometric, kinetic	Level 0 Smart device	Level 0 Begin of Life (BoL)
Level 1 Near field / production system	Level 1 Bidirectional	Level 1 Daily	Level 1 Automated	Level 1 Dynamic	Level 1 Control behavior	Level 1 VR / AR	Level 1 Mid of Life (MoL) + BoL
Level 2 Field / factory environment	Level 2 Automatic; e.g., context dependent	Level 2 Hourly	Level 2 Part automated (weak AI support)	Level 2 Ad hoc	Level 2 Multiphysical behavior	Level 2 Smart hybrids	Level 2 End of Life (EoL) + BoL+MoL
Level 3 World (full object interaction)		Level 3 In real time / event-based	Level 3 Autonomous (full cognitive behavior)	Level 3 Predictively descriptive			

Design element 6 – "Intelligence and state machine" – represents the link between master and shadow, and communication with the data memory. In addition, this also provides control of the hardware and software components.

Implementation in the company

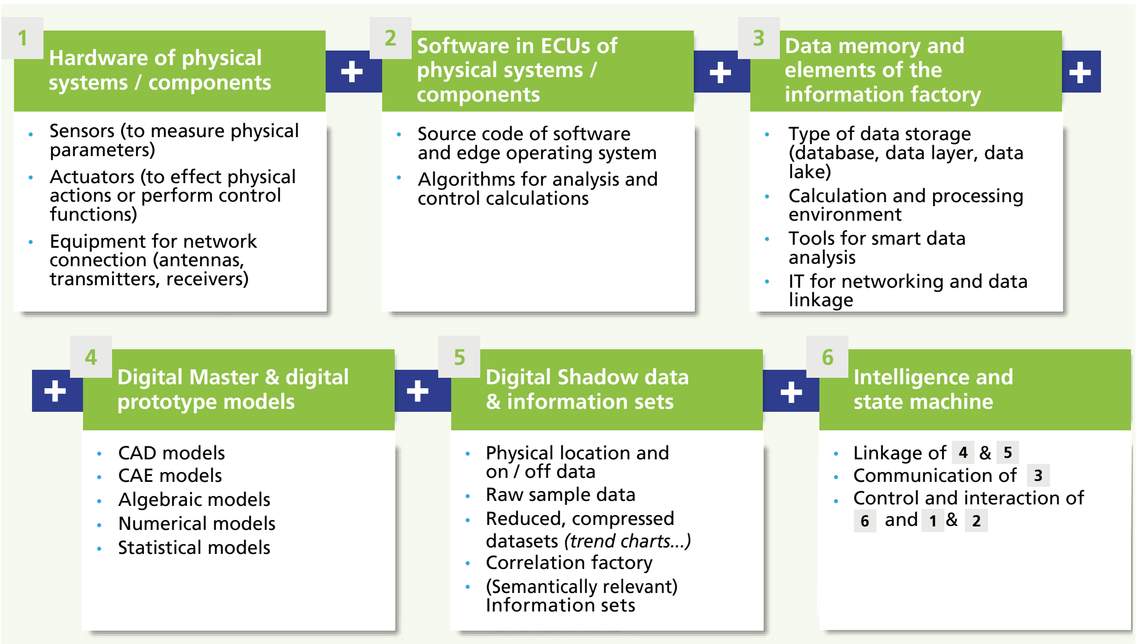
(Implementation model)

Development environments that are used to develop not only product systems but also Digital Twins require advanced integration. This is because Digital Twins require the use of tools and capabilities from the domains of mechanical engineering, electronics, IT and the services sector. The engineering operating system (EOS) was developed in order to map a holistic picture of the development environment, thereby enabling smooth interaction between all the dimensions involved *(Lünnemann et al. 2017)*. For the purposes of this study and to accommodate the specific characteristics of Digital Twins, this model has been expanded to include the dimension of benefits, which should be at the core of all implementation measures.

The implementation model maps four intersecting dimensions (see fig. 6). The dimension most frequently discussed today is that of processes and company organization. This describes process and organizational structure at the company in departments and in relation to project-related business and the tasks associated with it. Also mapped here are procedural rules on working processes such as product development, product release, product change and product ordering. A second dimension describes the available tools. Nowadays, especially in product development, there are an increasing number of IT systems that enable digital value creation.

The nature of the disciplines involved in the development process and the highly specialized software used has led to a growth in the number of tools deployed in the development infrastructure. A particular challenge is to ensure effective data linkage between the various systems in order to achieve a high degree of information consistency. The application of IT systems is mapped at the intersection of tools and processes. This area defines which tools are to be used at which stage of the development

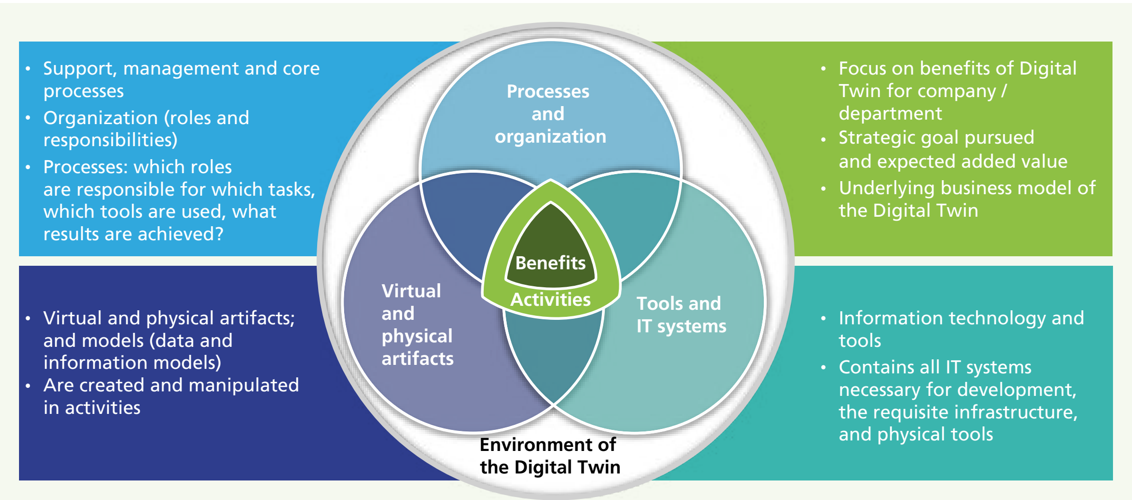
Figure 5: Design Elements (Stark et al. 2019)



process, which tasks they must perform and which capabilities and properties they must possess. The tools dimension also intersects with that of data and information models, which is the third dimension in the implementation model. Many IT tools use specific data models that can only be interpreted by these systems. They also feature export functions, which, however, usually entail a loss of information. The third dimension of the implementation model describes the artifacts in product development. These contain all the information and models used, modified or generated in the course of development along with their structural representation in the data system. In addition to overlapping with tools, the artifacts dimension also intersects with that of processes. This dimension describes the expected results in terms of their format and quality as well as, where appropriate, terms of their increased maturity compared to the processes. For example, the development environment can be analyzed and redesigned as part of a methodical data flow analysis *(Lindow et al. 2017)*. These three fundamental dimensions form the basis for all the actual value-creating activities performed by people and machines.

The implementation model plays a special role in relation to Digital Twins. For the purposes of the present study, a model was developed for the implementation of Digital Twins in companies. On the one hand, the development process must include the creation of the master models required for the Digital Twin. On the other hand, information from the Digital Twin is fed back into the development process, meaning that new artifacts and IT systems have to be incorporated in the design process. Finally, a new operating system, which seamlessly connects to the operating system of the development environment, has to be created for the Digital Twin. It is vital to ensure a high level of consistency between the development and operating platforms and across all dimensions of the implementation model. Only a comprehensive coordination of processes, company organization, IT systems, and

Figure 6: Implementation model for use with Digital Twins



virtual and physical models creates the opportunity to reliably generate value from Digital Twins and to realize the envisaged benefits.

Laws and regulations

To date, there are no standards or norms clearly applicable to Digital Twins. The following therefore offers a summary of the relevant issues.

Given the increased connection of IT and physical systems resulting from the use of Digital Twins, data security is one of the prime considerations in the development of Digital Twins. In this regard, standards provide an important source of guidance on technical and organizational issues. Certificates that demonstrate compliance with these standards bolster the credibility of such products and services. The increased level of digitalization offers a broad target for cyberattacks. It is therefore vital to take the relevant security guidelines during development of a Digital Twin into account.

Moreover, given the involvement of people either interacting with a Digital Twin or using connected products, it is essential to ensure compliance with the EU's General Data Protection Regulation (GDPR), which governs the processing of personal data.

Standards can be grouped in three subcategories: functional safety, organizational safety and information security. Together, these form the main category of industrial security.

Based on the IEC 62443 standard, a holistic view of the overall system and the different areas of industrial security is now emerging. This standard incorporates the basic requirements of ISO 27001 and of VDI 2182, which focuses on organizational aspects. In the field of mechanical engineering, the topic of functional safety – i.e., safety related to the concrete function of the system – is covered by IEC 62061, ISO 14849 and, more generally, IEC 61508. The ISO 12100 standard provides general guidelines for design, risk assessment and risk reduction. ISO/IEC 15408 specifies the general criteria for assessing risk in information technology.

When developing a Digital Twin, it is vital to pay attention to standards at an early stage. ISO 12100 defines the requisite terminology and methodology. The application of ISO 12100 minimizes the risk of system failure during its lifetime. On this basis, ISO 13849-1 also sets out detailed requirements for the reduction of risk during the design and integration of safety-related parts. Unresolved issues include autonomous decision-making by systems, which may be of relevance to the actual use of Digital Twins, depending on their level of automation and autonomy.

Study design and execution

How was the study set up and executed?
Which sector of industry do the companies interviewed work in and what size are they?
What are the roles and responsibilities of the interviewees at their company?

42% of the companies are suppliers in the mobility sector.

58% of the companies have over 50,000 employees.

35% of the interviewees work in IT and 27% in product development.

42% of the interviewees have more than five years of experience in their role.

46% have a leadership role with disciplinary duties and managerial responsibilities (team leader).

Study design and execution

Study design

This study comprises qualitative interviews on the status of Digital Twin use at companies in the DACH region. The study was designed using a two-step approach. In the first step, companies were interviewed and assessed as to their current status of Digital Twin use. In the second step, this collated data was anonymized and evaluated for the purposes of the study. The interviews generated two results: an individual readiness assessment for each company and a Digital Twin Readiness Assessment for the manufacturing industry as a whole (cf. fig. 7).

The readiness model developed for this purpose is based on the initially presented procedure for the introduction of Digital Twins and related models, as presented above (cf. fig. 8).

The individual readiness levels are derived as follows (cf. fig. 9):

Readiness in the area of "understanding and use"

The readiness level in the area of "understanding and use" corresponds to a company's understanding of the concept of a Digital Twin. The study takes a critical look at companies' ideas for the use of Digital Twins, their level of prior knowledge and experience in this field and whether this knowledge is based largely on theoretical models or on practical experience.

Readiness in the area of "strategic goal and concept"

The readiness level in the area of "strategic goal and concept" was assessed on the basis of two key factors. First, the strategic goal pursued by companies was assessed. This focused primarily on their reasons for introducing a Digital Twin and whether this strategic goal is realizable on the basis of the company's concept.

For this purpose, the concept being pursued in collaboration with the interviewees

Figure 7: Procedure followed in the interviews

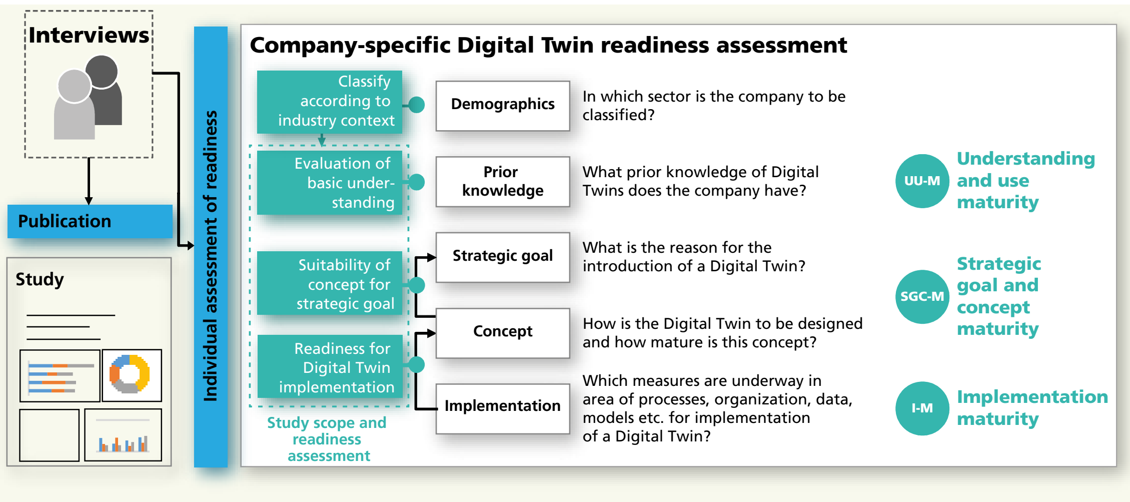
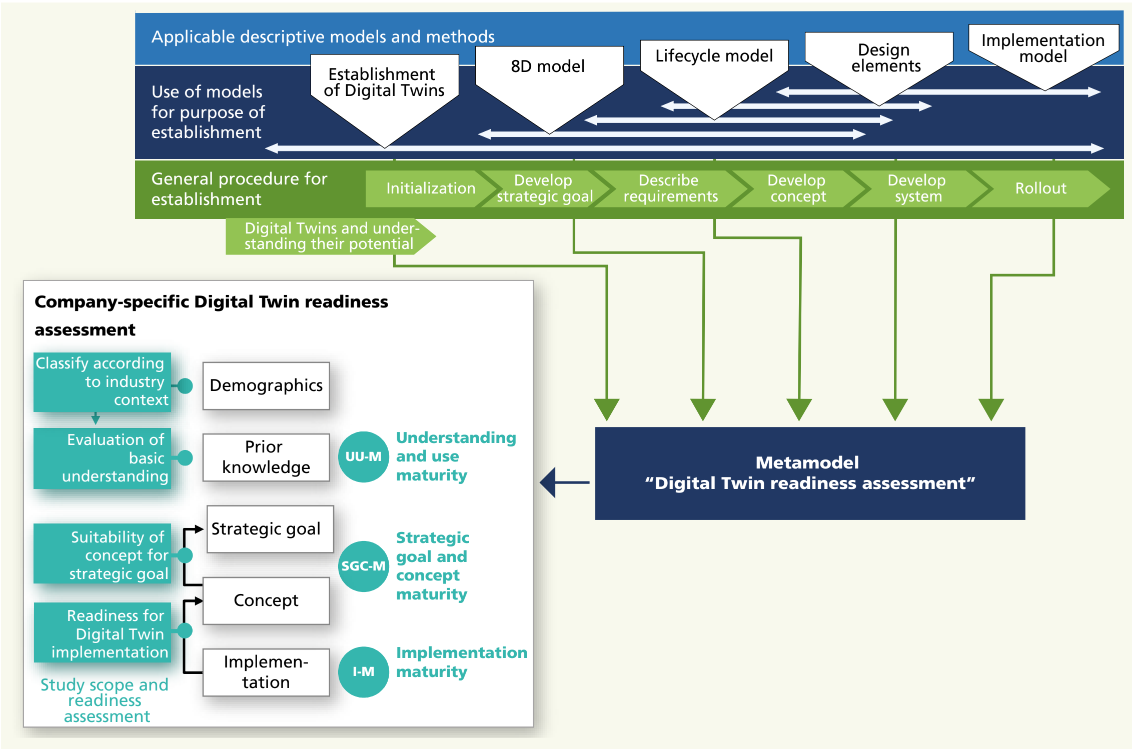


Figure 8: Deduction of readiness on the basis of a generalized procedure for the introduction of Digital Twins

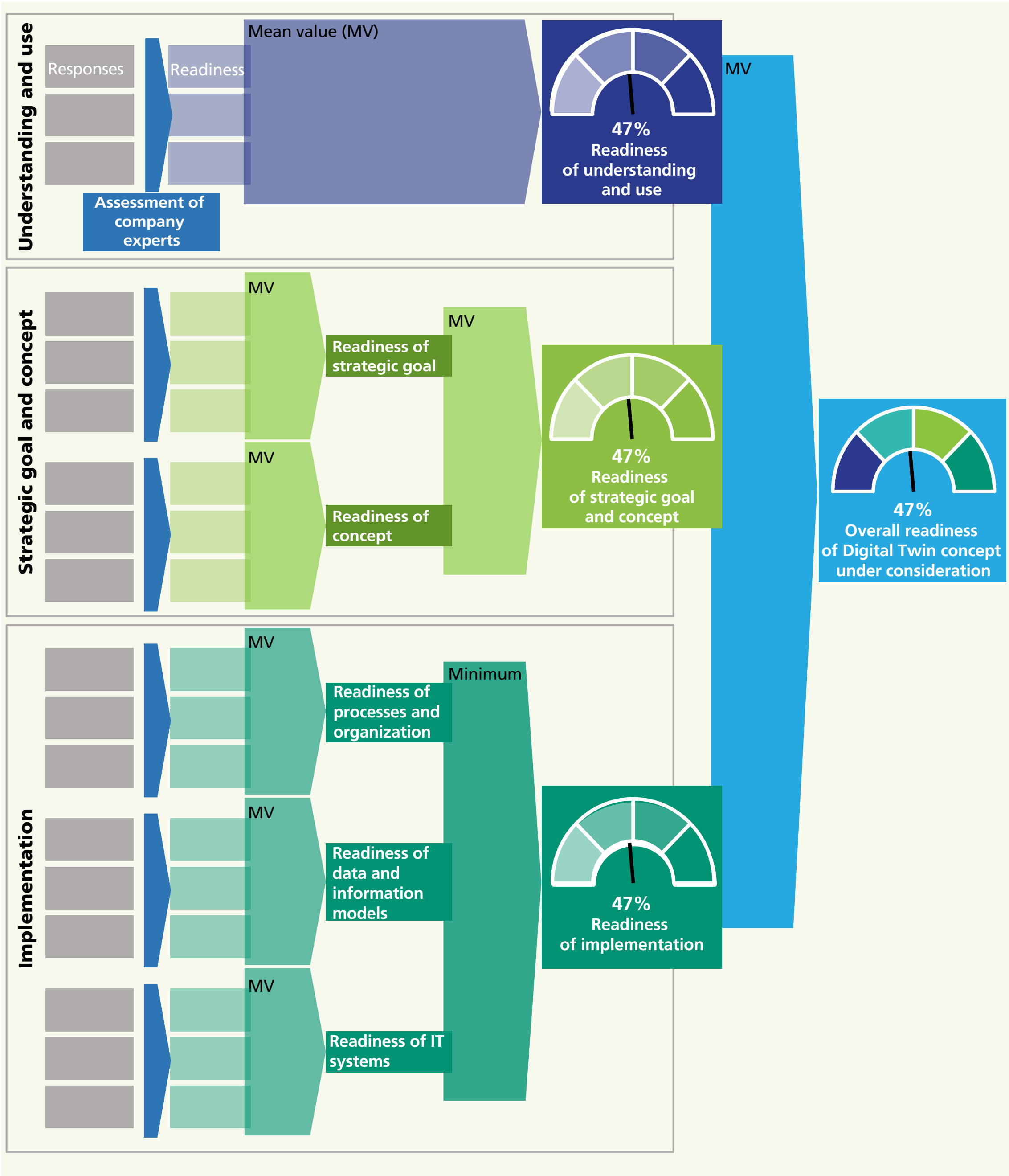


is outlined in the generalized description model for Digital Twins. To achieve greater detail, questions about strategic goals, changes to business models and the system (product or process) represented by the Digital Twin, and individual benefits were asked. The strategic goal then provided the basis for the assessment of subsequent readiness levels, including concept readiness. This addressed not just the concept's coherence and comprehensiveness but also critically reviewed its suitability for realizing the strategic goal described. To deepen the examination of the concept initially described, companies' intended use of their Digital Twin over the entire life cycle was investigated together with the interviewees. Where the concept had a sufficient level of detail, the 8D model was used to describe where shadow data is collected, master models are created, and value is generated from the use of the Digital Twin. In the interest of further detail, the envisaged functions of the Digital Twin, the system properties represented in the Digital Twin, the issue of information transfer, and simulations and interactions was also looked at. Additionally, the relevant laws and regulations were determined.

Readiness in the area of "implementation"

The described concept will be considered in subsequent assessments. Following the establishment of the concept, the implementation readiness was evaluated. In accordance with the logic of the implementation model, the design of processes and company organization (Dimension 1), IT systems (Dimension 2) and data and information models (Dimension 3) were assessed. Here, the overall implementation readiness was determined according to the lowest level of implementation readiness across all dimensions of the implementation model. This follows the logic that a single dimension of the implementation model impacts the overall efficiency to such an extent that other dimensions are unable to compensate for a low readiness level in that one dimension.

Figure 9: Assessment of the readiness levels



In the dimension for processes and company organization, necessary changes in process organization and organizational structure, along with the skills required for the development and operation of Digital Twins were addressed. In the dimension of data and information models, the areas of data generation, data management and the availability of models were examined. And with respect to IT systems, the intended architecture, including subsystems and data transfer between these subsystems was reviewed.

The readiness level was assessed by experts from Fraunhofer IPK on the basis of the answers given to each question. Readiness was graded according to the following ordinal scale: zero readiness, idea, concrete concept, implementation started, implementation completed. The evaluations were always conducted by teams of two. All results were then compared in order to achieve a uniform assessment that was as objective as possible.

On a numerical scale of 0–1, the maximum readiness level was assigned a value of 1, thereby resulting in the following values in the ordinal scale:

Ordinal scale	**Numerical scale**
Zero readiness	0
Idea stage	0.25
Concept stage	0.5
Implementation started	0.75
Implementation completed	1

Summaries of the assessed readiness levels were developed for each of the companies interviewed. Each company was also given the option of an anonymized, generalized comparison with other companies. For the readiness levels described, the evaluated responses were combined as an equally weighted mean value to denote a generalized, representative value of the level of readiness achieved.
In cross-company analyses, the readiness achieved was likewise calculated as the mean value of the specific group.

In addition to – and distinct from – the readiness assessment, the potential for using Digital Twins to perform sustainability assessments along with companies' ideas on the future use of Digital Twins was also surveyed.

The experts and senior managers who took part in interviews were chosen by msg and Fraunhofer IPK in the course of specialist events and meetings of interest groups. Selected to participate in the study were companies with over 1000 employees in various sectors of the manufacturing industry along the value chain in the DACH region.

For each question, responses were compiled into clusters and analyzed. Here, key statements and divergences were counted proportionally. In a next step, comparative analyses of response clusters by demographic group were then carried out in order to identify trends in the responses given.

Execution of the study

The expert interviews were conducted from August 2019 to March 2020. A total of 26 experts and senior managers were interviewed. The steps used to execute the study were as follows:

1. Preparation of interviews, provision of organizational aspects and privacy statement
2. Signing of the declaration of consent by interview partners
3. Interviews of 90 minutes conducted either virtually or in person, including a written record
4. Evaluation of the written record and individual assessment of the level of readiness
5. Anonymization and aggregation of the interviews and evaluation of all interviews for each question
6. Analysis and interpretation of evaluations to produce consolidated findings
7. Visualization and writing up of the findings in the present study
8. Follow-up interviews with participating companies to present individual readiness assessments

In preparation for the interview, the interviewees were provided with documentation outlining the procedure as well as information on data privacy.

Interviews were conducted by telephone or in person by either msg or Fraunhofer IPK, on an equal basis. At least three people were involved: one or more persons from the company interviewed, along with the person conducting the interview and the person keeping a written record, who was from either msg or Fraunhofer IPK. On average, each interview lasted around 90 minutes.

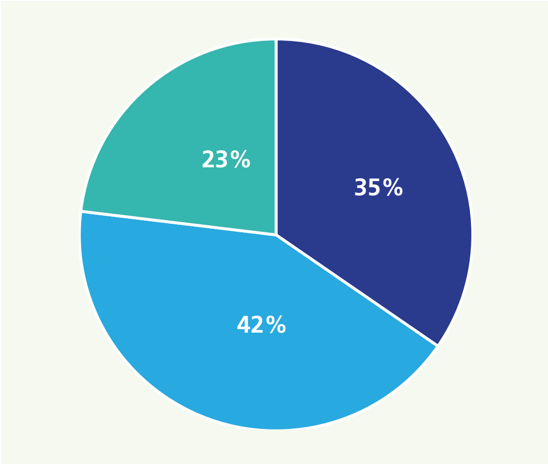
In the first instance, the transcripts of the persons keeping a written record and the notes of the persons conducting the interviews were prepared for further individual evaluation. This provided the basis for the individual readiness assessments, which were carried out by a team of experts from Fraunhofer IPK, with the support of msg. The evaluations of the interviews were then fed into an aggregated database for the study. This was used by researchers from Fraunhofer IPK to produce the results that are presented below. They analyzed and interpreted the data in order to produce key findings, which can be found in the following chapters, on specific questions and to conduct comparative analyses across different sectors or company departments.

Participating companies were also given the option of providing a statement on Digital Twins, which have been included in the published study. In order to discuss the individual results of the readiness assessment, follow-up interviews were held with the study participants.

Demographic distribution of the study participants

The study participants all work at companies in various sectors of the value chain in the manufacturing industry within the DACH region. Overall, the study focuses on discrete manufacturing and companies that manufacture and supply products and systems. No pure service companies were interviewed. The interviewees all have some connection to the topic of Digital Twins. This section provides an overview of the demographic spread of the interviewees in terms of their role and activity at their respective company. The largest group (42%) of the interviewees comprises suppliers in the mobility sector (cf. fig. 10). The second-largest group of the interviewees comprises original equipment manufacturers (OEMs) of mobility solutions for road, rail and air. Of this group, the majority (7 of 9 the interviewees) produce road vehicles. In addition, six companies in the mechanical and plant engineering

Figure 10: Demographic distribution of the interviewees according to industry group

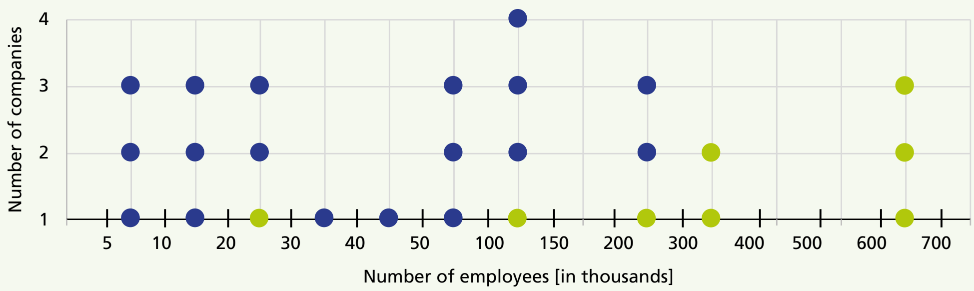


Legend for figure 10

- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

and equipment technology sectors took part in the study. Figure 11 shows the distribution of the companies by size. Most of the companies have over 50,000 employees, and three of the interviewees work in companies with over 600,000 employees. Eight companies are independent subsidiaries of companies invited to participate in the interview (see light-green dots in fig. 11). Start-ups and microenterprises were not included in the interview. Figure 12 shows the spread of the interviewees according to company department. Most of the interviewees work in either IT or product/system development. Almost 25% work in staff units. A substantial proportion (36%) of the departments in

Figure 11: Company size in number of employees



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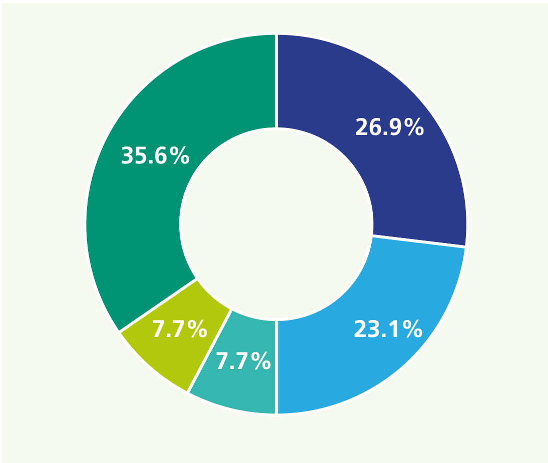
- Interviewees are employed in a subsidiary of the company
- Interviewees are employed in an independent company

which the interviewees work have over 50 employees (see fig. 13). Of the remaining departments, 24% have less than 50 employees and 24% less than ten employees.

Figure 14 shows the role of the interviewees in their respective company. A large proportion of the interviewees (46%) have a leadership role with disciplinary and managerial responsibilities (team leader). Almost 20% are either experts or project leaders. Figure 15 shows the experience of the interviewees in this role as number of years on the job. Most of the interviewees have five or more years of experience in this role.

Figure 12: Demographic distribution of the interviewees according to department / area of work



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- Development
- Staff unit
- IT
- Production
- Management

Figure 13: Number of employees per department / area of work

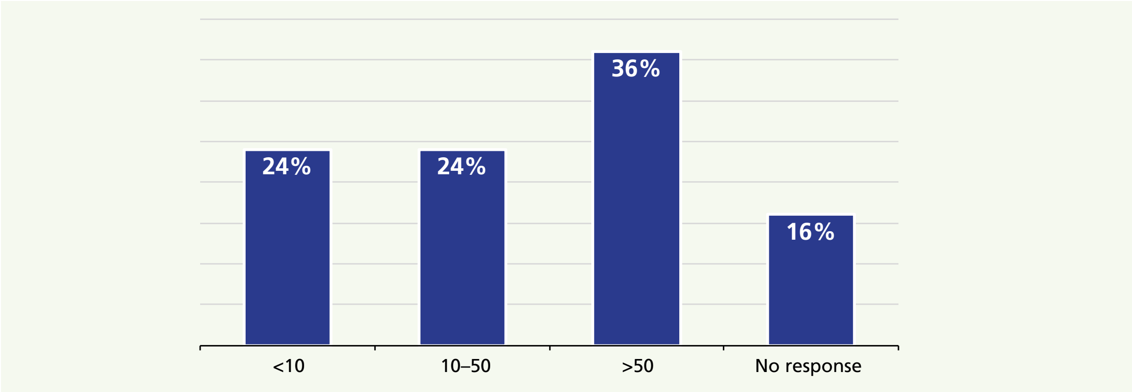
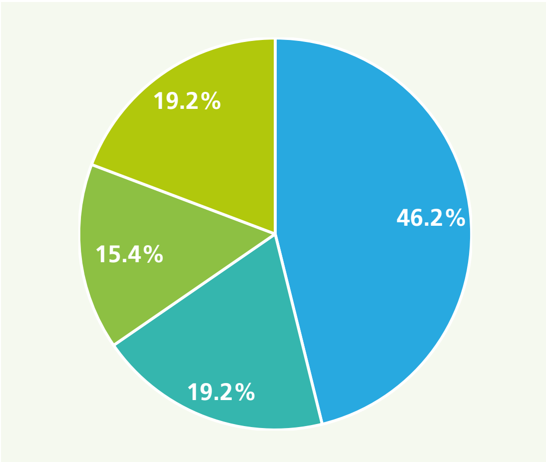


Figure 14: Interviewees' role in the company



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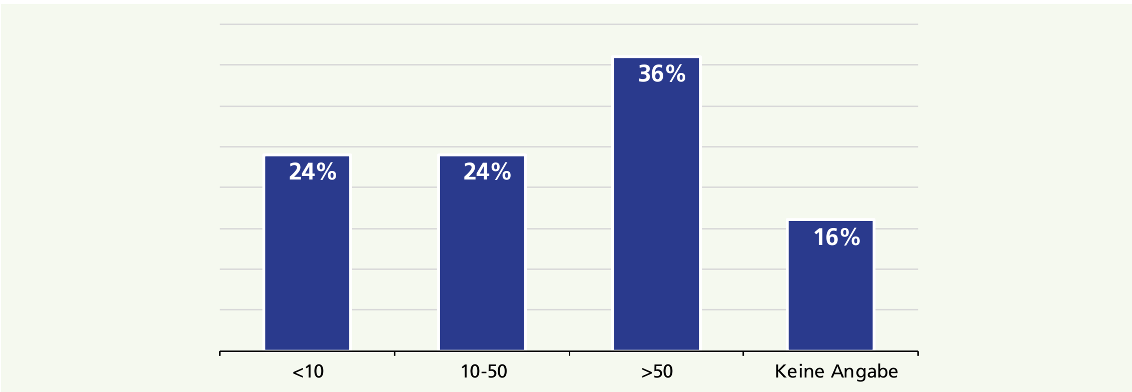
- Team lead
- Technical expert
- Program lead
- Project lead

Figure 15: Interviewees' experience in this role in number of years



STUDY RESULTS

Understanding and the current use in industry

What is industry's understanding of Digital Twins?
How advanced is the use of Digital Twins in companies?

20% of the companies interviewed do not have a uniform definition of a Digital Twin.

46% of the companies interviewed are of the opinion that a Digital Twin contains a digital shadow.

85% have already developed their own Digital Twin concept. Only 54% possess a corresponding strategy.

8% are already making full use of Digital Twins. And as many as 35% have already started implementation.

"For AVL, a Digital Twin offers added value not only because it enables us to virtually map all the relevant properties of smart IoT objects over the product life cycle but also because it offers a fundamental basis for new digital offers."

Andrea Denger

"Digital Twins and the underlying digital systems are key technologies to help companies safeguard their future viability."

Dr. Jens Fürst

Understanding and current use in industry

The earliest precursors of Digital Twins are to be found in the aerospace industry of the 1960s. These simulation models were used to validate aircraft and missiles. Since the turn of the millennium, their use has spread to other sectors of industry. Many companies are now exploring ways of digitally mapping products and, increasingly, processes and services. This expansion in the use of Digital Twins has been accompanied by a diversification in the way in which this technology is defined and a broadening of its field of application. In both industry and the academic world, there are now numerous definitions of what constitutes a Digital Twin, as promulgated by committees, stakeholder groups, business associations and research institutions. These definitions reveal a variety of views on the basic components or elements of Digital Twins, the tasks they perform and the capabilities they have. This chapter explores how different companies define Digital Twins and how the interviewees at these companies are developing and refining their knowledge of this topic. In addition, we also examine the state of use of Digital Twins at the companies interviewed.

Knowledge in relation to Digital Twins

In order to survey the level of prior knowledge in this field, the interviewees were asked to specify and assess their prior knowledge by means of examples, actions and measures.

On average, the interviewees report possessing a good or very good level of prior knowledge (see fig. 16). Among the interviewees, 12% rate their prior knowledge as low, 46% as good and 35% as very good.

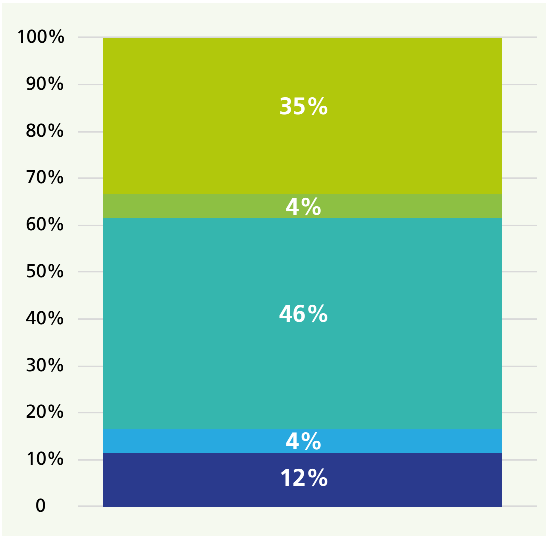
A breakdown by the industry group in which the interviewees work (see fig. 17) shows that companies in sectors for mechanical and plant engineering and equipment technology rate their prior knowledge the highest. The majority of suppliers in the mobility sector also place themselves at the upper end of this scale. OEMs in the mobility sector display the greatest diversity with respect to the level of prior knowledge. In a breakdown by the company department in which the interviewees work, no trend emerged.

The actions, measures and activities undertaken by the interviewees correlate with their level of prior knowledge (see fig. 18). Here, 24% of the interviewees refer to concrete experience from actual applications. Other interviewees are active in Digital Twin research (20%) or motivated by specific requirements (20%). Smaller groups are involved in their company's own Digital Twin strategy (12%), are active in associations (12%) or are in dialogue with other stakeholders (12%).

An examination of the correlation between measures undertaken and the self-assessment of prior knowledge (see fig. 19) indicates that experience with actual applications leads, as might be expected, to very good level of prior knowledge. Likewise, a dialogue on this topic with other stakeholders also has a positive impact on the self-assessment of prior knowledge. In the main, participation in research projects correlates with a good or very good level of prior knowledge.

QUESTION *What is the level of knowledge in relation to Digital Twins?*

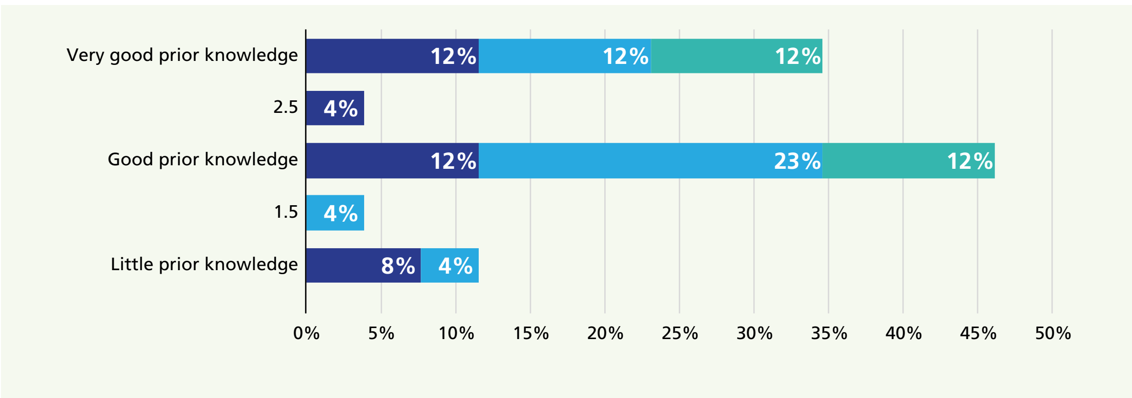
Figure 16: interviewees' self-assessment of prior knowledge



Legend for figure 16

- Little prior knowledge
- Little to good prior knowledge
- Good prior knowledge
- Very good prior knowledge
- Good to very good prior knowledge

Figure 17: interviewees' self-assessment of prior knowledge according to industry group



Legend for figure 17

- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

Figure 18: Measures named by the interviewees to develop this knowledge

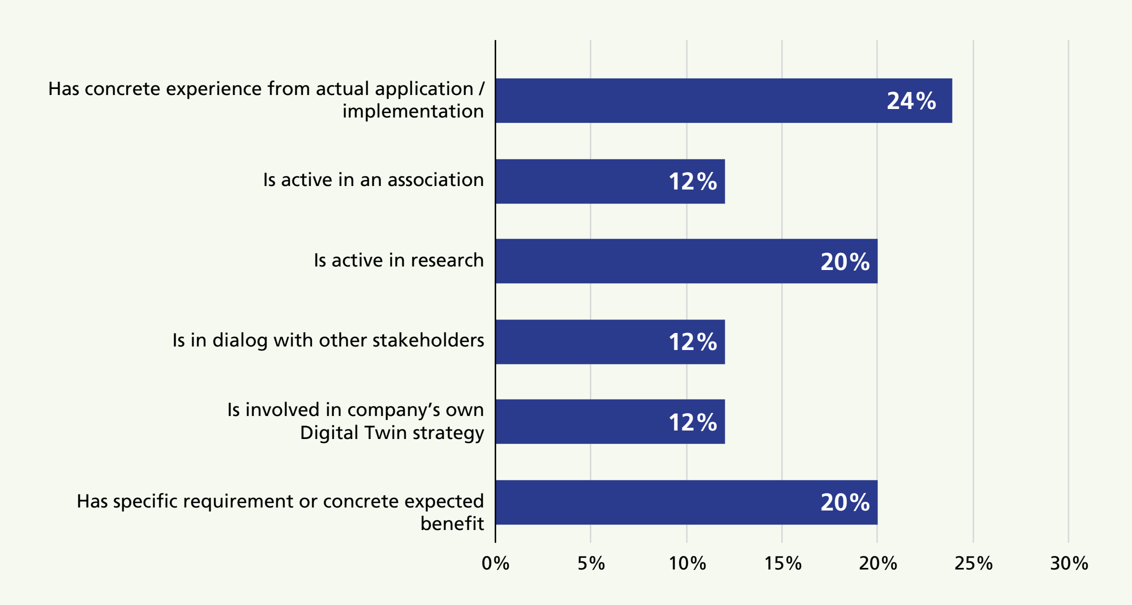
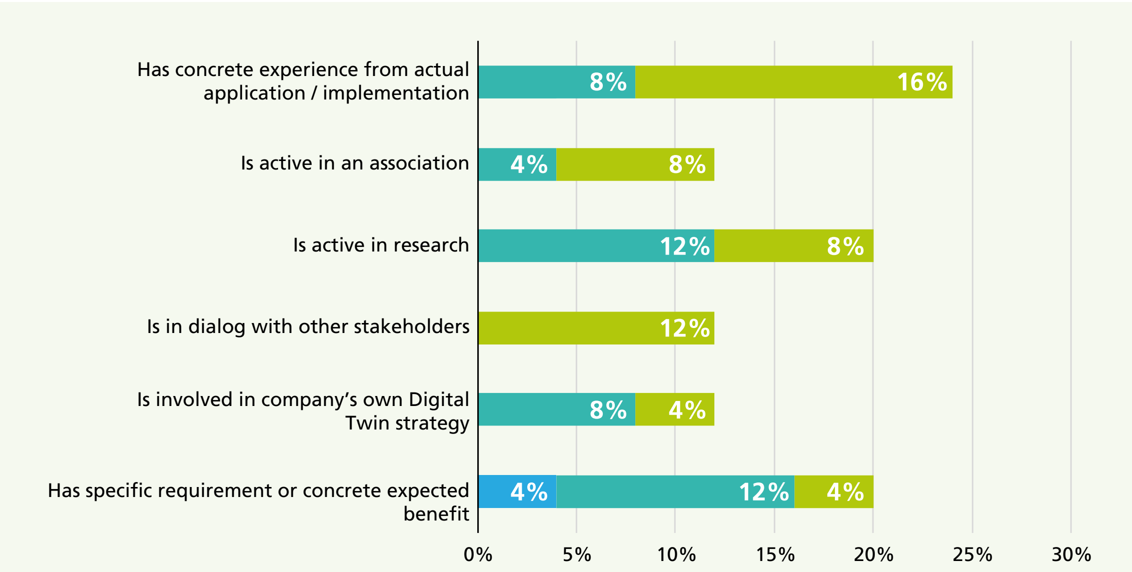


Figure 19: Interviewees' self-assessment of prior knowledge compared to measures named to develop this knowledge



Legend for figure 19

- Little prior knowledge
- Little to good prior knowledge
- Good prior knowledge
- Very good prior knowledge
- Good to very good prior knowledge

Definition of Digital Twins in companies

Alongside the definitions provided by science and research, companies often have their own Digital Twin definition, which is influenced by the sector in which they work, by the context in which the Digital Twin is used (product or production/assembly) or by the specific application. On the basis of these definitions, it is possible to identify different priorities in the application of the general concept. The study also identified erroneous or incomplete interpretations.
A detailed breakdown of the aspects specified in definitions reveals that the vast majority of the interviewees (92%) envisage using a Digital Twin to represent a product (see fig. 20). In addition, 69% of the interviewees expand this to include the digital representation of an object in general – and name, as an example of this, systems and services. Half of the interviewees also include the digital representation of production systems and manufacturing processes. Here, 19% of the interviewees specify the representation of specific product configurations and variations, and 46% the representation of functions, behavior and processes. For 19% of the interviewees, the definition also includes a consideration of the life cycle and, in a small number of cases, a representation of the system environment.

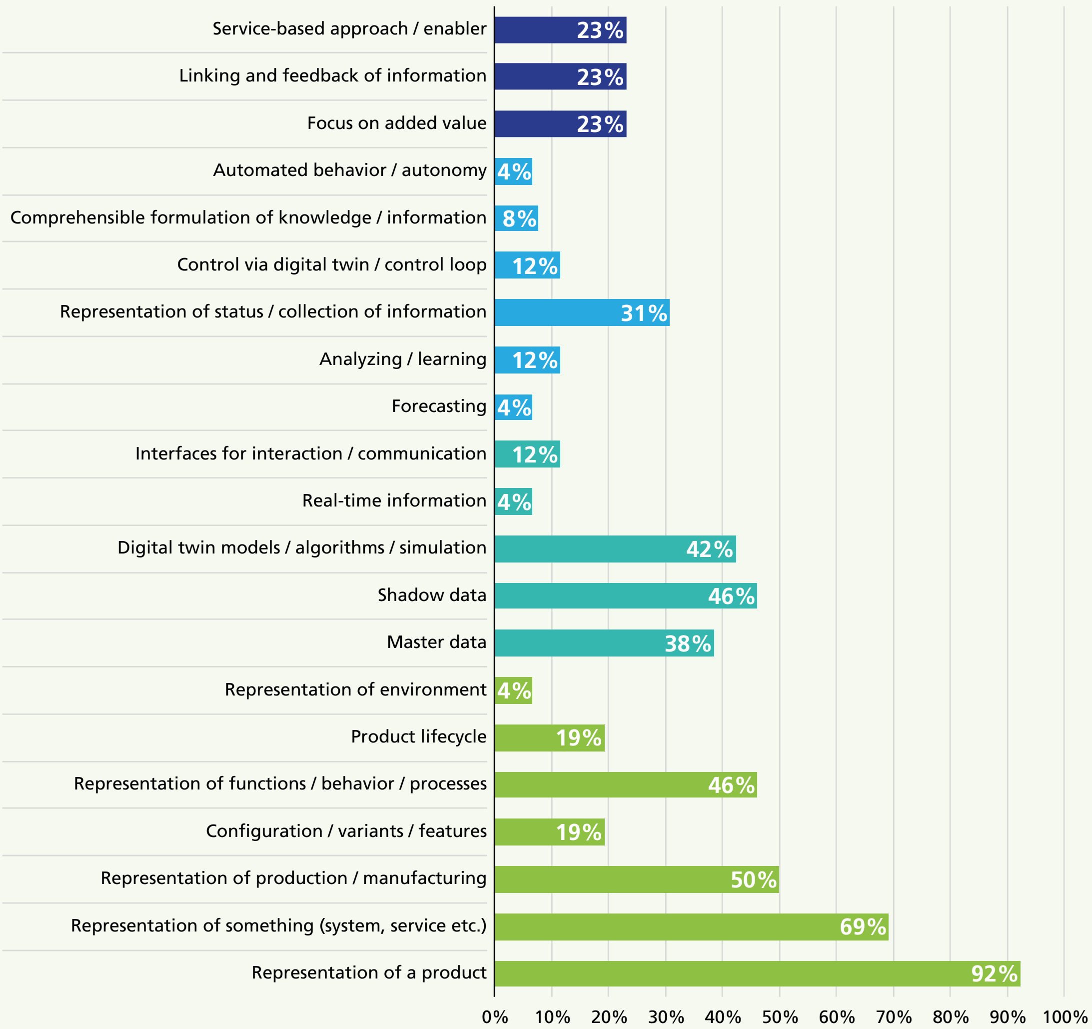
In all, 77% of the interviewees specify the elements featured in a Digital Twin. Here, 38% name master data, and 46% shadow data. In addition, 42% also considered functions and models, including simulations, as part of Digital Twins. In some cases, the definition specifies the real-time capability of Digital Twins. For 12% of the interviewees, the definition also includes the communication capabilities of Digital Twins and the use of interfaces.

For 58%, the definition includes a reference to the Digital Twin's functions. In this case, the function most frequently named (31%) is the representation of system status and the collection of information. This is followed by control functions (12%) and analysis and learning functions (12%). To a lesser degree, the preparation of knowledge and autonomous behavior are also named.

For 46% of the interviewees, the benefits of a Digital Twin are part of the definition. Such benefits are equally spread between the general creation of value, the exchange and feedback of information and the provision of services.

QUESTION *How does industry define Digital Twins?*

Figure 20: Breakdown of the aspects named in Digital Twin definitions



Legend for figure 20

- Benefits
- Functions
- Elements
- Represented system

State of use of Digital Twins in industry

The state of use of Digital Twins varies among the interviewees. According to their own assessment (see fig. 21), 85% of the interviewees already possess a concept for the use of Digital Twins. However, it is noteworthy that only 54% are also pursuing a strategy for the use of Digital Twins. Around half of the interviewees (46%) have produced a prototype based on their concept. Some companies are still in the process of preparing Digital Twins for market readiness (14%), while others are already preparing to operate Digital Twins in the market environment (15%). This has been partially implemented by 19% and fully implemented by a further 19%.

This self-assessment can be compared with the readiness assessment conducted by Fraunhofer IPK. This is shown in figure 22. A substantial share of the interviewees (38%) are still at the concept stage – a finding that essentially corresponds to companies' own assessment. According to assessments with the readiness model, 35% of the interviewees have already begun implementation. In companies' own assessment, this share is substantially lower. This is also because their assessment of market use is, in part, higher. In the readiness assessment, by contrast, this is lower, at only 8%. In companies' own assessment, however, 19% of the interviewees indicate partial and a further 19% full market implementation.

In a further analysis of possible causes for this substantial deviation in the assessment of implementation readiness, it is evident that some of the interviewees are pursuing a Digital Twin concept that, in a detailed comparison with the definition presented above *(see "Definition" on page 20)*, cannot be characterized as such. For example, such concepts do not include the continuous feedback of data from real systems. In all, 27% of the concepts submitted by the interviewees do not fully meet the definition of Digital Twins.

A breakdown of readiness level by industry group reveals substantial differences (see fig. 23). Concepts in the mechanical and plant engineering group display the highest readiness level. In this instance, 15% of the interviewees have reached the concept stage, and 8% have already begun implementation. For suppliers in the mobility sector, readiness levels are broadly spread, ranging from the idea stage (12%) to concept stage (12%), implementation started (15%) and, in a few cases, implementation completed. For OEMs in the mobility sector, the spread was even wider.

A breakdown of the level of implementation according to the type of physical system that is digitally represented (see fig. 24) shows that in the case of production-related systems there are not yet any implemented concepts. However, 8% of companies have already started implementation of concepts in a production/assembly-related context. Here, a further 8% are at the concept stage, and 12% at the idea stage. In product-related approaches, there is once again the full spectrum of readiness levels: no readiness (4%), idea stage (4%), concept stage (31%), implementation started (27%) and implementation completed (8%).

QUESTIONS *How far advanced are companies?*
Are Digital Twins already in use?

Figure 21: Self-assessment of the state of use of Digital Twins

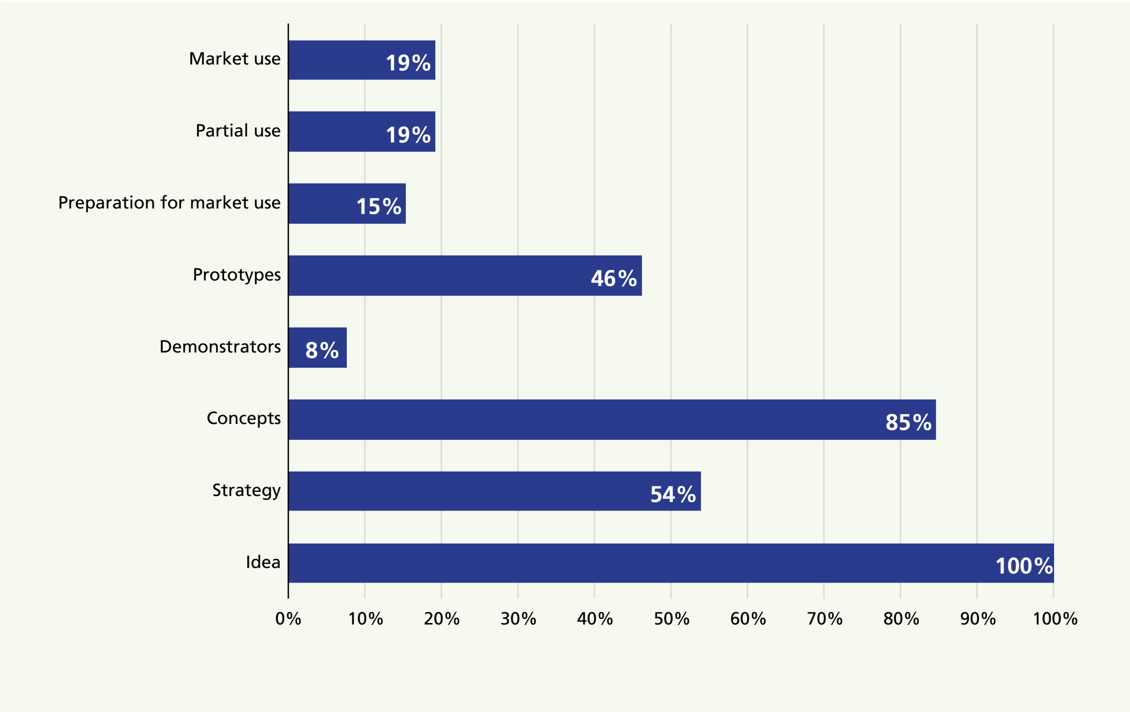


Figure 22: Assessed readiness of the state of use of Digital Twins

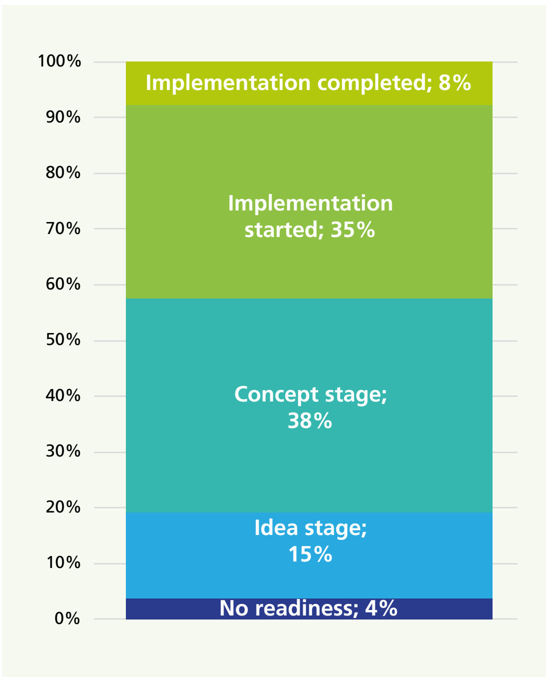
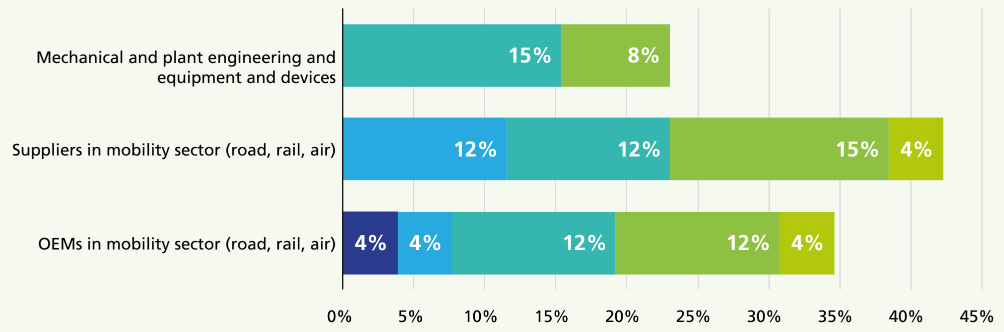


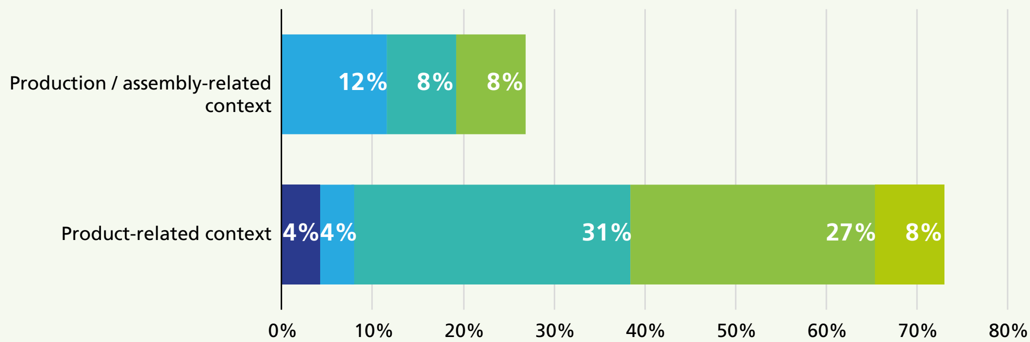
Figure 23: Assessed readiness of the state of use of Digital Twins according to industry group



Legend for figure 23

- No readiness (0%)
- Idea stage (25%)
- Concept stage (50%)
- Implementation started (75%)
- Implementation has been completed (100%)

Figure 24: Assessed readiness of the state of use of Digital Twins according to type of system represented



Legend for figure 24

- No readiness (0%)
- Idea stage (25%)
- Concept stage (50%)
- Implementation started (75%)
- Implementation has been completed (100%)

Summary and conclusion

A large share of study participants have a good to very good level of prior knowledge of Digital Twins. A number already have experience with application and implementation. Many are already involved with research institutions or stakeholder groups. This is partly explained by the basic interest in Digital Twins that exists among the interviewees of this study. Indeed, none of the study participants report no prior knowledge of this topic.

Despite differences in content, definitions for Digital Twins vary less In their basic features than originally expected. Around 20% of companies state they have no uniform definition. There is broad agreement that the purpose of Digital Twins is, in most cases, to provide a digital representation of a product. Equally, almost all the interviewees recognize the importance of data from the field – the digital shadow – as an elementary feature of Digital Twins.

Although feedback-to-design was frequently mentioned in the course of this study, surprisingly few companies make any reference to digital master data. It is also striking that the tasks to be performed by Digital Twins are, by and large, simple in nature: the collection of information and the representation of current status are frequently named as key tasks. Contrary to expectations, the definitions submitted rarely refer to the intelligence of the Digital Twin or to a feedback of data to its physical counterpart. In this respect, comparatively few participants regard a Digital Twin as an enabler of services. Below, this study will consider the topic of business models and services in more detail. It shows that business models and services do indeed play a key role in specific concepts, despite the fact that the definitions submitted make little mention of them. This indicates a rather conservative view of Digital Twins.

According to companies' own assessment, a high proportion of Digital Twins are already in use. On closer inspection, however, not all of the concepts submitted actually meet the study's proposed definition of Digital Twins. And contrary to companies' own assessment, not all projects are already in operative use. This reveals differing interpretations of the concept of a Digital Twin. Frequently, what are being described as Digital Twins are in fact highly detailed simulation models or condition-monitoring systems without any feedback to the actual system. All in all, a large number of concepts and prototypes have been developed.

Business models, strategic goals and added value

How do Digital Twins impact business models?
What added value should Digital Twins create?
How will the systems represented by Digital Twins need to change for this purpose?

35% **intend to change their business model with the implementation of a Digital Twin.**

27% **of the interviewees intend to introduce new products with the help of a Digital Twin.**

15% **anticipate no change to their business model.**

31% **hope to accelerate existing company processes with a Digital Twin.**

"To enable future areas of business, such as digital after-sales, we most certainly need a digital representation of all our physical products, both on the hardware and software level."

Felix Prischenk

"The added value of Digital Twins is a contentious issue in industry. This shows that while it is essential to consider economic factors when assessing digitalization, such factors are not sufficient on their own. Only the experience with established systems can tell us whether there is value in being able to agglomerate data and present it in a way simplified for human perception."

Katja Räntzsch

Business models, strategic goals and added value

A variety of expectations, strategies, potential benefits and hopes of new value creation drive the planning and implementation of Digital Twins. This chapter investigates the strategies that drive the introduction of Digital Twins at the companies interviewed and the changes to their business model they expect or hope to see as a result of this. The specific benefits they expect in the area of use is also queried. Additionally, the way in which the physical counterpart to the Digital Twin – e.g., the product, process or system – will have to change in order to accommodate that Digital Twin is explored.

The strategic goals of introducing Digital Twins

Generally speaking, the introduction of a Digital Twin is not an end in itself. It should always be in pursuit of a strategic goal. In this respect, the interviews revealed a mixed picture. In essence, it was clear that the interviewees are unable to consistently distinguish between specific benefits in the concrete area of use and the company's strategic goal in introducing a Digital Twin. The goal most frequently pursued by the interviewees (35%) is the development of new business models. Then comes a reduction in costs (31%), followed by simulations, virtual representations and validation of physical objects.

The responses provided can be grouped in the following clusters:

- Enhancing product or manufacturing quality
- Adding new product features and changing existing ones
- Increasing efficiency and effectiveness; optimizing processes
- Expanding or redesigning business models
- Reducing costs
- Increasing the degree of automation in value creation

Figure 25 shows the distribution of strategic goals in relation to the type of digitally represented system. This indicates that concepts in the context of production and assembly focus primarily on enhancing product and production quality and on reducing costs. The prime strategic goal of concepts designed to represent products is to enhance quality, add new product features, differentiate a product from that of competitors and increase efficiency. In all, 37% of companies pursuing a product-related concept are planning to develop new business models. By contrast, cost reduction (16%) and automation (16%) play a minor role. None of the companies pursuing a production-related concept names automation as a strategic goal.

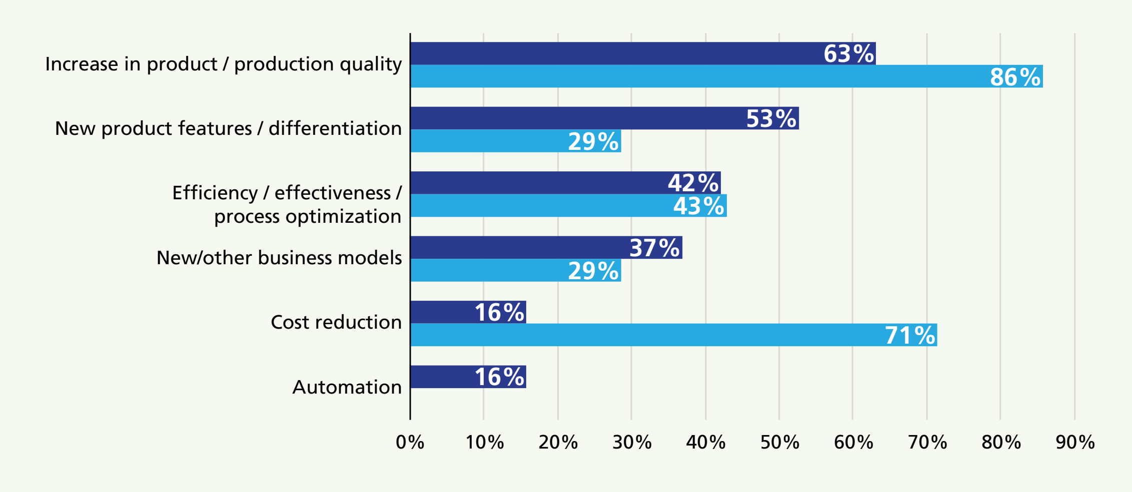
A breakdown according to industry group reveals further differences. By far the majority of OEMs in the mobility sector (89%) name quality enhancements for products and production as their prime strategic goal (cf. fig. 26).

This is also the most frequently named strategic goal for companies in sectors for mechanical and plant engineering and equipment technology (67%). Cost reduction also plays a significant role for 50% of companies in these sectors. For suppliers in the mobility sector, enhanced quality, added product features and increased efficiency are similarly important – each of these factors is named by 55% of the suppliers interviewed.

It is also possible to distinguish between strategic goals with an internal or external impact. Goals with an internal impact are primarily those that optimize processes within the company. This includes processes involved in value creation or in the provision of information for development or production. In the main, goals with an external impact refer to a product or its functionality – for example, in terms of quality or the range of functions. These differences are particularly evident when comparing the systems considered by the concept. In the case of product-related concepts, companies are much more likely to pursue external goals (84%) than they are with concepts in production/assembly-related contexts (43%; cf. fig. 27). Conversely, companies with Digital Twin concepts designed to represent production or assembly processes are more likely to pursue internal goals.

QUESTION *What strategic goals are companies pursuing in relation to Digital Twins?*

Figure 25: Strategic goals for the introduction of Digital Twins compared to type of system represented

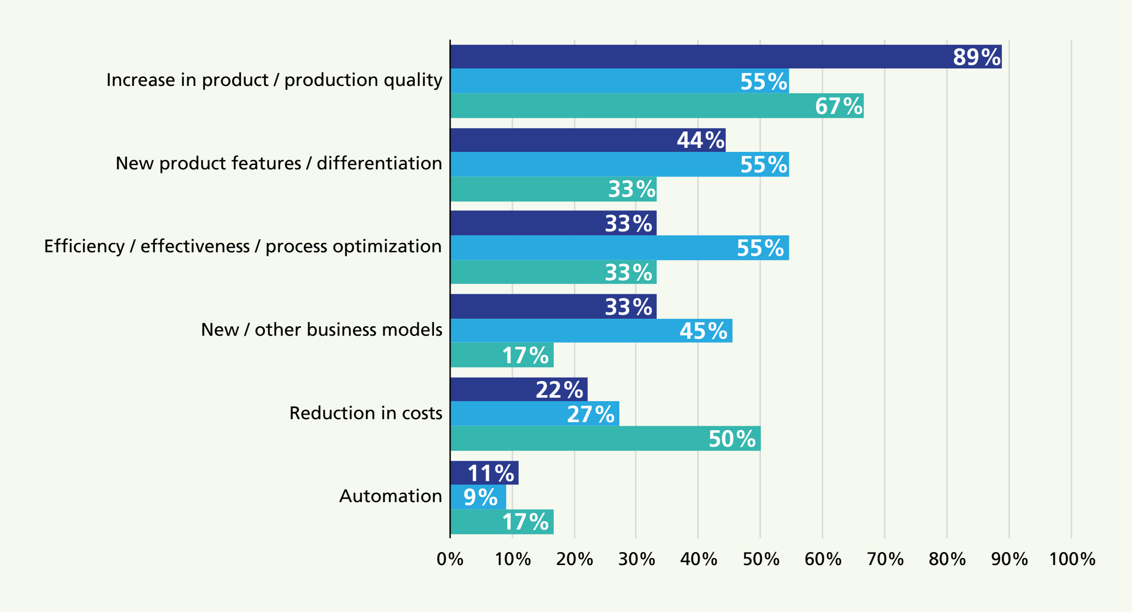


Legend for figure 25

Product context

Production / assembly context

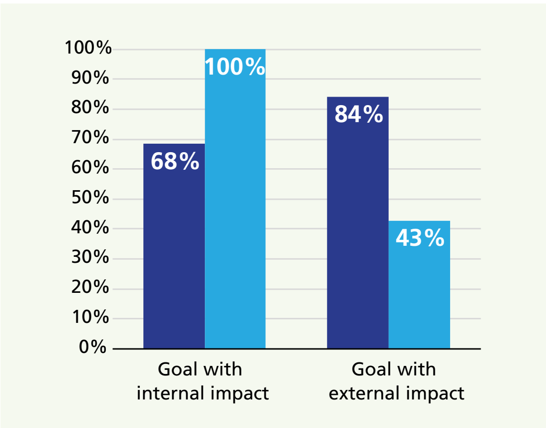
Figure 26: Strategic goals for the introduction of Digital Twins compared to industry group



Legend for figure 26

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Figure 27: Area of impact of strategic goals



Legend for figure 27

- Product context
- Production / assembly context

Changes to business models due to Digital Twins

Digital Twins will influence existing and future business models of companies in different ways. So far, however, there is no clear picture of what this will mean across different sectors. Digital Twins will either change existing business models or become an integral part of them. In some companies, they may not even result in any change – if, for example, they are used for purely internal purposes. When asked about strategic goals, some companies mentioned new business models (cf. fig. 26). However, in the industry group for mechanical and plant engineering and equipment technology, very few of the interviewees name a shift to alternative business models or the addition of new ones as a strategic goal (17% compared to 33% and 45% in the other two industry groups). Figure 28 shows how exactly business models will change. The expansion of business models and the sale of services are mentioned most frequently (each is named by 38%). Closer inspection reveals that the sale of services is a strategic goal pursued especially by companies that are developing Digital Twin concepts for products (47% compared to 14%). Over one-quarter of the interviewees (27%) express an intention to offer new products.

The interviewees were asked to rate the degree of change on a scale. This revealed a trend towards major changes (cf. fig. 29). Overall, 27% of the interviewees anticipate a complete change in their business model. Around 27% expect a shift in focus of their business model. Only a small proportion of the interviewees anticipate no change at all. A breakdown according to different industry group shows that companies in mechanical and plant engineering expect a shift in focus. Suppliers in the mobility sector expect either a complete change or a shift in focus. In the case of OEMs, the picture is split: 33% of the interviewees expect a complete change and 33% expect additions to their business model (cf. fig. 29).

QUESTION *How will business models be modified as a result of the introduction of Digital Twins?*

Figure 28: Changes in the business model

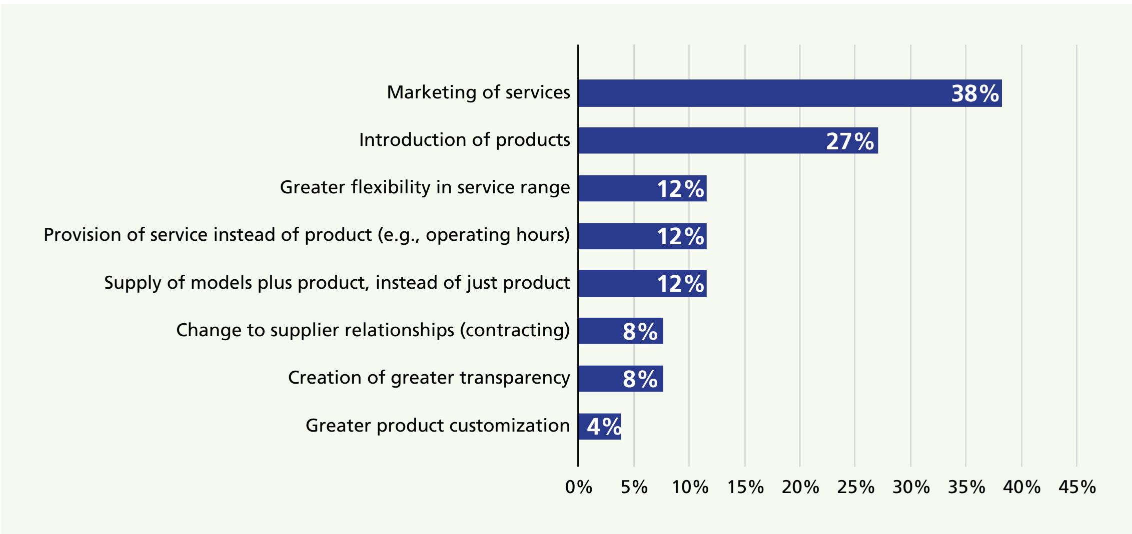
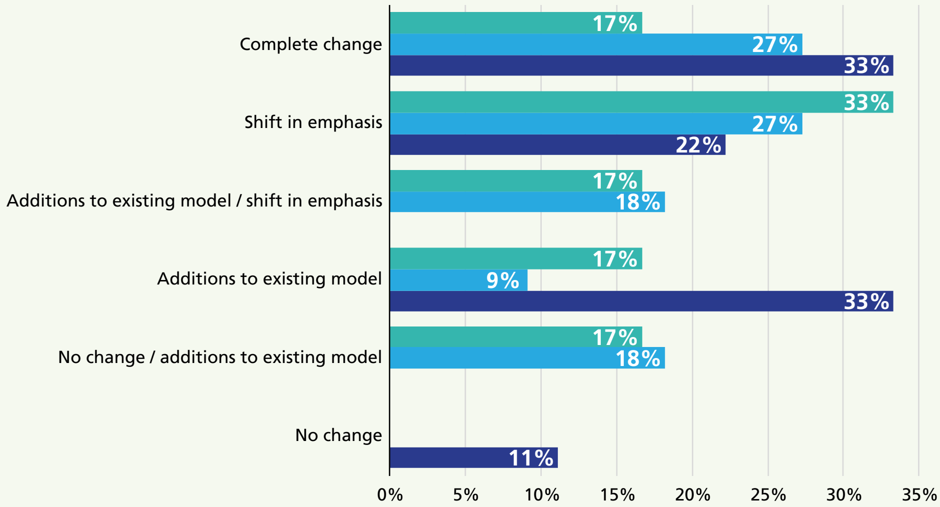


Figure 29: Degree of change in the business model according to industry group



Legend for figure 29

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Added value in the area of use

In addition to strategic goals, companies also expect that a Digital Twin will generate added value. This expectation is predominantly about being able to reduce the time required for a variety of processes (31%). In addition, some hope it will boost efficiency (27%) and reduce costs (27%). In all, 23% of the interviewees expect to gain better insight into a product, including its behavior in the field, features used, downtime periods and modes of operation. Similarly, 19% of the interviewees anticipate that an improved understanding of product use will enhance customer loyalty to the product system.

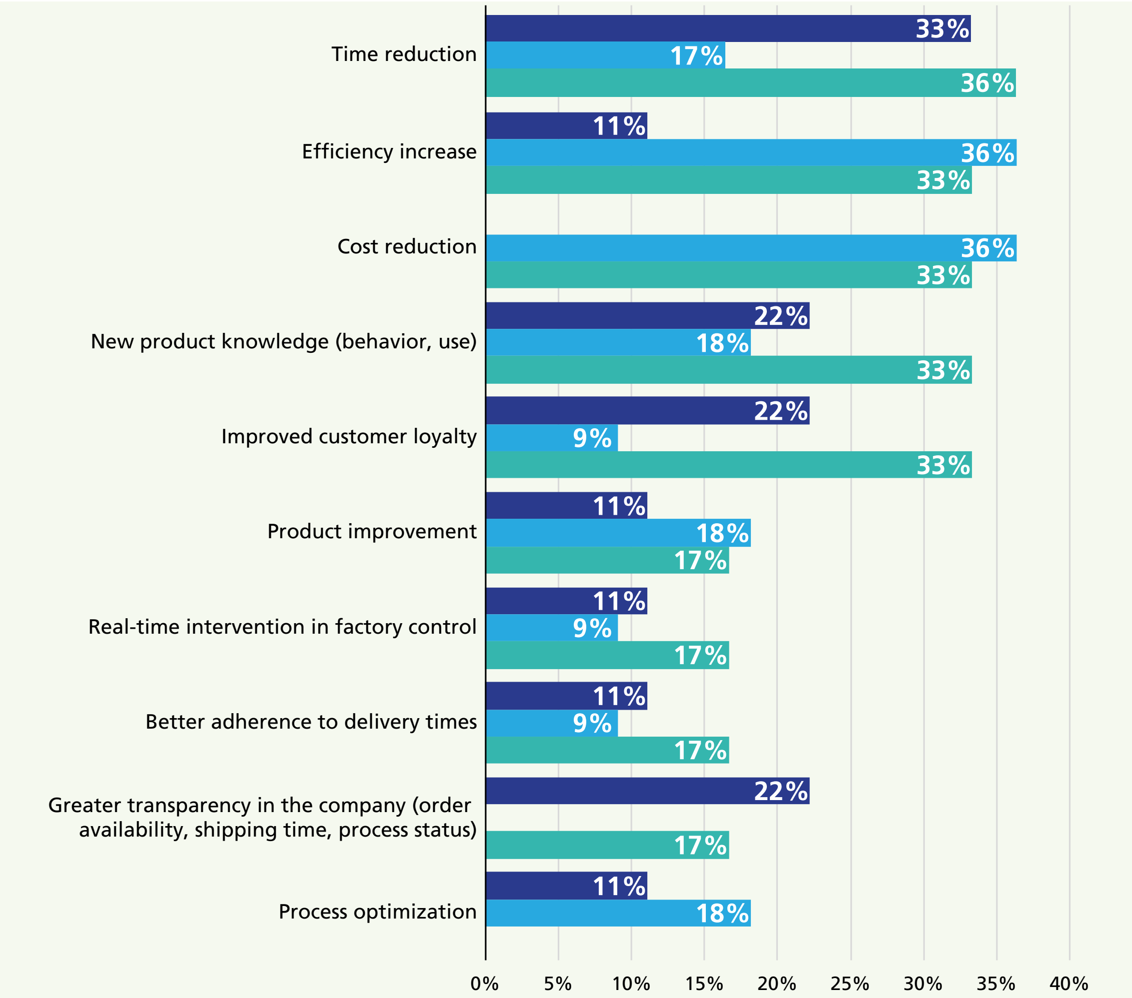
In addition to these most commonly expected benefits, the interviewees also mentioned the following points:

- Improved transparency and adherence to delivery times
- Optimized processes
- Enhanced internal and external cooperation
- Greater flexibility in production and increased automation

A breakdown according to industry group (cf. fig. 30) shows that OEMs and suppliers in the mobility sector primarily expect process improvements and greater efficiency. For companies in the sectors of mechanical and plant engineering and equipment technology, however, there is also a substantial expectation that Digital Twins will help them gain more knowledge. Unlike OEMs, suppliers in the mobility sector and machine and plant manufacturers also name cost reduction as an expected benefit.

QUESTION *What added value should Digital Twins generate?*

Figure 30: Expected benefits compared by industry group

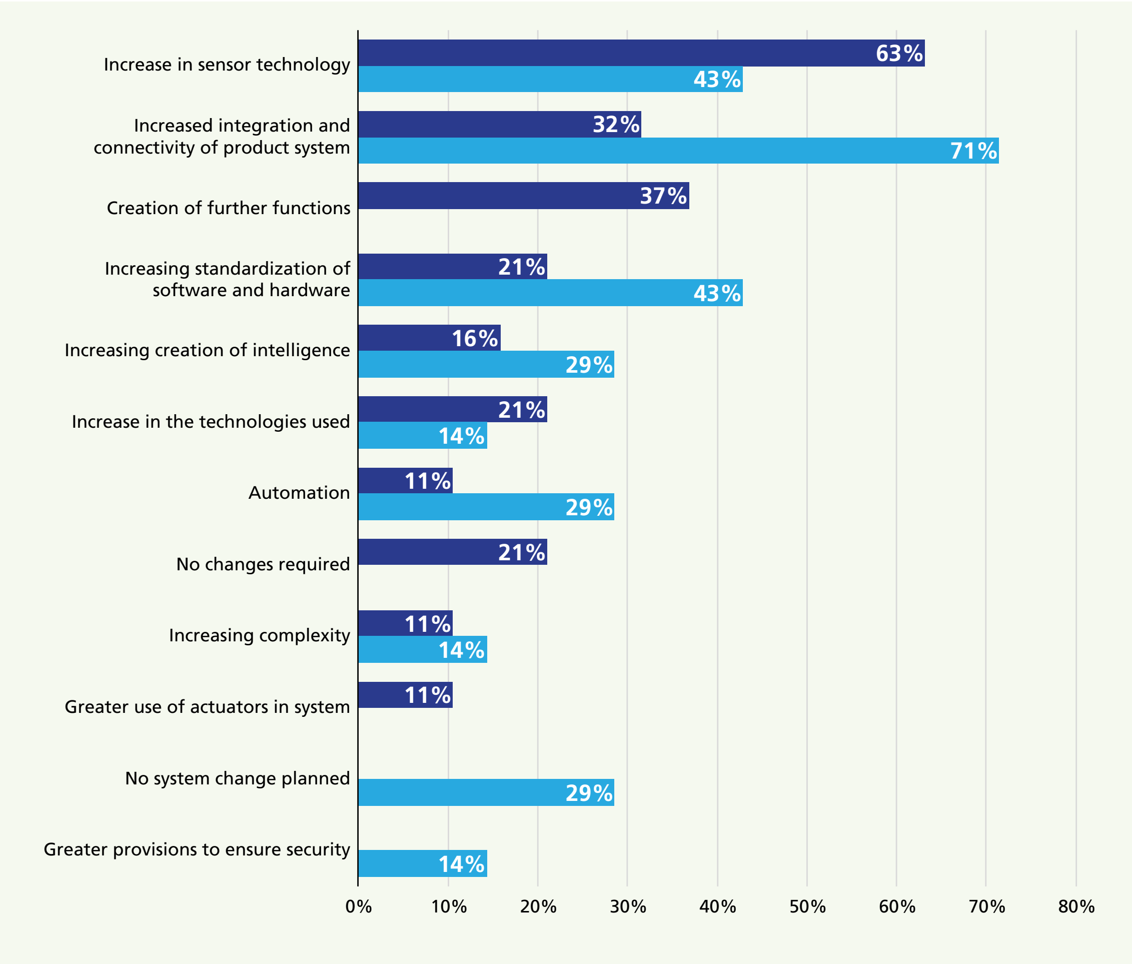


Legend for figure 30

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

QUESTION *How will systems change through the introduction of Digital Twins?*

Figure 31: Changes to product according to type of system represented by the Digital Twin



Legend for figure 31

Product context

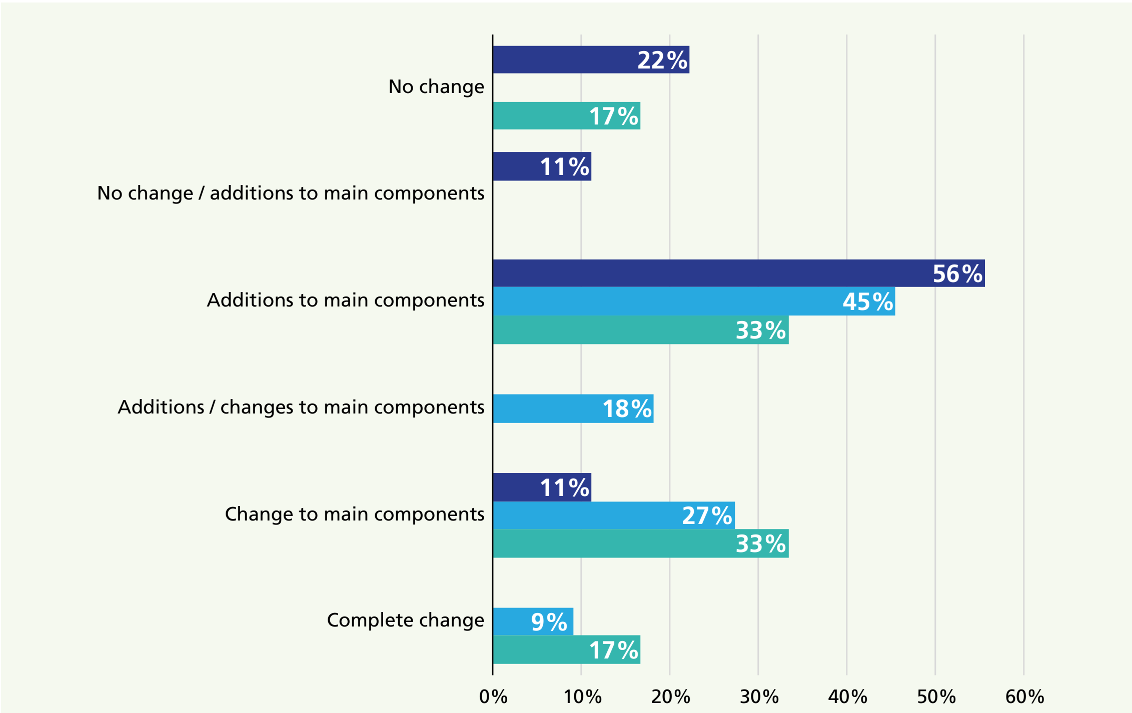
Production / assembly context

Changes to the product system

In order to achieve their strategic goals, companies will also be obliged to make some changes to the product or system represented by the Digital Twin. Figure 31 shows the type of changes that companies anticipate having to make. The most frequent assumption is that extra sensor technology will be added to the system. In addition, there will be a greater integration and connectivity of product systems. This is mentioned by a large proportion of the interviewees (71%) with concepts in production/assembly-related contexts. In the case of digital product twins, 37% of the interviewees see a coming need to add new and formerly nonexistent product functions. As per the interviews conducted, this is not relevant for concepts in production/assembly-related contexts. There are two principal reasons for this: machine and plant are already connected and controllable or companies are seeking to introduce manual processes of data transfer *(see "Digital Twin concepts" on page 64)*. For 43% of the interviewees with production-related concepts, standardization is a key feature. This view is also shared by 21% of the interviewees with product-related concepts. Other factors are greater intelligence in systems and the use of new technology. Automation plays a key role (29%) for concepts in production / assembly-related contexts.

When asked to qualify the degree of change on a scale ranging from "no system change" to "complete system change", OEMs in the mobility sector anticipate only minor changes or none at all (cf. fig. 32). By contrast, suppliers in the mobility sector and companies in sectors for mechanical and plant engineering and equipment technology expect bigger shifts such as changes to main components or even full-scale changes.

Figure 32: Degree of change to product / system according to industry group



Legend for figure 32

- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

Summary and conclusion

All in all, there are numerous hopes, expectations and strategies associated with Digital Twins in terms of new business models. As the study shows, the topic of Digital Twins highlights the challenges that already exist in the development environment (e.g., data consistency, efficiency, information availability). These issues are typically addressed as part of the implementation process of Digital Twins.

A large number of the interviewees, especially those in the mobility sector, intend to develop new business models. Here, there is an increasing focus on service-based offerings that can be provided as part of the Digital Twin environment. In addition, new products based on Digital Twins are being conceptualized. This will be accompanied by a growing flexibility in the range of services. Likewise, the marketing, rather than the sale, of services based on a product system and the marketing of models that describe systems will become an option for some companies. All these changes to business models are assessed as being major or even disruptive.

Other companies are pursuing strategic goals that have primarily an internal impact. For example, the interviewees here focus on reductions in cost, increases in efficiency and improvements in quality. In particular, improvements in quality will result from the feedback of information from the field and from simulation models that are progressively enhanced with field data. In general, it is evident that companies are pursuing strategic goals that have both an internal and an external impact.

A closer look at the added value that the interviewees expect from Digital Twins highlights once again the classic challenges in today's development environments – efficiency, data consistency, information availability and process optimization. Companies also expect to improve customer loyalty and increase their understanding of products to include networked systems and services. It can therefore be assumed that Digital Twins will change the development process in two ways: not only will Digital Twins be developed alongside products and systems, their use in development, production planning and production itself will also change the way of working.

For the implementation of product-related Digital Twin concepts, the introduction of data-collection technology (creation of a digital shadow) and communication systems (transfer of shadow data) as well as new functionality are expected. This view is also confirmed by the interviewees in this study. In addition, there is a recognition of the need for standardization. This is reflected in the expectation that Digital Twins will be able to cooperate and intercommunicate. The interviewees predict major changes to business models, but less so in the case of products. Predictions range from no change at all to additions to existing products and changes to main components.

A key challenge when implementing new business models based on Digital Twins is ensuring that data is provided from the use phase. But this can be particularly difficult for manufacturers of products in the B2C sector. By contrast, B2B manufacturers of the machinery and plant used in the production environment are already one step ahead here.

Digital Twin concepts

What functions do Digital Twins cover?
How are Digital Twins used and how do they get the data they require?
What technologies are used for Digital Twins?

73% of Digital Twin concepts are designed to represent product systems.

42% of the interviewees use Digital Twins in product development.

64% of the interviewees see data provision as one of the key functions of a Digital Twin.

36% of the interviewees still do not know how information is to be transferred from the physical system to the Digital Twin.

"Higher quality due to greater test depth, accelerated test results from high-performance computers and fewer test vehicles thanks to virtual resources – the Digital Twin will have a key impact on the entire product development process."

Matthias Schultalbers, Chief Digital Officer and Area Manager Powertrain Mechatronics at IAV

Digital Twins concepts

There are numerous expectations and strategies associated with Digital Twins. Equally, there are numerous approaches towards implementing Digital Twins. As a basic principle, Digital Twin concepts can be differentiated according to the systems they are designed to represent: There are Digital Twin concepts that are production-oriented and therefore intended primarily to represent production processes; and there are product-related concepts, which are designed to represent the behavior and features of product systems. In addition, Digital Twin concepts can be distinguished according to their use or application. This is particularly evident over the various phases of the product life cycle, where Digital Twins can be used to provide or collect information.

Similarly, the functions provided by a Digital Twin depend very much upon the benefits it is intended to deliver. Here, the range is almost limitless: from basic functions such as data provision, monitoring, analytics and notification to more complex tasks such as system control, representing product features for consumers and adaptive (learning) product systems. This study helps to develop a picture of how the interviewees intend to use their Digital Twin concept and explores how they intend to realize the potential benefits they envisage. In order to simplify concepts, the interviewees were asked to focus on the Digital Twin concept that was used as part of the survey.

The system represented by the Digital Twin

The interviewees could provide answers in either a product-related or a production-related context. Here, product-related concepts cover, in the main, entire product systems or components thereof. Production-related concepts refer not only to processes such as assembly and maintenance but also to entire production facilities, individual machinery, and plant and production lines. In the interview, 73% of the concepts examined refer to product twins. In other words, they describe Digital Twins that represent either products in their entirety or components thereof. The following are named as categories of information that might be represented by a Digital Twin:

- Status
- Performance
- Behavior
- Installed components
- Features and their use
- Geometry

The remaining 27% of the interviewees have Digital Twin concepts that focus on production/assembly-related scenarios (cf. fig. 33). Here, the following were specified as categories of information that might be represented by a Digital Twin:

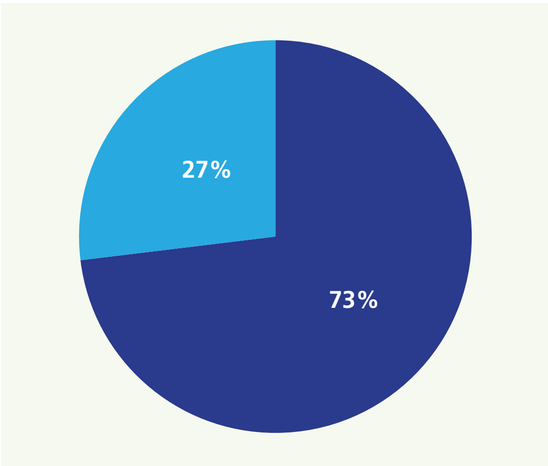
- Tolerances
- Control behavior
- Functions
- Kinematics
- Geometry
- Status
- Material flows
- Assembly status
- Key performance indicators

A breakdown according to industry group indicates further differences (see fig. 34). Of all industry groups, it is OEMs in the mobility sector that focus most clearly on Digital

Twins to represent their products – and, specifically, products as entire systems. This is understandable, since in the value chain it is OEMs that have the product overview. For suppliers in the mobility sector, the proportion is therefore lower. Here, Digital Twins are more likely to be used to represent their product components (36% of suppliers interviewed) or assembly and maintenance processes (36% of suppliers interviewed). Companies in sectors for mechanical and plant engineering and equipment technology use Digital Twins to represent entire products, subsystems and processes as well as individual machinery, plant and assembly processes.

QUESTION *Which type of system is represented by Digital Twins?*

Figure 33: Type of system represented by the Digital Twin

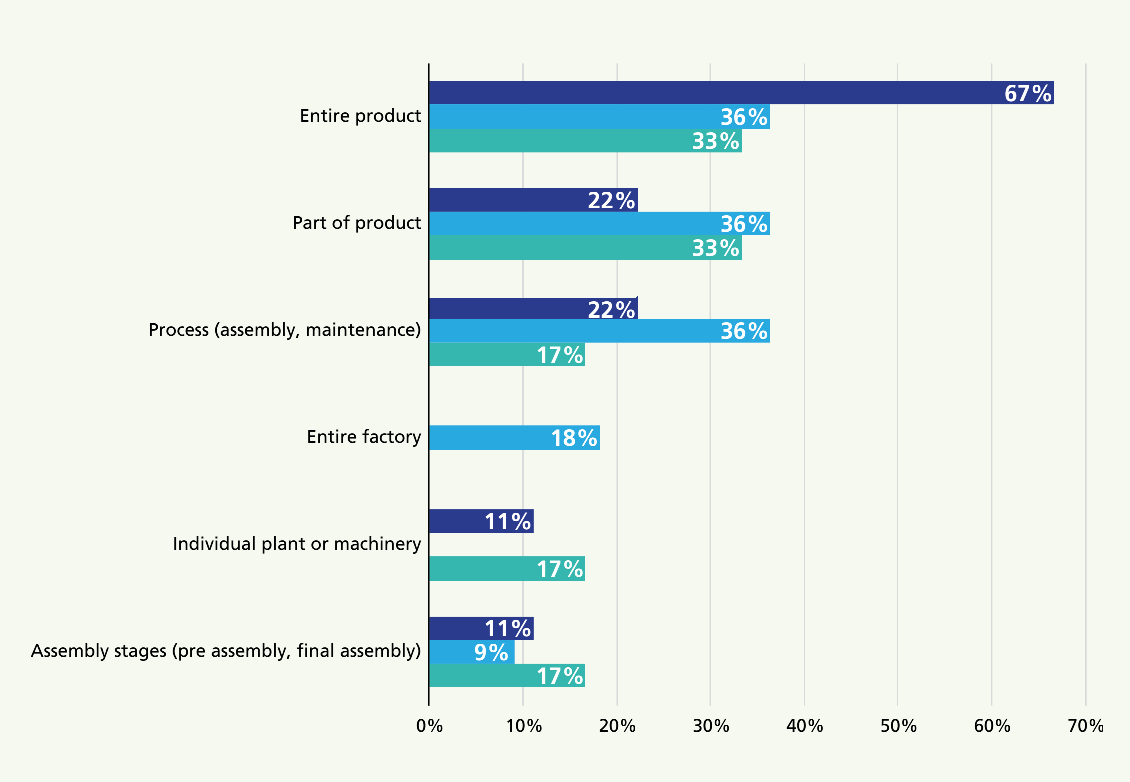


Legend for figure 33

Product context

Production / assembly context

Figure 34: Type of system represented by the Digital Twin according to industry group



Legend for figure 34

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Product life cycle phases

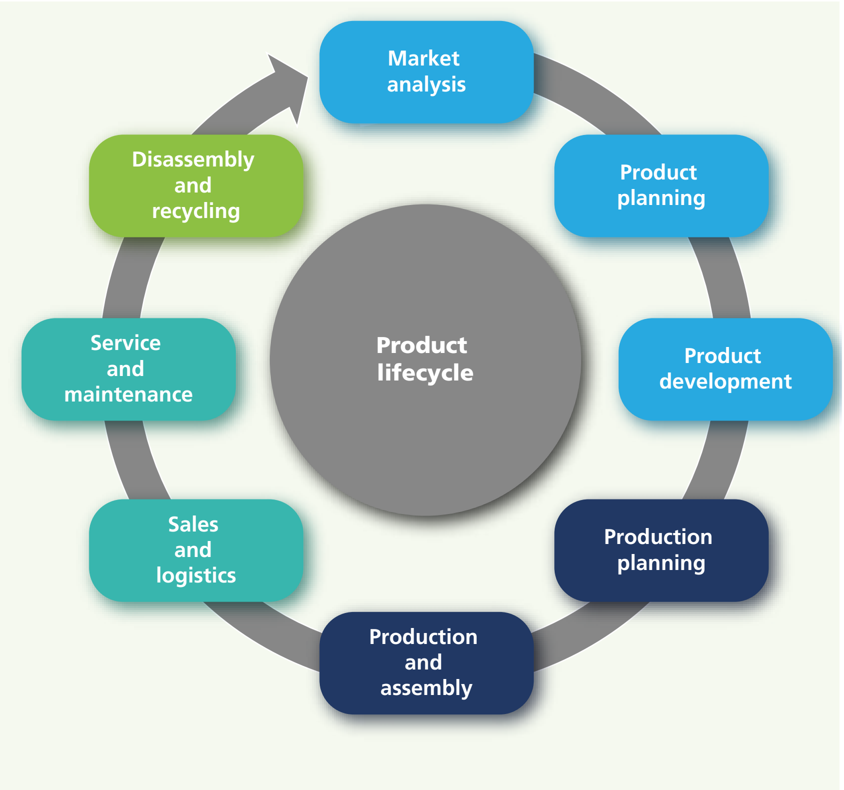
The strategic intentions of the interviewees are mirrored in the product life cycle phases that they focus on. Product twins, for example, collect data over several phases of the product life cycle and are therefore used in a wider context (cf. fig. 35). Here, the interviewees also specify early phases of the product life cycle and disassembly and recycling. In addition, product twins are also used in product development and service. By contrast, production twins are used primarily for production planning and for production and assembly. The main phases for the collection of master data are product planning and product development. Sales and use phases of Digital Twins are less relevant for this concept.

A comparison of industry groups (cf. fig. 36) indicates three key phases: product planning and product development; production; and operation. The final phase – disassembly and recycling – receives the least consideration.

OEMs in the mobility sector focus primarily on product development (89% of the interviewees reported this as relevant) as well as service, maintenance and operation (67%). Suppliers in the mobility sector focus on the areas of product planning, product development and production. Companies in sectors for mechanical and plant engineering tend to focus on product development, production, and service and maintenance.

In line with the definition presented above *(see "Definition" on page 20)*, Digital Twins

Figure 35: Product life cycle of the Digital Twin



Legend for figure 35

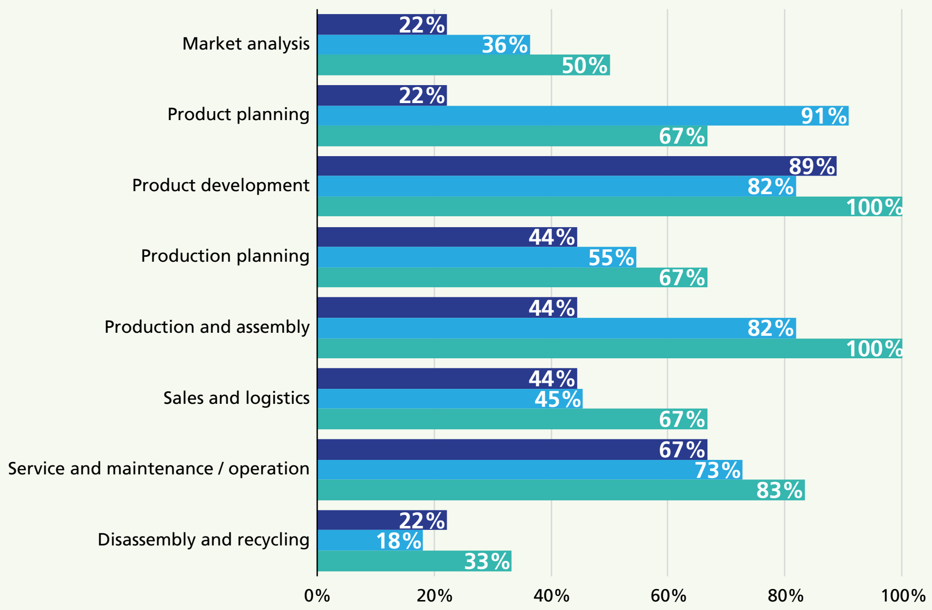
- Product planning and development
- Production planning and production
- Use phase and services
- End-of-life phase

contain data – in the form of a digital master and digital shadow – and algorithms for generating added value. The interviews show that the digital master is created in the course of product development and planning, and that the digital shadow is created during production (through enrichment with production information such as quality data) and also during use (data on use, data from sensors and data from the field). This picture is also reflected in the interview responses (cf. fig. 37).

In all, 46% of the interviewees state that the digital master is generated essentially during product development. In the case of other concepts – in particular, production twins – the key phase here is that of production planning. Data for the digital shadow is provided primarily during the phases of production and assembly, service and maintenance, and operation. Digital Twins are used over the entire product life cycle and, in particular, during the phases of product development (42% of the interviewees mentioned this) and operation (27%). Other phases here include market analysis, product planning and sales.

QUESTION *Which life cycle phases are covered by Digital Twin concepts?*

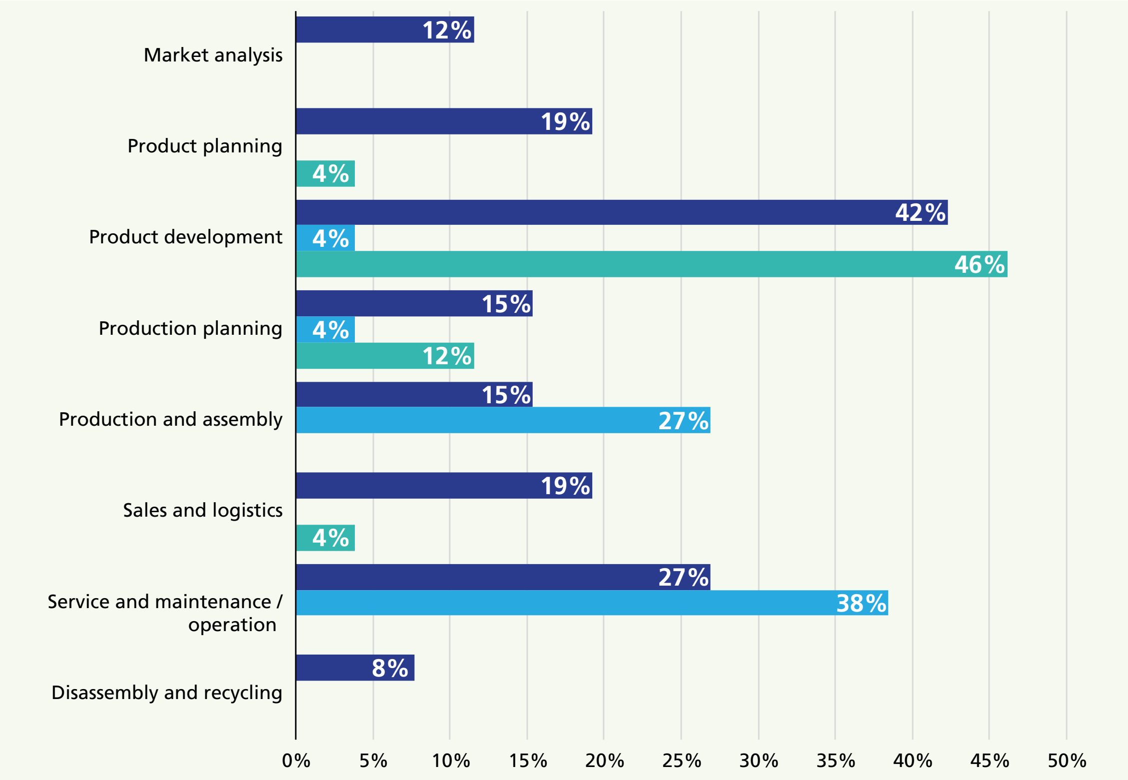
Figure 36: Life cycle phases taken into consideration according to industry group



Legend for figure 36

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Figure 37: Life cycle phases taken into consideration according to key components or elements of the Digital Twin



Legend for figure 37

- Use of the Digital Twin
- Provision of the Digital Shadow
- Generation of the Digital Master

Digital Twin functions

The basic concept of Digital Twins covers a multitude of possible functions. The interviewees' expectations in this regard are equally diverse. By grouping these diverse functions into clusters, we obtain the picture shown in figure 38.

Here, the primary function of Digital Twins is data provision and validation – two tasks for which the use of Digital Twins is ideally suited. A Digital Twin can be used to collect data over the entire product life cycle. It is therefore a rich source of, in particular, production and field data. In turn, the data collected by a Digital Twin can be used to optimize products – e.g., validation of product behavior, a product's manufacturability or customer functionality. This is the result of, on the one hand, the improved availability of data and, on the other, the use of simulations based on field data.

Fault analysis is used, in particular, for products in the field. The aim here is to use system data to identify a product's status and the cause of a fault without the need for anyone to be physically on-site. An increase in utilization and efficiency is based on the expectation that Digital Twins will provide a more accurate picture of products in the field. This also means that machinery can be run more precisely within its operating parameters, depending on the actual load conditions.

In the area of planning, the idea is to have Digital Twins automatically plan production processes. Prediction or forecasting refers to the use of operating data to identify the need for maintenance. Adaptive product systems, which are able to adapt according to their actual operating environment, also rely on operating data. In fact, some of the interviewees say the function of a Digital Twin should be to represent the real in its entirety. Given the cost and effort required, they do recognize that this would be an extremely ambitious goal.

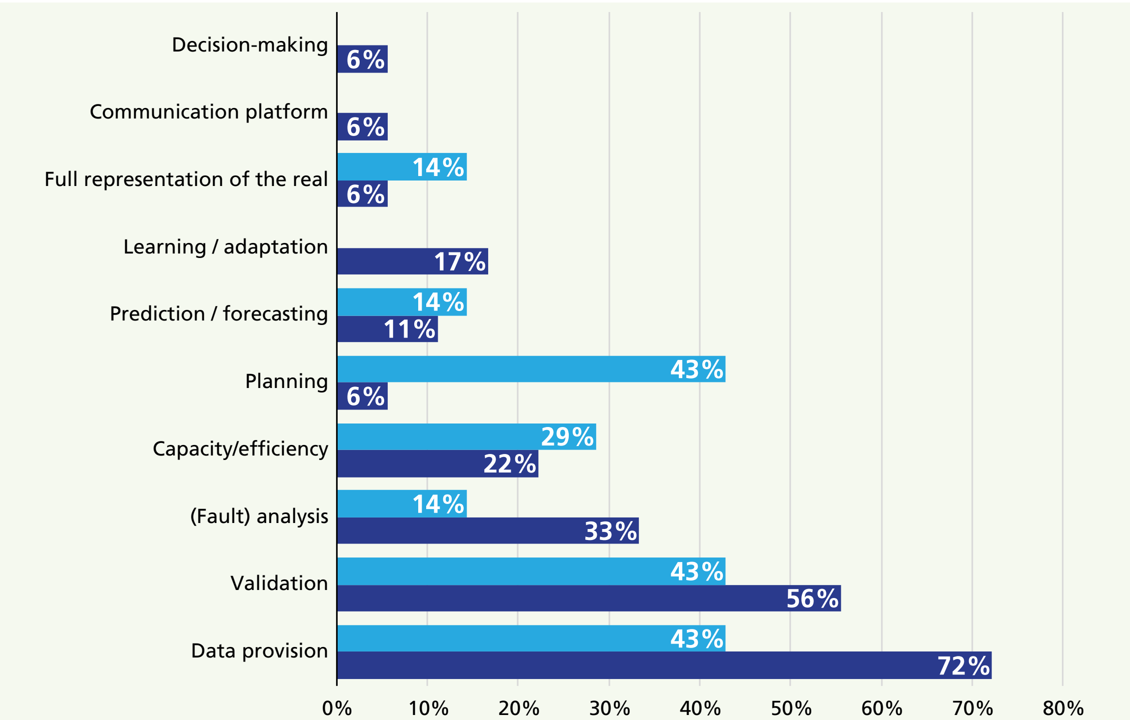
A breakdown according to the type of system represented by a Digital Twin shows that product twins are to be primarily used for the purposes of data provision and validation. In addition to providing these two functions, production twins are also to be used for planning purposes and to increase efficiency. In comparison with product twins, however, fault analysis plays only a minor role here.

There are numerous ways of realizing the envisaged functions; these can be classified as follows (cf. fig. 39):

- Data analysis
- Automation of functions
- Correlation of information
- Simulation of system behavior
- Data exchange between systems
- Product control via a Digital Twin
- Installation of additional sensors

QUESTION *What functions do Digital Twins perform?*

Figure 38: Functions of the Digital Twin



Legend for figure 38

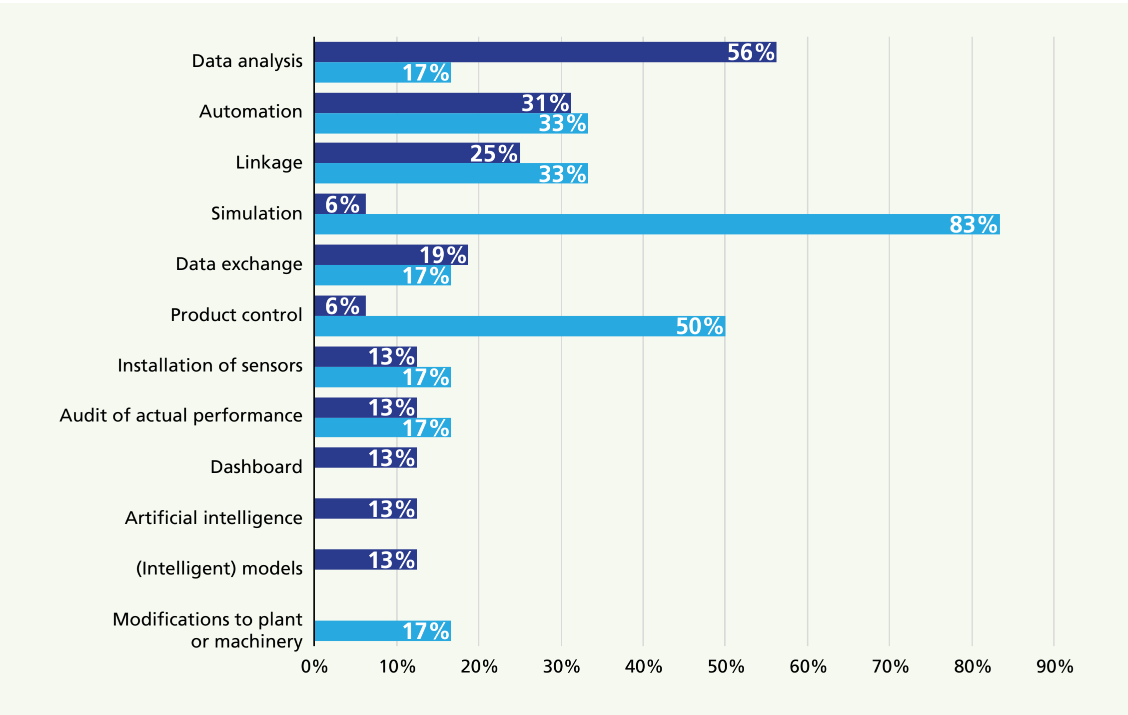
Product context Production / assembly context

- Updating of virtual models on the basis of field data
- Presentation of information in a dashboard
- Use of artificial intelligence
- Creation of adaptive (intelligent) models

Among the interviewees, data analysis is the method of choice for implementing the envisaged functions. This is followed by automation and data correlation, both of which are also frequently mentioned. A comparison of system type shows that whereas product twins make big use of data analysis, production twins focus more on simulation (83% of the interviewees name this method). Similarly, production twins are much more likely to be used for control proposes (50% compared to 6%). The updating of virtual models and the installation of sensors are equally important tasks. However, dashboards and artificial intelligence are only mentioned in connection with Digital Twin concepts designed to represent production systems.

QUESTION *How are the envisaged functions implemented?*

Figure 39: Methods to implement the functions of the Digital Twin



Legend for figure 39

Product context   Production / assembly context

System properties represented by Digital Twins

In order to implement the envisaged functions, a range of system properties must be represented by the Digital Twin – typically, within the digital master. There is a high variance here. In many cases, this is due to the fact that the digital master is based on the Digital Twin concept and therefore has an extremely specific design. By far the most commonly named property to be represented is that of the geometry of the product system (60% of the interviewees). This is surprising inasmuch as it is not absolutely necessary for many of the envisaged concepts. When evaluating field data, for example, a behavioral model is often more useful than a geometric one.

On the other hand, geometric models are already available from, for example, the development or planning phase. A breakdown according to industry group reveals that many companies in sectors for mechanical and plant engineering and equipment technology are interested in being able to digitally represent kinematics and system control functions (50% of the interviewees from this industry group mentioned this; cf. fig. 40).

Data on product behavior and environment is also relevant, especially to suppliers in the mobility sector. In practice, however, this can pose a challenge, since suppliers often lack access to their systems during actual operation. In addition to the system properties specified above, the following categories of data are also named:

- Operating data
- Simulations
- Performance data
- Customer data
- Components/parts list
- All data should be recorded (nonspecific)
- Planning data
- Functionality data
- Company data
- Order data
- Logistics data
- Human data
- System models

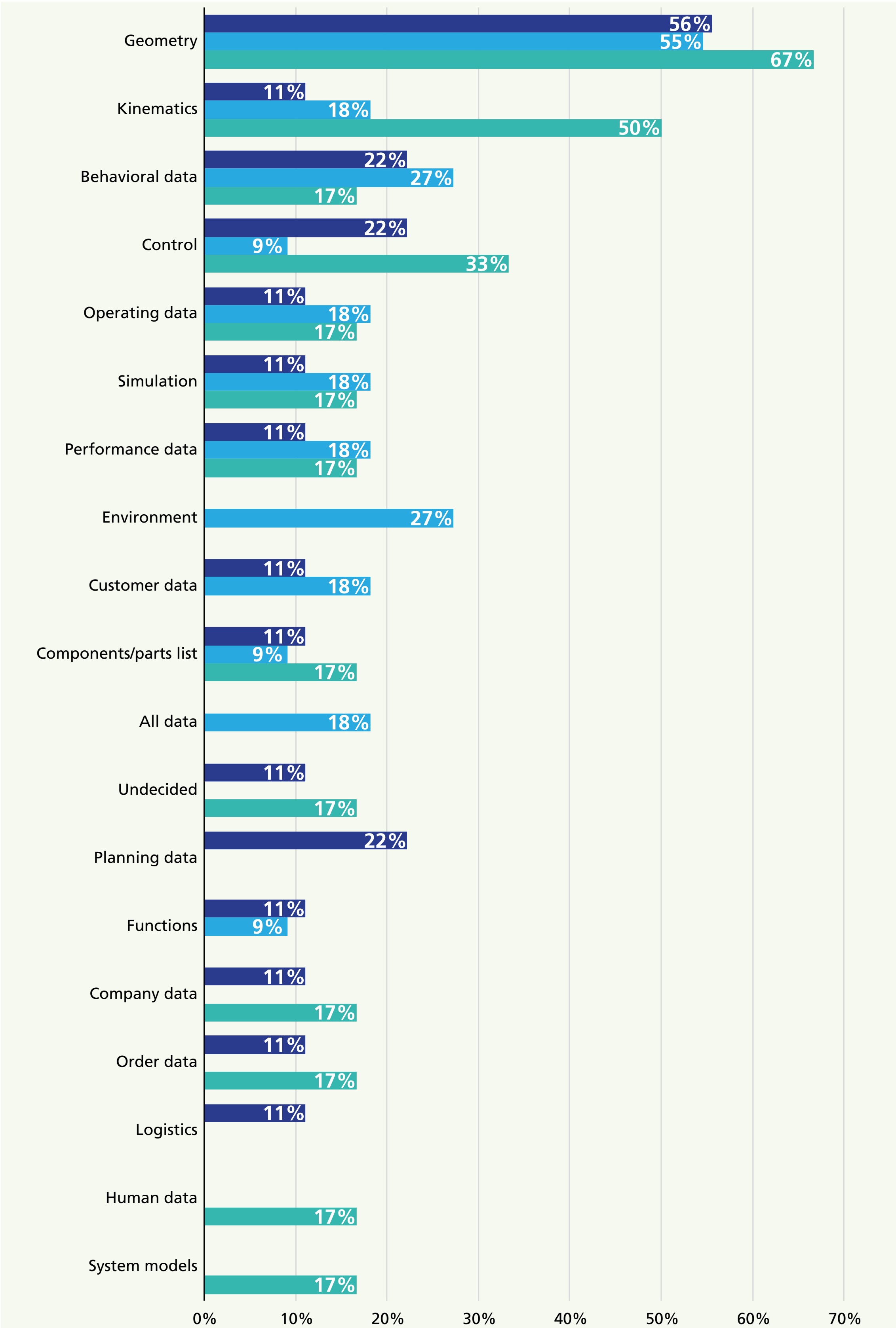
A breakdown of relevant system properties according to the mean readiness of concepts delivers the picture illustrated in figure 41. Two feature are striking here: Digital Twin concepts involving logistics data display a high level of readiness, whereas those that are supposed to represent all product properties display a very low level of readiness. The latter are extremely ambitious in scope. On average, they display a level of readiness even lower than that of concepts that are as yet unclear as to which system properties they should represent.

QUESTION *What system properties are represented by Digital Twins?*

Legend for figure 40

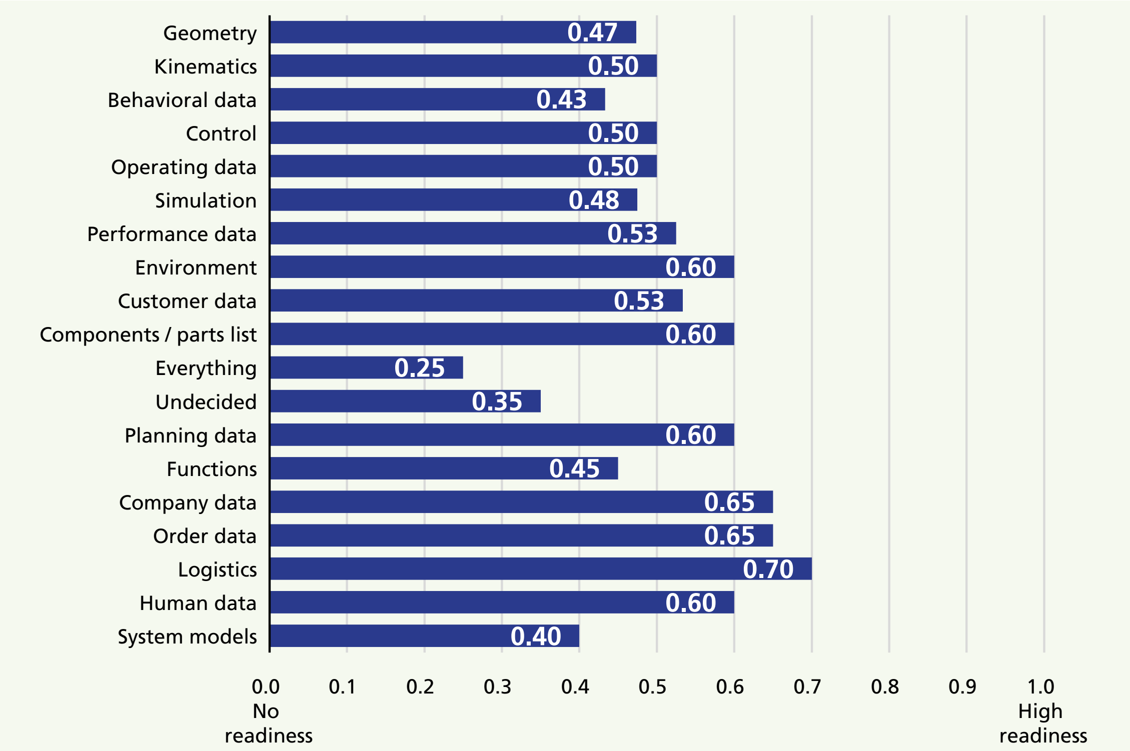
- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

Figure 40: System properties represented by Digital Twins according to industry group



Legend on page 74

Figure 41: Impact on assessed concept readiness according to system properties represented by Digital Twins



Information exchange, simulation and interaction

A Digital Twin concept always requires a provision of data for the digital shadow. A variety of methods can be used for the purposes of data exchange. An overview of the responses supplied to this question is presented in figure 42. For most companies in the mobility sector – particularly suppliers – there is still uncertainty as to how information should be exchanged or how regularly this should occur.

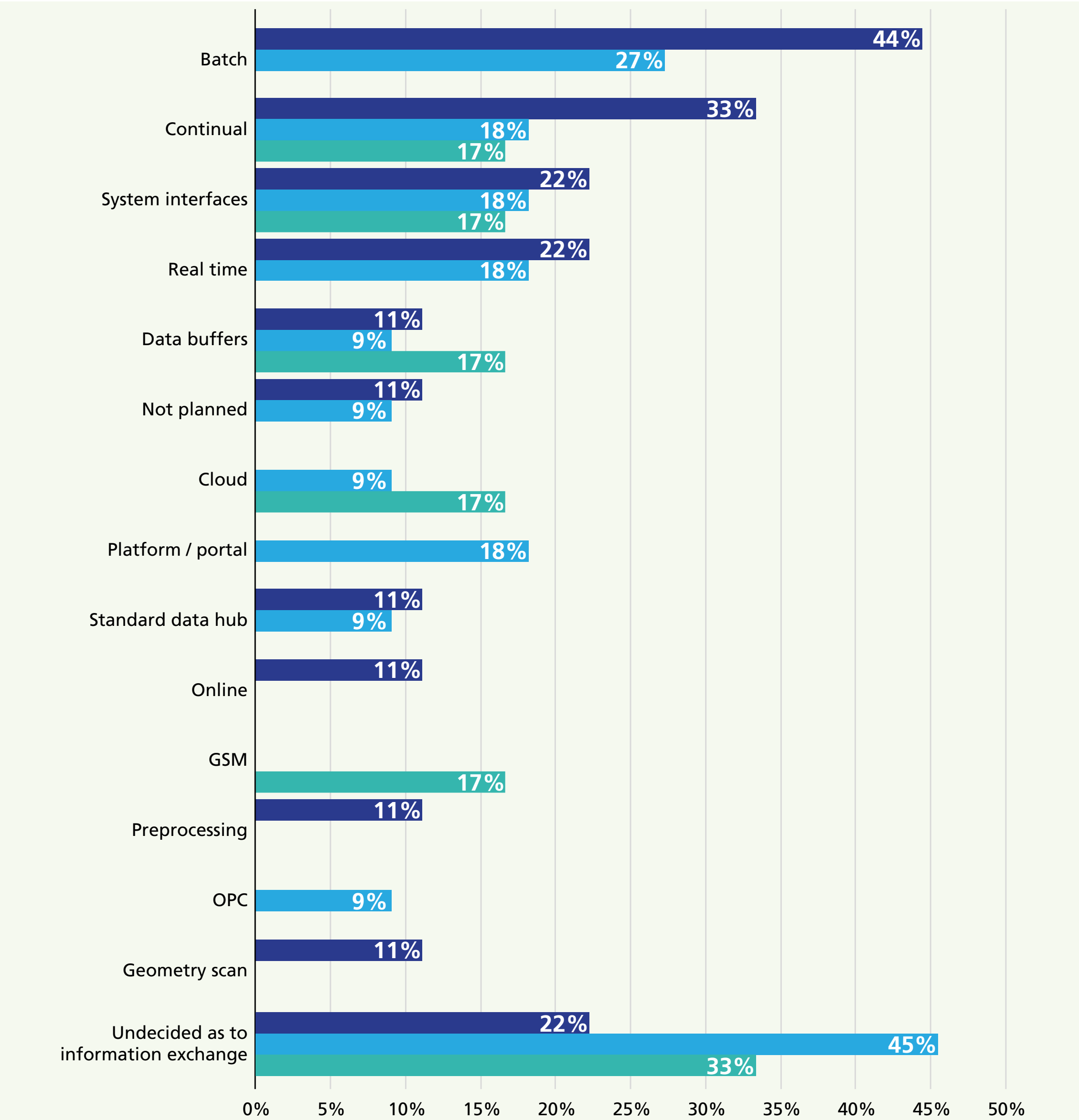
Batch transfer of data as required was the method most frequently mentioned (28%). Some companies are planning to continually exchange data (i.e., at regular intervals; 24%) or exchange data in real time (16%). To enable this, systems will require suitable interfaces (20%) and data buffers (12%). The interviewees with a concept that does not fully meet the definition of a Digital Twin do not envisage any data exchange at all. With regard to appropriate technologies for data exchange, the interviewees are still unsure In a few cases, GSM (Global System for Mobile Communications) and OPC (Open Platform Communications) are mentioned. Here, however, key trends have yet to emerge. A number of the interviewees are planning to use cloud systems or standard data hubs for the purposes of data exchange (8%).

A breakdown according to industry group reveals that for OEMs in the mobility sector, secure data transfer is a higher priority than in other groups. Companies in this group tend to favor batch processes and continual data transfer.

For companies in sectors for mechanical and plant engineering and equipment technology, data transfer in real time does not play a role. It would therefore seem that when Digital Twins are to be used for control purposes – as is frequently the case – they are to undertake higher, coordinative tasks rather than being directly linked to a system. In other words, individual machinery and plant are probably controlled by local systems, whereas Digital Twins are used to orchestrate production as a whole.

QUESTION *How is information exchanged between product systems and Digital Twins?*

Figure 42: Information exchange between Digital Twins and the represented system according to industry group



Legend for figure 42

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

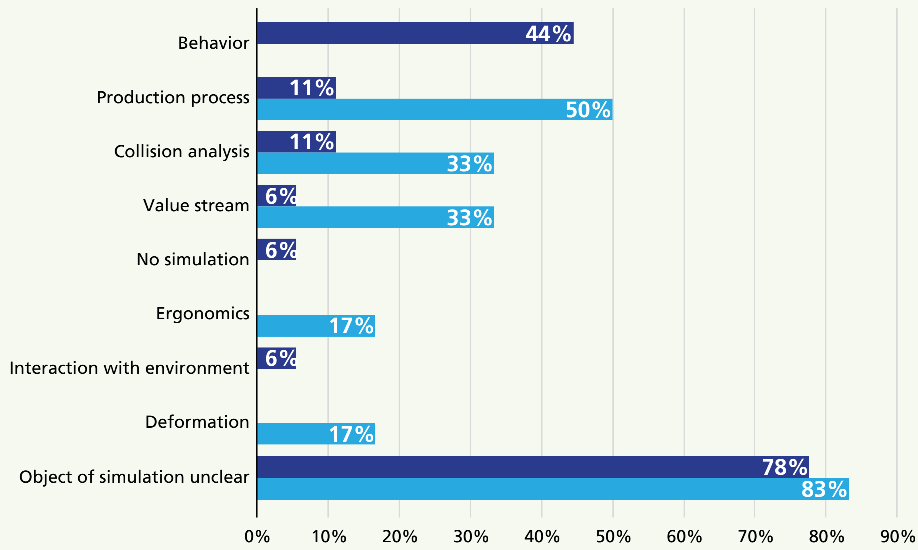
Simulation plays a key role in many concepts. This was also confirmed by the interviewees. In the case of both production twins (83%) and product twins (78%), however, it is not yet clear what exactly they should be simulating (cf. fig. 43).

In areas where security is already high, the interviewees favor using product twins to simulate behavioral aspects. In the case of production twins, the aim is to use them primarily for simulating production processes. Other intended uses include simulations of system geometry and of value streams. In a few cases, companies intend to use Digital Twins to simulate ergonomics and to model deformation processes.

There is also the further question as to whether a Digital Twin is to have a human and/or machine interaction. The answers here deliver a relatively clear picture (cf. fig. 44). In most cases, the concept envisages a human interface to the Digital Twin (80%). In addition, 44% of the interviewees also see the need for machine interfaces. For 12% of the interviewees, it is not yet clear what kind of interface will be required.

QUESTION *What kind of simulations are performed by Digital Twins?*

Figure 43: Type of simulation performed by Digital Twins



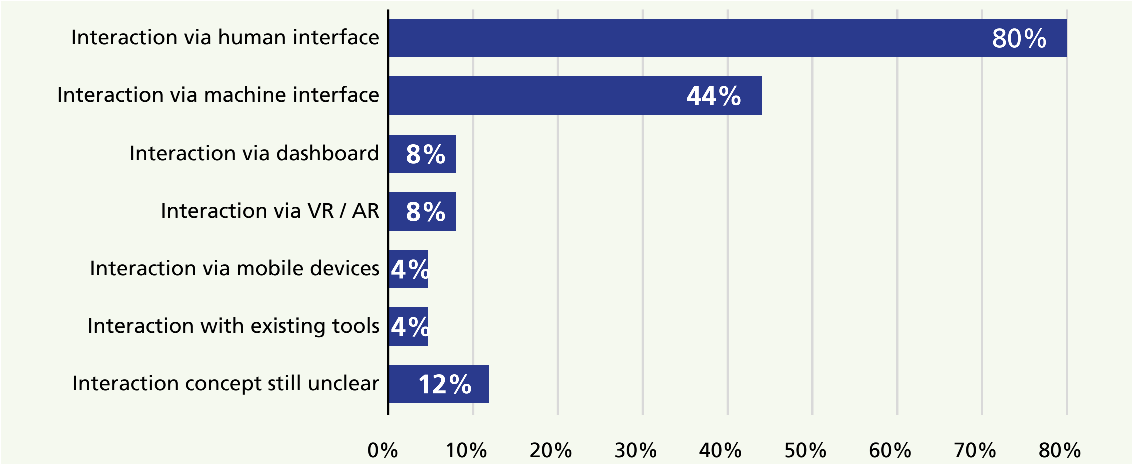
Legend for figure 43

Product context

Production / assembly context

QUESTION *What forms of interaction are envisaged with Digital Twins?*

Figure 44: Interaction with Digital Twins



Laws and regulations in the context of Digital Twins

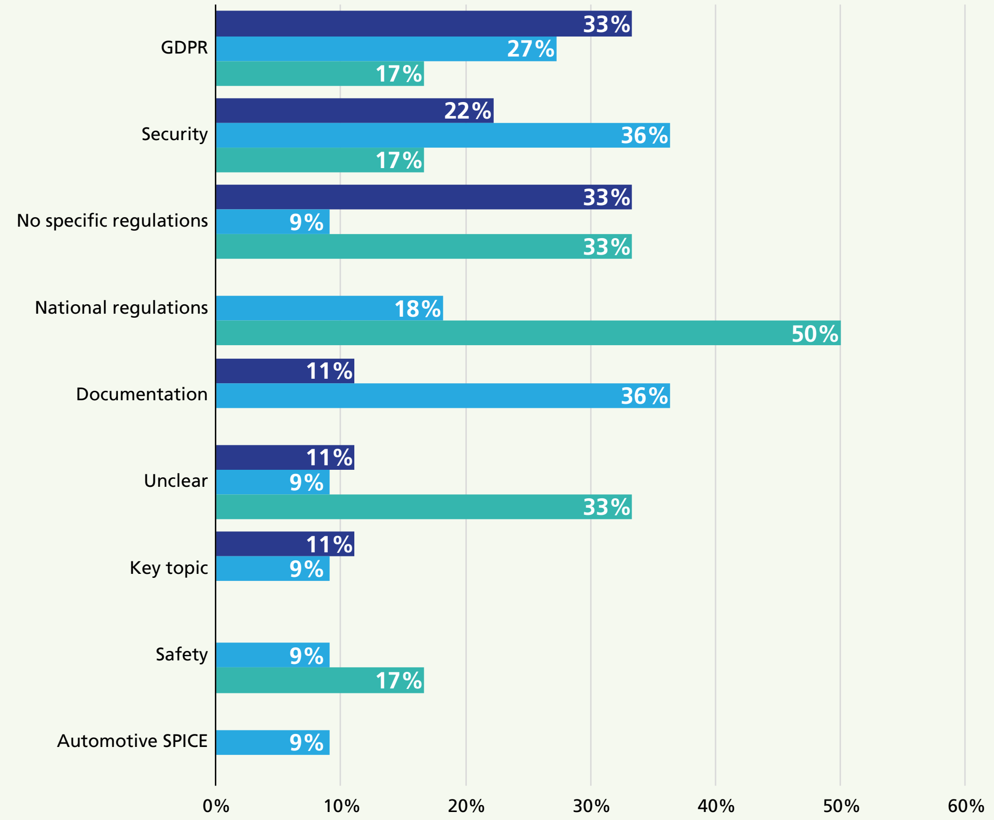
Digital Twins not only collect a huge amount of data. In some cases, they also actively make decisions or form part of a system to control machinery or products. The question therefore arises as to the applicability of existing laws and regulations. Here, there are some clear differences between industry groups (cf. fig. 45).

The General Data Protection Regulation (GDPR) plays a significant role in all groups (28%). The same is true for IT security (28%). For 24% of the interviewees, there are no particular regulations.

For suppliers in the mobility sector, data security during transmission is a key issue; for companies in sectors for mechanical and plant engineering and equipment technology, national regulations are crucial. Here, in particular, it is still unclear which guidelines should be followed, partly because they are still being drawn up.

QUESTION *What laws and regulations must be considered in relation to Digital Twins?*

Figure 45: Laws and regulations said to impact Digital Twins according to industry group



Legend for figure 45

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Summary and conclusion

The interviewees associate a variety of strategic goals and future business models with their Digital Twin concept. The methods they describe to realize these strategic goals are also diverse. These concepts focus primarily on the realization of added value in the areas of product development, production and system operation.

A significantly higher proportion of the interviewees are looking to set up product twins rather than production twins. Such concepts refer not only to products as total systems but also to individual components. Given that supply chains are usually extensive, with know-how equally spread out, it seems likely that individual product systems will feature a combination of many Digital Twins.

The digital master is created primarily during product development but also during production planning. The digital shadow is generated essentially during system operation but also during production and assembly. The functions provided by Digital Twins find greatest application during the phases of product development and operation. They also impact other phases of the product life cycle, except for disassembly and/or recycling, which are barely mentioned.

According to the concepts submitted, Digital Twins are to be used primarily to provide data for the purposes of validation and fault analysis. However, this is at odds with the strategies initially described. Although these strategies refer to new product features, the latter are barely reflected in the actual functions provided by Digital Twins. This might be down to the interviewees drawing a distinction between product features and Digital Twins or to a continuing uncertainty as to how such product features are to be implemented by means of a Digital Twin.

In the first instance, data analysis and automation are the methods of choice for realizing the envisaged functions of Digital Twins. In the case of production twins, simulation also plays a key role. Here, the intention is mainly to simulate production processes. In the case of product twins, the focus is on the simulation of behavior. Although most of the interviewees intend to use Digital Twins for simulation purposes, they are largely still unclear as to what should be simulated.

An examination of the kind of models found in the digital master indicates that geometric models predominate, followed by kinematic models and behavioral data. There is still uncertainty as to how information should be exchanged between a Digital Twin and the product. A substantial group of the interviewees favor batch methods or continual data exchange.

Of all the laws and regulations governing concepts, GDPR is the most significant. This is followed by regulations governing the security of data exchange and by national regulations. In many sectors, especially mechanical and plant engineering, there are still no regulations or guidelines on how to develop Digital Twin concepts.

Implementation measures and required skills

What measures are required for the implementation of Digital Twins?
What skills and capabilities are required for the implementation of Digital Twins?

85% of the interviewees expect changes in company organization due to the implementation of Digital Twins.

44% say it is unclear what new responsibilities will result from changes to business and development processes.

24% are relying on an internal IT solution for Digital Twin implementation.

72% of the interviewees anticipate requiring additional IT skills for Digital Twin implementation.

50% of the interviewees anticipate requiring additional employees for Digital Twin implementation.

"In principle, there are millions of possible manifestations of Digital Twins, but so far these have only been implemented as prototypes. Only an incremental implementation in terms of minimum viable products (MVPs), followed by operational use and continuous improvement to these implementations, will enable us to realize our (individual) vision of a Digital Twin."

Sebastian Neumeyer

"Open-source software plays a key role for us."

Christian Kindl, BHS Corrugated Maschinen- und Anlagenbau GmbH

Implementation measures and required skills

The implementation of the planned concept is another challenge companies face in addition to the actual development of Digital twins. It is therefore important to consider all the relevant factors in the development environment, as presented in the section on implementation in the company *(see "Implementation in the company" on page 24)*. Processes and company organization have to be adapted to accommodate the development of the Digital Twin, its integration in product development and production planning, and also its operation and use. At the same time, systems also need to be developed and maintained to ensure that the Digital Twin is provided with the requisite information and can be properly operated. Lastly, the requisite data and information models need to be created, networked and managed. It is only then that value-creating activities can be reliably implemented and the envisaged benefits of the concept fully realized. In line with this logic, the examination of implementation readiness, as presented in the present chapter, is broken down into the following elements:

1. Organization and processes
   - Processes (process organization)
   - Organization (organizational structure)
   - Skills
2. Data and information models
   - Required models
   - Data management
3. IT systems
   - Required IT systems
   - Information exchange
   - Principle of data acquisition

Certain measures are required for the implementation of Digital Twins in companies. These were surveyed as part of the study. Given the current state of Digital Twin use *(see "Understanding and current use in industry" on page 42)*, not all the interviewees were able to make reliable statements on the degree of implementation at their company.

Processes and organization

The area of processes and organization describes the manner in which a company coordinates and manages its processes (process organization) and its organizational structure.

Processes (process organization)

According to the interviewees, it is primarily development processes (32%) and data-management processes (24%) that will be subject to changes (cf. fig. 46). In addition, production processes (16%) and customer processes (16%) are mentioned, as are quality-assurance processes (12%) and communication and planning (12%). Also mentioned are processes related to new business models and processes in maintenance and service. A few of the interviewees said that no changes to processes would be required. For the majority of the interviewees (44%), however, it is still unclear which processes will be required for implementation.

A breakdown of processes according to the department in which the interviewees work shows that 50% of the interviewees from development believe that data-management processes will be especially impacted by the implementation of a Digital Twin. Conversely, 56% of the interviewees from IT believe research and development processes will be especially impacted. A breakdown by industry group shows that 45% of suppliers in the mobility sector consider the issue of centralized data management as relevant, although this view is not shared by any of the OEMs in this sector (cf. fig. 47). For companies in sectors for mechanical and plant engineering and equipment technology, the uncertainty about future responsibilities is higher than in other industry groups (50%). Figure 48 shows how much companies expect processes to change due to the implementation of Digital Twins. A partial change is anticipated by companies in the sectors for mechanical and plant engineering and equipment technology (67%) and by suppliers in the mobility sector (73%). For OEMs

QUESTIONS *What business/development processes and procedures are impacted by the implementation of Digital Twins? How will these be modified or redesigned?*

Figure 46: Processes impacted by Digital Twin implementation

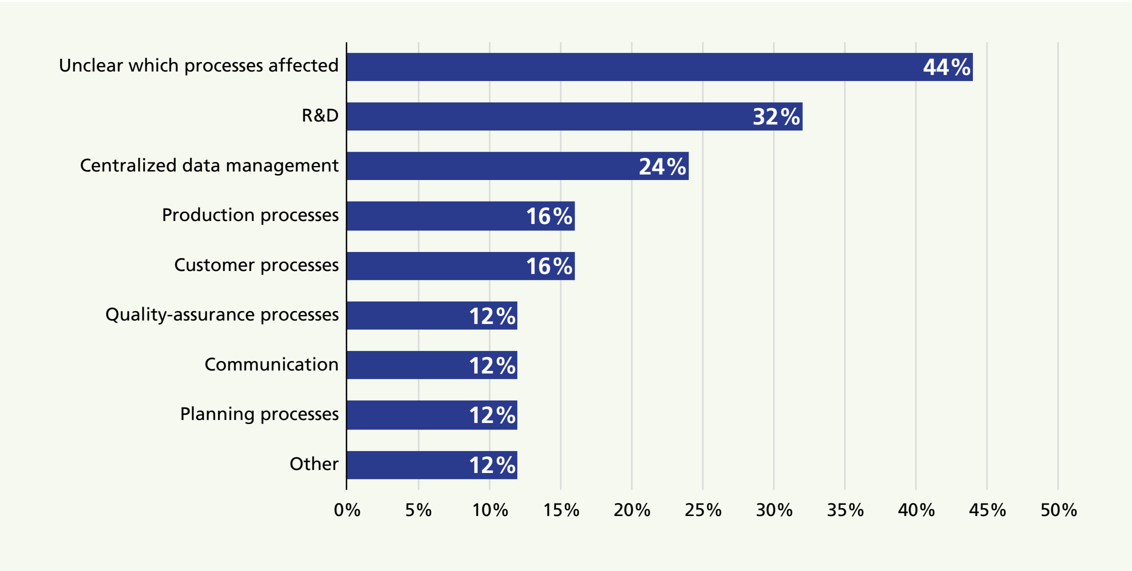
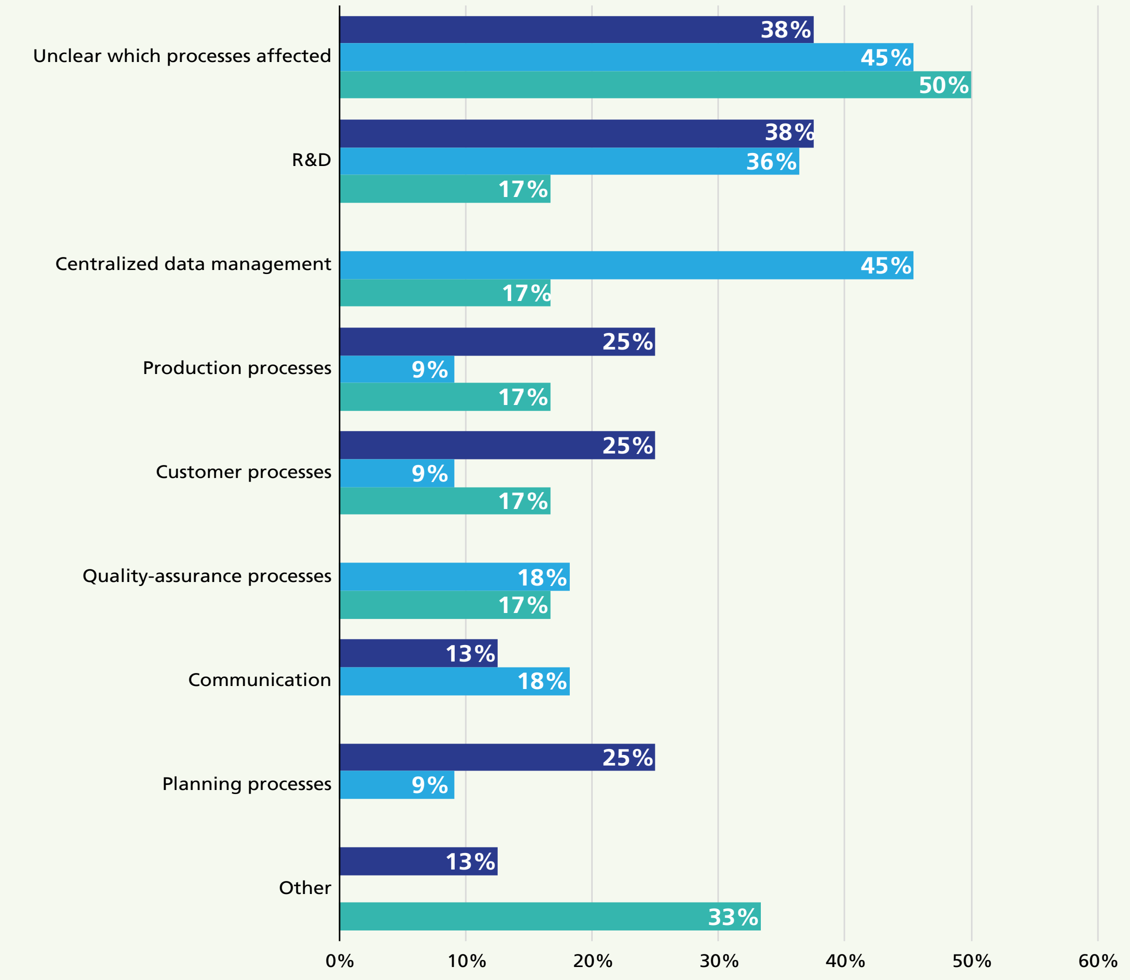


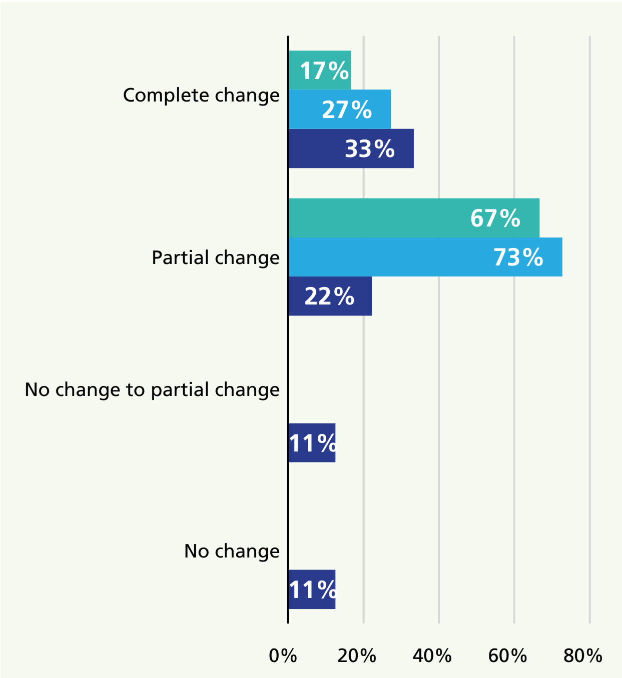
Figure 47: Processes impacted by Digital Twin implementation according to industry group



Legend for figure 47

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Figure 48: Degree of change in processes according to industry group



Legend for figure 48

- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

in the mobility sector, the range of responses is wider. The largest group, however, expects a complete change (33%).

Organization (organizational structure)

Around 85% of the interviewees say that the organization of their company will change as a result of the implementation of Digital Twins (cf. fig. 49). The key changes will be the creation of new responsibilities – mentioned by 59% of the interviewees who anticipate change – and the development of new employee skills (55%; cf. fig. 50). In particular, holistic thinking (e.g., systems understanding) will be required from those involved in development activities.

At the same time, 18% of the interviewees expect a more agile organization, 14% the introduction of new governance mechanisms, and 14% a greater focus on future viability. Some of the interviewees (18%) felt that the implementation of Digital Twins in the company requires comprehensive change management.

Irrespective of industry group, most companies anticipate a partial change to company organization (66%), while 24% of the interviewees expect a complete change. A breakdown by industry group shows that OEMs in the mobility sector expect change to be less severe compared to suppliers in the mobility sector or companies in sectors for mechanical and plant engineering and equipment technology (cf. fig. 51). Above all, it is companies in sectors for mechanical and plant engineering and equipment technology that expect complete change (20%), whereas 27% of suppliers in the mobility sector expect partial to complete change.

QUESTION *How will company organization change as a result of the implementation of Digital Twins?*

Figure 49: Change in company organization

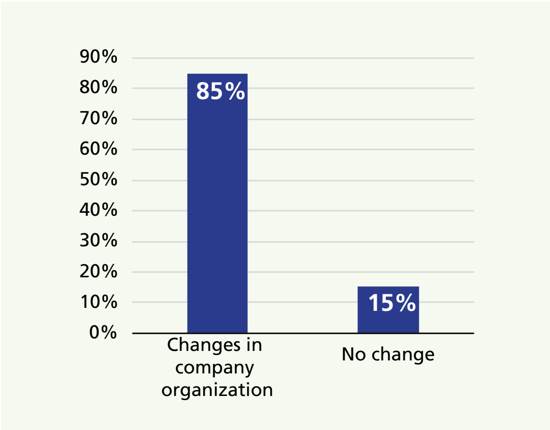


Figure 50: Focus of change in company organization

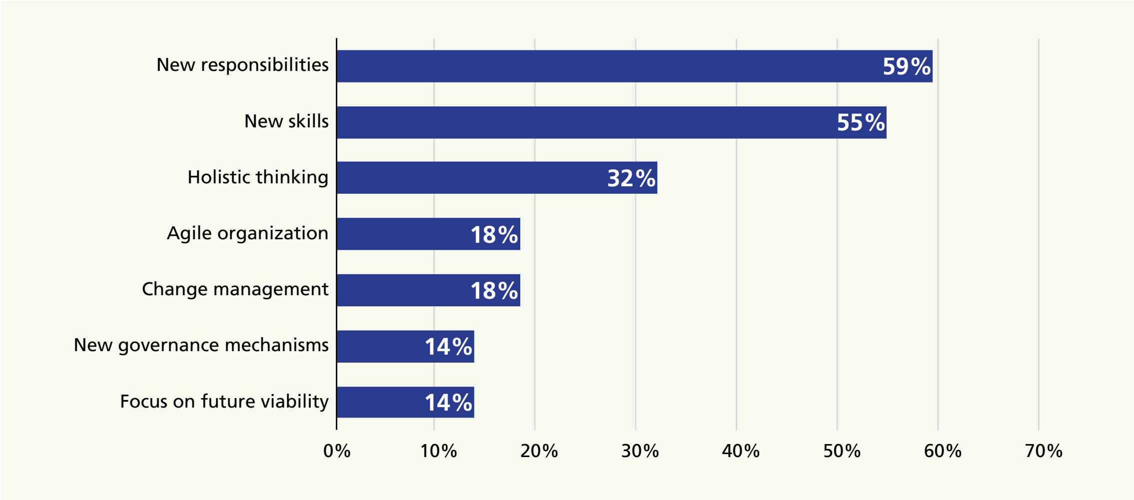
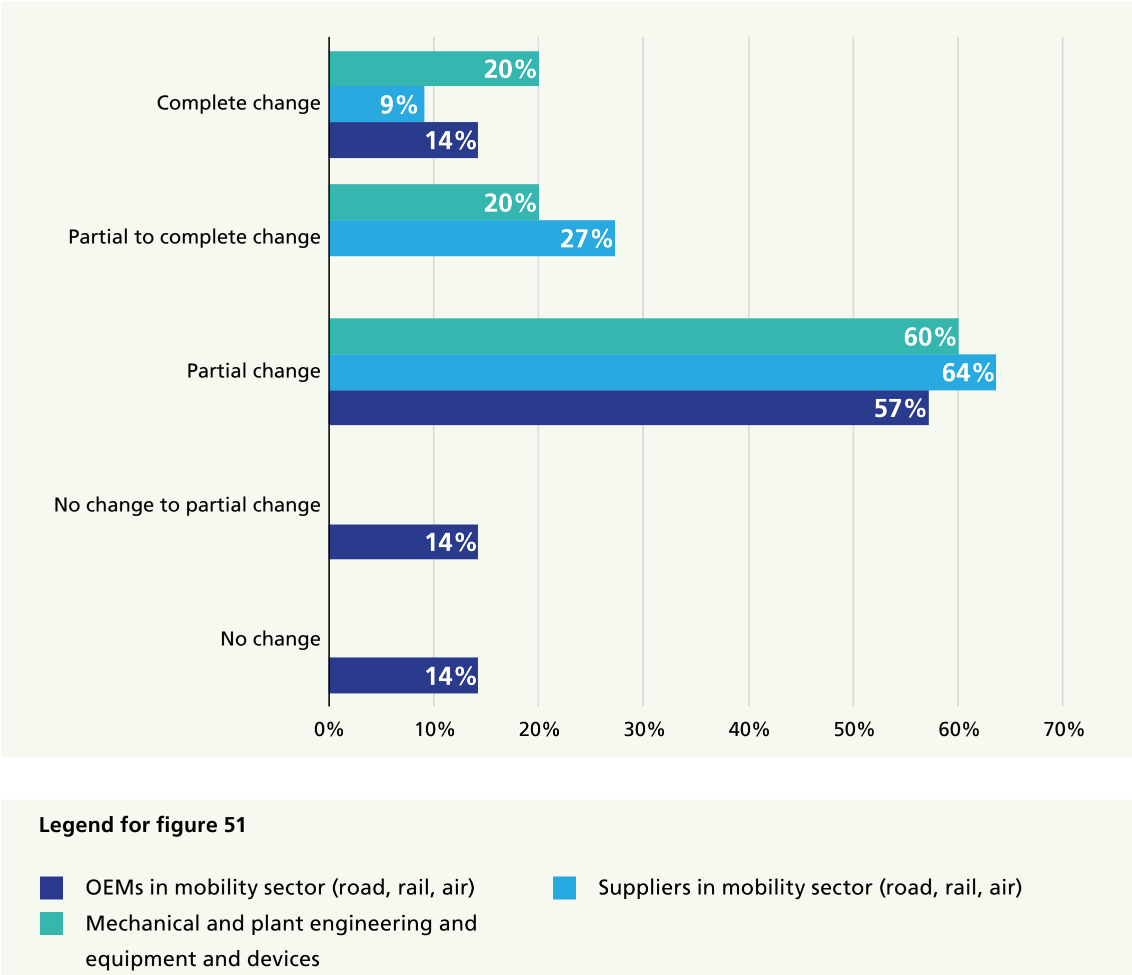


Figure 51: Degree of change in company organization according to industry group



Skills

Of all the skills required for implementation, the most frequently mentioned are IT skills (72%; cf. fig. 52). This includes skills in software architecture and development, information and database management, and simulation. Technical skills (56%) are the second most frequently mentioned skills, with 52% of the interviewees also stating a need for new skills not yet available within the company. Then come the following categories: holistic thinking across different fields (40%), enhanced qualification and further training (36%), and skills in data analytics and artificial intelligence (36%). In a few cases, transformation skills and social skills are also mentioned. A breakdown according to the type of product offered by companies (cf. fig. 53) shows that skills in data analytics and artificial intelligence (AI) are required much more frequently for vehicles (63%) than for other product groups. In the case of vehicles, the biggest need is for IT skills (75%). This also holds true for components and drive systems (83%). The majority of manufacturers of machinery and plant state a requirement for new skills in general (73%). In the case of 38% of the interviewees, their answers also offered an indication of how these skills might be developed (cf. fig. 54). Here, the largest group (50%) favor the recruitment of new employees. Other measures named are further training (40%), in-house training of company employees (30%) and collaboration with universities (10%).

QUESTION *What skills do companies require for the implementation of Digital Twins?*

Figure 52: Skills required for implementation

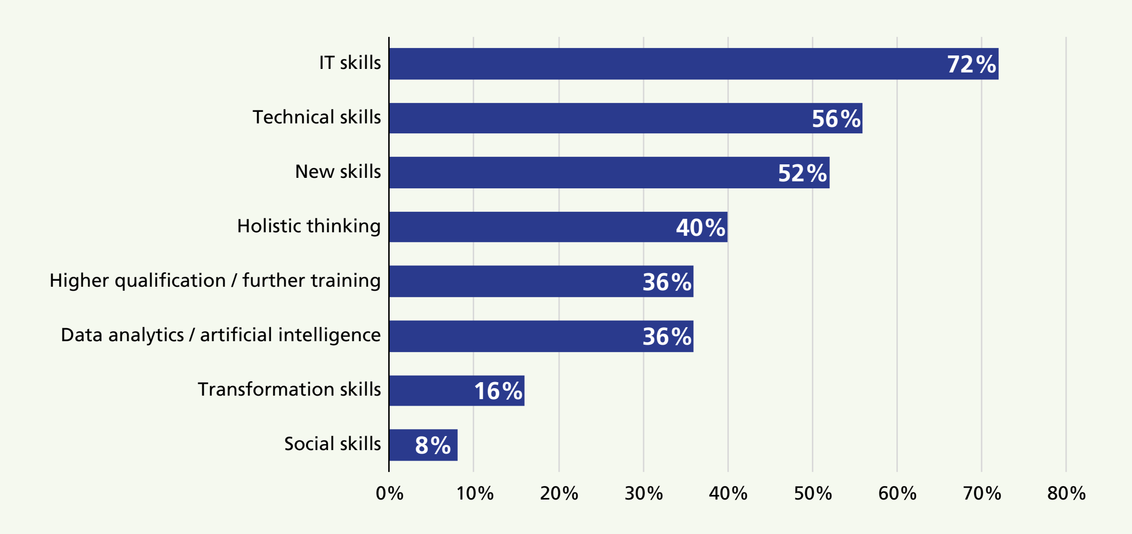


Figure 53: Skills required according to product group

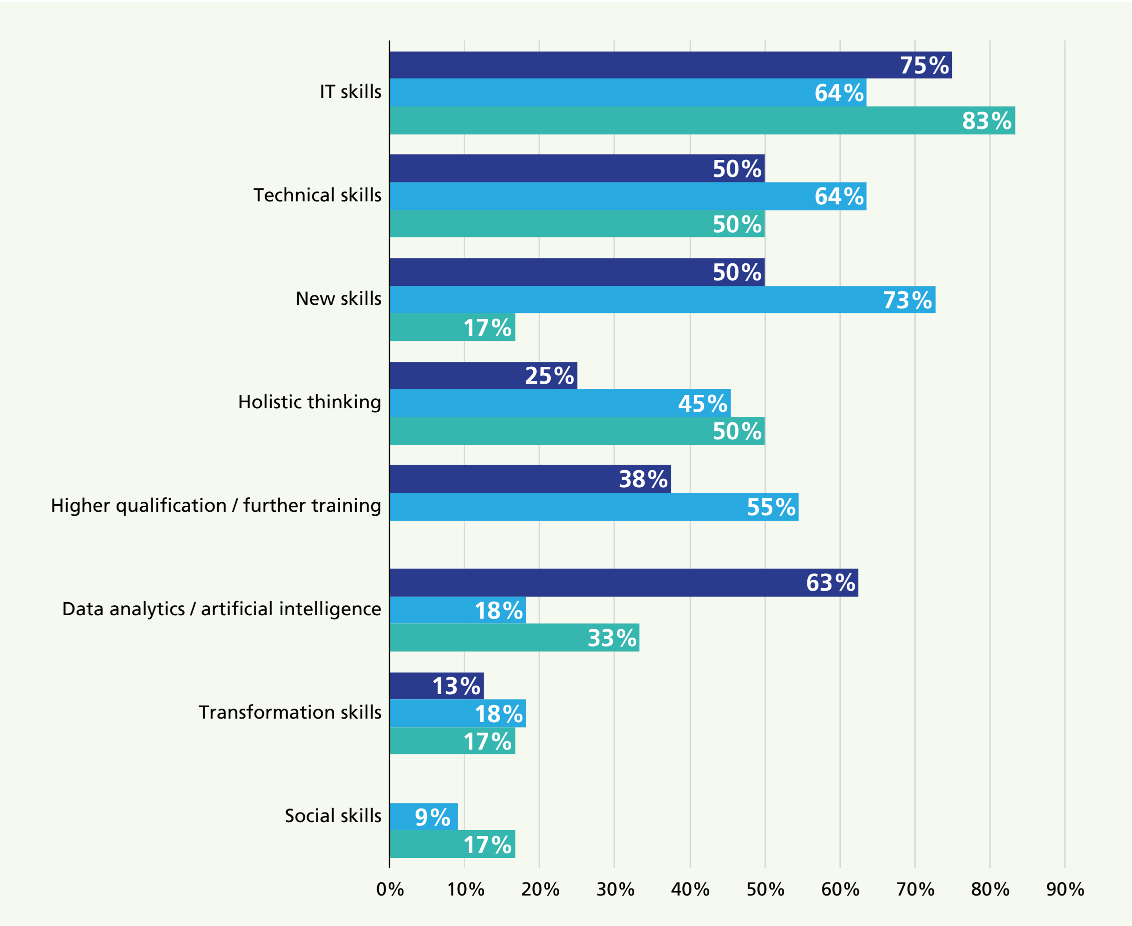


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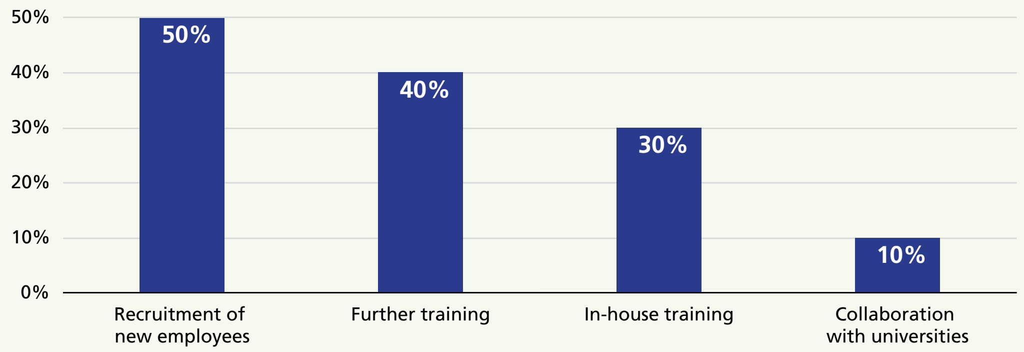
Figure 54: Measures to develop required skills



Data and information models

This area concerns virtual and physical artifacts along with the data and information models they contain. In the case of Digital Twins, these models are required for the digital master, for the digital shadow and for the link between the two.

The companies interviewed were asked which of these models they had already created either partly or in full. Their answers are presented in figure 55. The most frequently mentioned are models for the digital master, either fully (13%) or partially (58%) realized. Only three companies say they have already created, either fully or partially, models for both the digital master and digital shadow. This is explained by the fact that existing data, such as CAD models, can often be used for the digital master. A breakdown of models developed according to the systems represented (cf. fig. 56) shows that a number of companies with product twins have already fully realized the models required for the digital master (18%) and for the digital shadow (12%). In the case of production / assembly twins, the requisite models have only been partially completed.

Also of interest, is how companies intend to organize data management when implementing the Digital Twin. PDM / PLM systems (25%) and cloud solutions (25%) are the two methods most commonly mentioned (cf. fig. 57). Centralized data management comes next (17%), closely followed by local solutions (13%). The breakdown according to industry group reveals substantial differences (see fig. 58). Centralized solutions are favored by 27% of suppliers in the mobility sector. By contrast, none of the OEMs mention this form of data management, preferring instead local solutions. The latter, in turn, are not mentioned by suppliers in the mobility sector.

Legend for figure 53

- Vehicles (rail, air, road)
- Machinery and plants
- Components and drive systems

QUESTION *Which models are required and to what extent are these already available?*

Figure 55: Required models already established

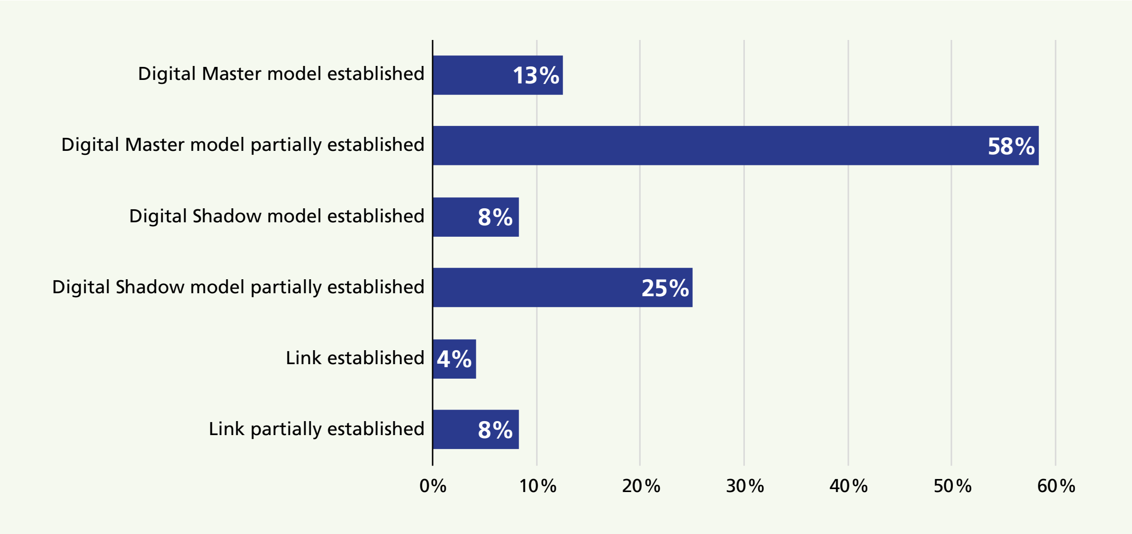
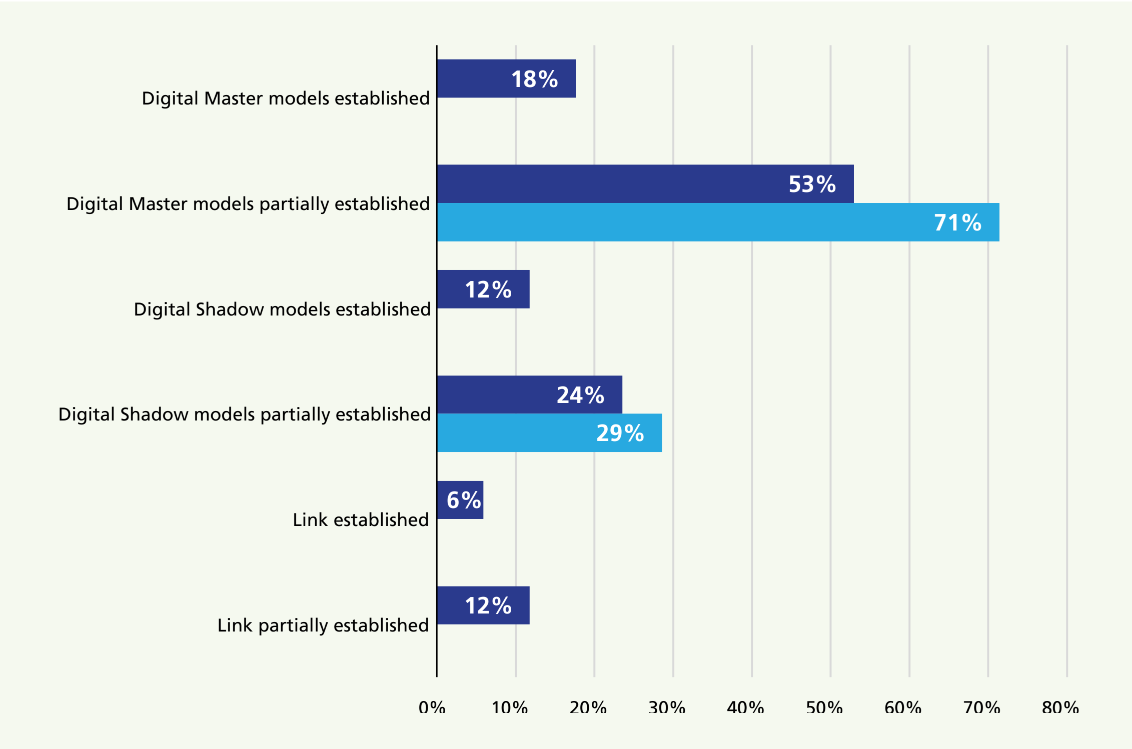


Figure 56: Required models already established according to type of system represented



Legend for figure 56

Product context
Production / assembly context

QUESTION *How is data storage organized during the implementation of Digital Twins?*

Figure 57: Organization of data management

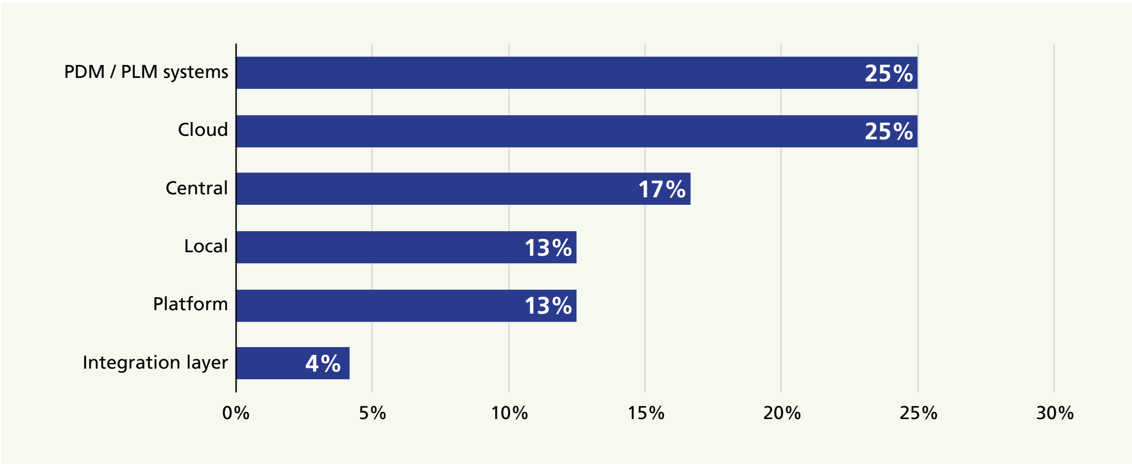
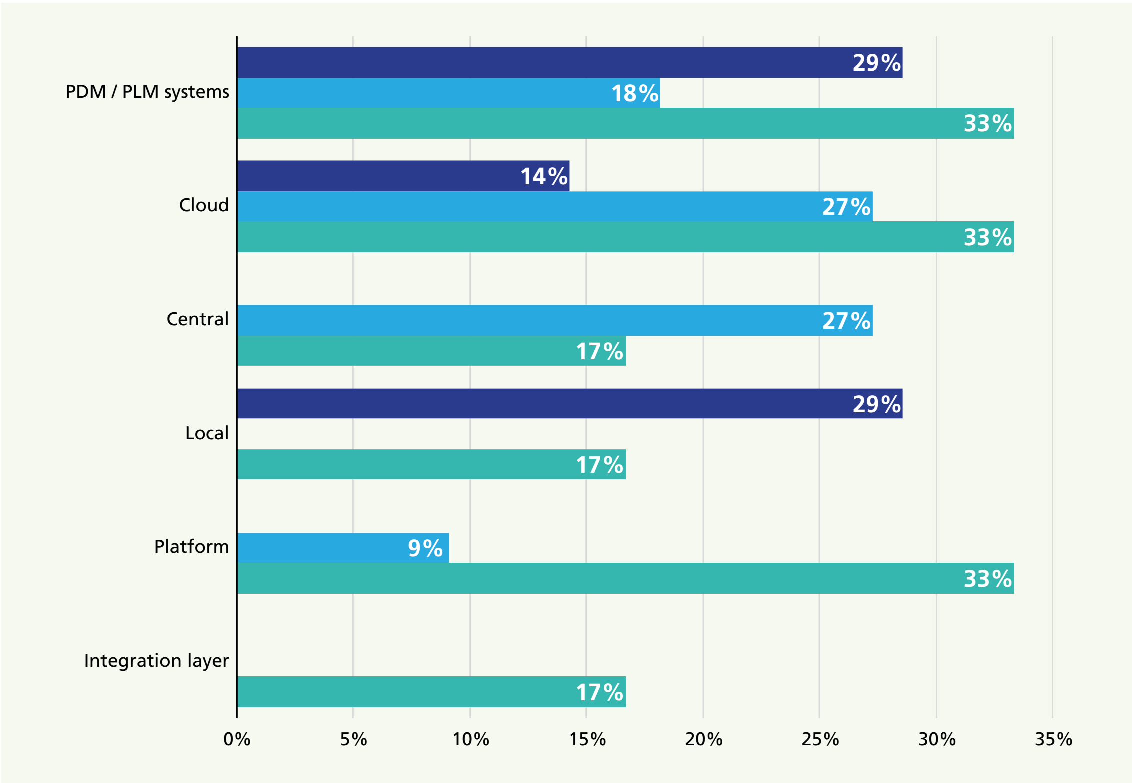


Figure 58: Organization of data management according to industry group



Legend for figure 58

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

IT systems

The third area of implementation concerns IT systems. Here, we focused on the type of solution mentioned, such as cloud, PLM or ERP system. Many of the interviewees named concrete systems from a range of vendors. These have all been anonymized for the purpose of this study.

This question attracted more than 15 different answers, indicating a highly heterogeneous IT landscape with respect to Digital Twins. Therefore, only those solutions that featured in over 20% of responses are listed here. The most frequently named are PLM systems (28%) and ERP systems (24%; cf. fig. 59). Strikingly, 24% of companies rely on IT solutions that are developed in-house.

A number of the concepts submitted did not meet the definition of Digital Twin used in the present study. Seen from this perspective, these concepts do not represent genuine examples of Digital Twins. A comparison of actual Digital Twin concepts with those submitted for this study reveals significant differences in the IT systems used (cf. fig. 60). Actual Digital Twin concepts tend to rely more frequently on PLM systems and less so on ERP systems or in-house solutions.

The interviewees were asked about the method used for exchanging information between various IT systems and models. This produced answers in more than 20 different categories. In other words, the results were extremely heterogeneous and lacking in specificity (cf. fig. 61).

More than one interviewee named the following ways to exchange information:

- Automated information exchange
- Feedback system to earlier phases of the product life cycle
- IoT solutions
- Installation of interfaces
- Use of cloud systems
- Model-based information exchange

In all, 24% of the interviewees were unable to give a response here. Overall, there is a high degree of uncertainty in this area.

Various physical principles can be used for the purposes of data acquisition (cf. fig. 62). In the majority of cases, optical systems, such as cameras (28%) or lasers (22%), are favored. The interviewees also name rotational speed measurement, pressure sensors and acoustic sensors (all 11%). For 11% of the interviewees, there are no plans to install any sensor systems. In all, 33% of the interviewees were unable to give a response here.

QUESTION *Which IT systems feature in Digital Twin concepts?*

Figure 59: IT systems used

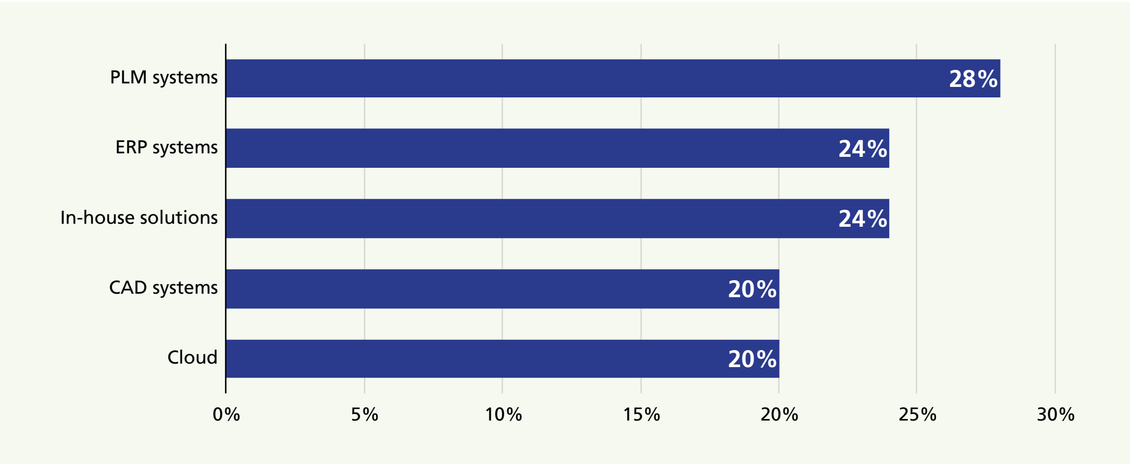
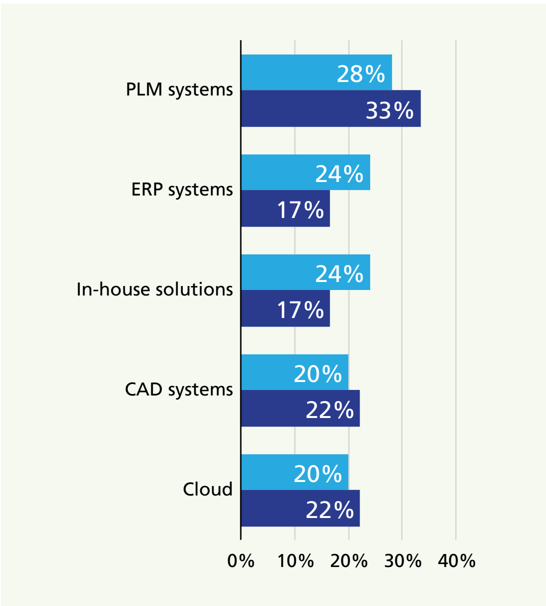


Figure 60: IT systems used in conjunction with actual Digital Twin systems



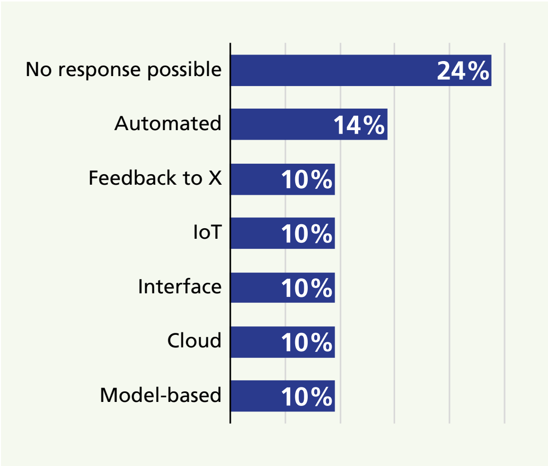
Legend for figure 60

Actual Twin Concepts

All concepts mentioned

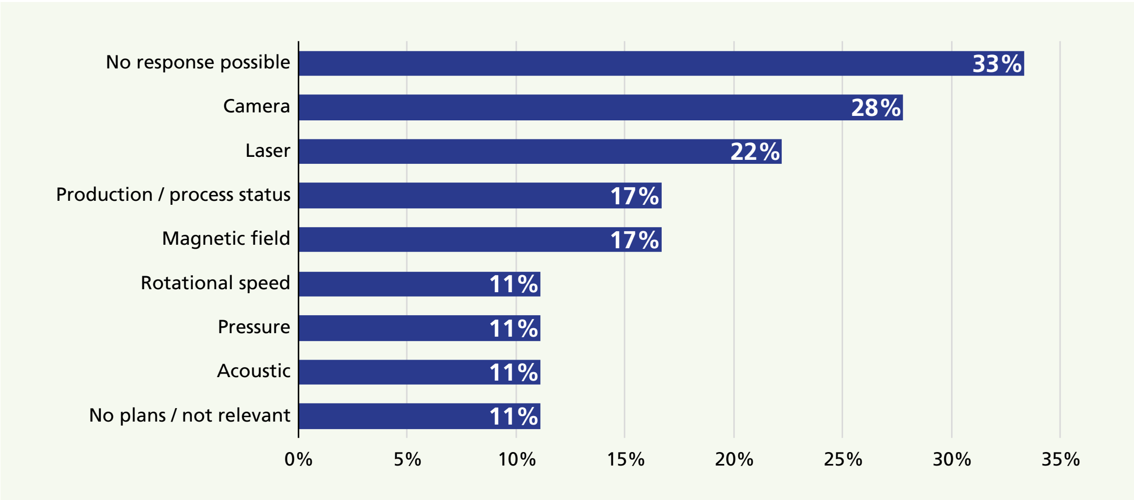
QUESTION *How will information be exchanged between the various IT systems and models?*

Figure 61: Implementation of data exchange



QUESTION *Which physical principles are exploited for the sensor and actuator systems used with Digital Twins?*

Figure 62: Sensor and actuator systems



Summary and conclusion

Most of the companies interviewed expect the implementation of Digital Twins to result in changes to company organization: new positions will be created along with new responsibilities. At the same time, future company organization will require greater agility and a holistic thinking on the part of employees. In particular, the responsibility for setting up and maintaining Digital Twins, along with the data they require, remains to be assigned. Very few companies have already implemented the changes that this is expected to bring. However, some of the interviewees do indicate that the required changes are being implemented as part of other digitalization projects that are running in parallel.

A range of company processes are impacted by the implementation of Digital Twins. The area most frequently mentioned here is research and development. It is noteworthy that many companies are still uncertain about how to manage this change. The individual departments tend to regard the necessary changes in isolation and as being beyond their own sphere of responsibility. IT thinks that the responsibility for this lies with product development, whereas product development thinks it lies with IT.

The skills primarily required by companies are IT skills, technical skills, holistic thinking and data analytics. For vehicle-related Digital Twins, it is clear that data analytics and AI are the most frequently required skills. For the most part, the required skills are to be acquired by means of recruitment and further training. Here, too, there are clear differences: whereas some companies plan to recruit new employees and maintain current jobs, others expect existing job profiles to change completely. In this case, it will no longer suffice to be an expert in a specific field. Rather, employees will additionally be expected to possess skills in data analytics.

In terms of Digital Twin implementation in data and information models, the creation of digital master models is the most advanced. This is understandable, given that these models have already been created during an extensively digitalized development process. It is frequently the case that these existing models can be reused in the digital master. A comparison of industry groups reveals differences in the approach to data management: OEMs prefer decentralized data management, whereas suppliers favor centralized data management solutions.

There are diverse approaches to Digital Twin implementation in IT systems. The most common are PLM or ERP systems and in-house solutions. Equally varied are the responses to the question about information exchange between the different IT systems and models. There is a high degree of uncertainty in this area. The picture is also very unclear with regard to sensor systems. This is particularly evident, as one-third of the interviewees are unable to provide more detailed information here.

The future of Digital Twins and their potential to boost sustainability

What does the future hold for Digital Twins?
What role can Digital Twins play in improving environmental and social sustainability?

35% expect that by 2040 their Digital Twin will be able to represent an entire system along with its environment.

38% hope that by 2040 their Digital Twin will have led to new or enhanced business models.

27% expect their Digital Twin to be in use before 2040.

63% see major potential for a future use of Digital Twins to perform sustainability assessments.

“The Digital Twin will have an impact on market performance similar to that of the mechanical loom in the 18th century.”

Dirk Denger

“At Deutsche Bahn, we already make extensive use of Digital Twins in network and infrastructure planning. In the future, we should see greater interaction and perhaps even the creation of an overarching system of Digital Twins. This ecosystem could then be used for virtual planning and for virtual control of entire areas of business. Digital Twins are therefore a key pillar of future digitalization.”

Cord Gatzka, DB Systel GmbH

The future of Digital Twins and their potential to boost sustainability

The analysis of current Digital Twin concepts in preceding chapters offers a good overview of the use of this technology in today's industry. It is evident that Digital Twins will increasingly change not only product and production systems but also – as a result of their implementation – processes, company organization, IT systems and data models. In short, the idea and concept of the Digital Twin will drive the entire value chain. At the same time, progress will also result from innovations in the digitalization of development environments and the approaches to Industrie 4.0 as well as in smart product development and advanced systems engineering.

The findings in the areas of understanding and use, strategic goal and concept, and implementation – where actual Digital Twin concepts were considered – raise the question of what the future holds for Digital Twins. The factoring of environmental and social sustainability indicators plays a key role in this context. This is because the Digital Twin concept offers a way of tracking and evaluating information on a product-specific basis. By means of its own Digital Twin, each product can be assigned an individual footprint, starting with the extraction of production materials and ending with their recycling. On the basis of this information, forthcoming product generations can then be designed and realized with a greater awareness of their environmental and social impact.

This chapter will therefore explore how the companies interviewed for this study envisage the future of Digital Twins over the coming 20 years – i.e., up until 2040. On the one hand, it investigates how companies view the future prospects for Digital Twins and, on the other, it explores how Digital Twins might help boost sustainability.

The future of Digital Twins

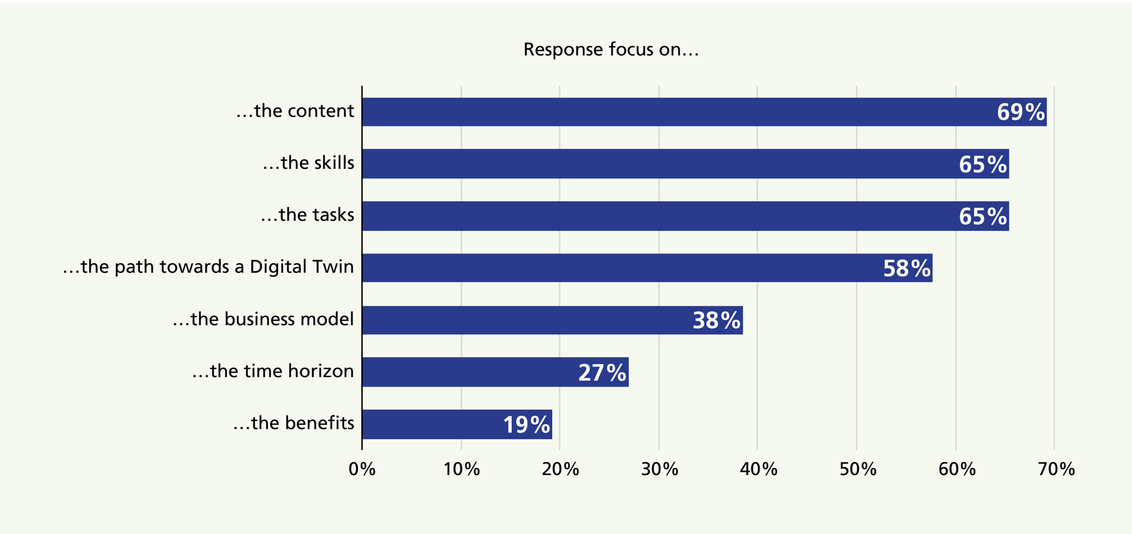
When asking for companies' visions of the future of Digital Twins, an extended time period of 20 years was deliberately selected. The aim was to find out how the interviewees envisage the further development and future significance of Digital Twins. For some of the interviewees, the prolonged length of time under consideration provoked uncertainty, as their industry had no concrete strategies or changes scheduled for this period.

It is interesting to discover which aspects the interviewees will be focusing on over the next 20 years and to see what steps they will need to take in order to be able to use Digital Twins beyond the concepts currently under consideration. Their answers show they are firmly focusing on content – i.e., the actual system represented by the Digital Twin and the related data and information required – and not, as assumed, on the anticipated benefits or the business model (cf. fig. 63). When asked to describe the future of Digital Twins, 69% of companies focus on content. Next comes a consideration of the capabilities required (65%) and the tasks Digital Twins will be expected to perform (65%). By contrast, only 38% focus on the opportunities that Digital Twins will offer for their business model. It is either the case that the interviewees regard the benefits associated with Digital Twins as self-evident or that they have not yet focused sufficiently on this aspect. This is a reminder, once again, that Digital Twins should not be developed as an end in themselves, but with a purpose in mind. A needs-driven concept always starts with specifications, which in turn have been derived from the intended benefit. At the same time, it is clear from companies' strategic goals and the assessment of their readiness that many have already begun laying the groundwork. This may well explain their focus on the design and further development of the technological aspects and capabilities of their Digital Twin.

An analysis of the responses in each of these categories reveals just how diverse a picture companies have of the future of Digital Twins (see fig. 64). This mirrors the huge diversity of the concepts examined in the course of this study and the broad spectrum of use cases. The following takes a look at future capabilities, business models, future tasks, added value, content and use of Digital Twins. In addition, it analyzes how the companies interviewed see the path towards this future use of Digital Twins and how they picture this future at the end of the period under consideration.

QUESTION *What topics will companies be focusing on in relation to Digital Twins over the next 20 years?*

Figure 63: The future of Digital Twins in 20 years: range of answers



Future capabilities

The preceding analysis of the concepts under consideration has shown that today's approaches to Digital Twins rarely involve complex scenarios. In fact, the capabilities of today's Digital Twin concepts frequently focus on the provision of information (cf. fig. 64). This changes as soon as the interviewees look towards the future. Here, Digital Twins are set to gain further capabilities. It is noteworthy that 27% of the interviewees envisage a greater role for Digital Twins in the areas of control and forecasting. At the same time, companies have broadened their focus to include the idea of a network of Digital Twins. This is evident in the fact that 31% of the interviewees predict future growth in connectivity and interactivity of Digital Twins. As many as 15% of the interviewees forecast that Digital Twins will lead to the automation of development processes. In other words, not only will Digital Twins provide support for the engineering activities involved in product development, they will also automate a number of them. Since research is already underway into the use of modularization as a way of automating product development, it seems perfectly realistic to assume that this approach might also be supplemented by the use of real-time data from a digital master and knowledge provided by a Digital Twin. It is therefore no surprise to see machine learning named as one of the future capabilities of Digital Twins. However, this seems to be an issue for only a very few of the interviewees (4%), especially as artificial intelligence is a much-discussed topic and highly relevant to smart systems and automated decision-making.

Future business models

New digital offerings are seen by 27% of the interviewees as an important driver of future business models. In other words, Digital Twins will continue to play a major role in the renewal of business models for the benefit of end customers. This was already evident in our examination in previous chapters of the business models associated with current Digital Twin concepts. Strikingly, only 4% of the interviewees say their goal is to sell Digital Twin models. This is especially worth mentioning as it shows that companies look set to continue protecting their proprietary know-how. Evidently, there is still no real focus on the sale of digital models and the knowledge based on them. As such, digital models will remain with the companies that develop them rather than being sold or handed on with the physical product. Presumably, many companies hope to gain access to the operating data – i.e., the digital shadow – through the 1:1 link between the physical product or system and the Digital Twin. The company that operates the Digital Twin can then analyze this data and generate new knowledge on this basis. This knowledge from the Digital Twin will then feed into the development of services that can be offered to customers as new digital offerings. This also explains the expectation on the part of some of the interviewees that customer ties will strengthen as a result of Digital Twins (12%).

Future tasks and added value

Even with a time horizon of 20 years, the companies interviewed in this study still predict that Digital Twins will perform similar tasks and generate similar added value as they do today. Companies will continue to focus on boosting internal productivity and efficiency (35%) – a task that was already identified as relevant in the analysis of current Digital Twin concepts and their use. It would therefore appear that companies believe that Digital Twins will continue to help them make internal improvements up until 2040. Specifically, 27% of the interviewees expect to make use of feedback-to-design – i.e., the improvement of development processes based on the information acquired from the Digital Twin. Here, there is evidently a desire to use the knowledge generated by Digital Twins during the use phase in order to improve the design and validation of products and systems. A variety of tasks were suggested as ways in which Digital Twins might improve internal processes. Each of the following was endorsed by 15% of the interviewees:

- Autonomously provide early recognition of new potential
- Enable company-wide data exchange and data consistency
- Actively provide decision-making support for users
- Provide clear information throughout the product life cycle, as with today's concepts

These responses reflect the full range of expectations with regard to Digital Twins. In its simplest manifestation, a Digital Twin should provide clear information and early support with decision-making. In its most advanced form, it should be capable of identifying new potential and, according to 8% of the interviewees, even take on key tasks at the heart of the company's value-creation processes.

What type of content should Digital Twins represent in the future?

In today's concepts, Digital Twins are frequently used to represent geometric models as part of complete product systems or assembly lines. However, this range of tasks is set to expand over the next 20 years. For 35% of companies, Digital Twins will be able to represent an entire system and its environment by the end of this period. At first glance, this may seem ambitious. However, it is fully in accordance with the idea that all the digital models from the development phase should be maintained and further enriched with shadow data over the entire product lifecycle. Product development already has access to extensive models containing a lot of information, including on areas such as the product environment and patterns of use. This will also be the case in the future as the system boundaries of Digital Twin models expand according to precise definitions.

The question is how companies intend to achieve this. Over a quarter of companies (27%) want their Digital Twin to become more precise, offer more detail and contain more information. Other companies, by contrast, are more interested in collecting and storing data and information in a targeted and structured manner. Around one-quarter plan to use Digital Twins to produce a lean representation of context-specific information.

The key here is to find a compromise between, on the one hand, the large-scale, purely explorative collection and storage of data to "represent everything" and, on the other, the collection of use case-specific data to deliver a "lean representation". The second approach bears the risk that in the future there will be insufficient data to answer questions that are still unforeseen today. However, the cost and effort required to collect, store and process data on an essentially speculative basis must be weighed up and, ultimately justified in terms of the anticipated benefit. The aim must therefore be to develop a strategy early on that enables data to be gathered in a structured way and then contextualized as it is being collected and stored.

Future use of Digital Twins

The interaction with Digital Twins will also change. In all, 12% percent of the interviewees expect there to be human interaction. Only a very few, however, anticipate full immersion in virtual reality (8%). When this finding is compared with the analysis from previous chapters, it is clear that very few of the interviewees expect Digital Twins to be able to process tasks independently and autonomously, either today or in the future. Some form of human-machine interface is always envisaged. This may also explain why so many of the Digital Twin concepts feature geometric models for visualization purposes. Either way, it is striking that only 8% of the interviewees refer to immersion in virtual reality, whereas 60% of the concepts examined in this study include geometric models (cf. fig. 40). In most cases, Digital Twins will continue to assist people with their current tasks in the future. It seems likely that they will operate partially in the background at the IT-system level. That said, it will be vital to ensure that the mode of information provision and human interface are designed to be as user-centric as possible.

The path to the future use of Digital Twins

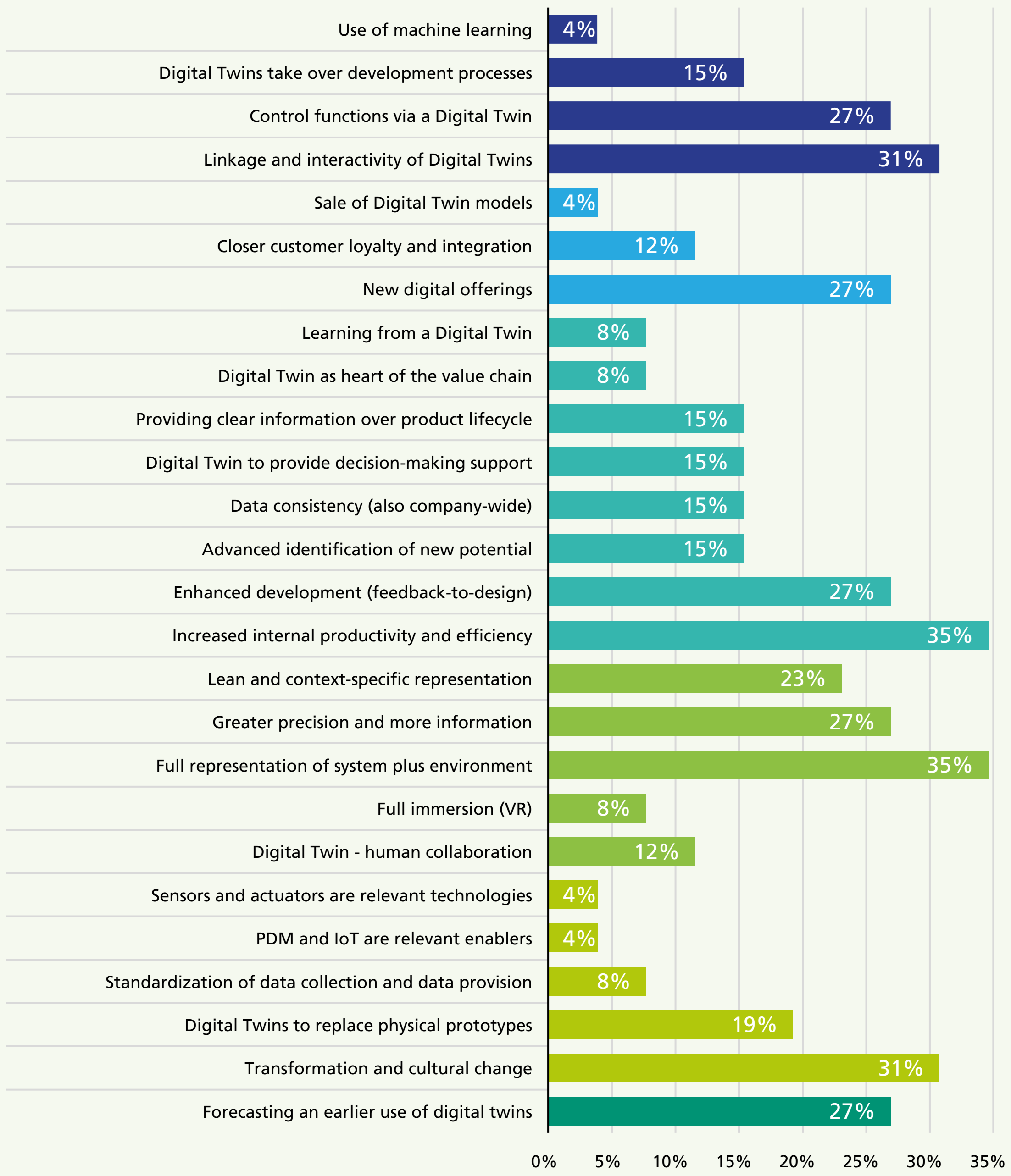
Some of the answers provided by the interviewees focus specifically on tasks that need to be addressed in the corporate environment and on the technological level over the next 20 years. For example, 27% of the interviewees emphasize that their company needs to undergo a major cultural change and transformation over the period until 2040 and before a full implementation of Digital Twins. This mainly refers to the establishment of cross-domain thinking and the abolition of silo-like working practices within individual departments – as envisaged in systems engineering. Cultural change also applies to the workforce and to employees' openness to the digitalization of processes and to the idea of working with and placing trust in intelligent systems – whether this involves decision-making support or a fully autonomous system based on artificial intelligence. At the same time, 19% of the interviewees expect to see a reduction in the use of physical prototypes. This will result from improvements in development and, in particular, the shift of design and validation processes to the virtual world. A surprisingly low number of companies regard the standardization of data collection and data provision as a relevant factor for the use of Digital Twins in the future. However, in order to ensure connectivity and interactivity of Digital Twins (in the area of future capabilities) and company-wide data consistency (in the area of future tasks), standardization or the development of open interfaces will be required. It is perhaps the case that many companies are hoping that this task will be addressed by initiatives or interest groups. In the area of IT systems, a very small number of companies (4%) identify one of the following as a key technology: PDM systems, the Internet of Things (IoT), and sensor and actuator systems. Although not mentioned by all companies, it can be assumed that the role of PLM / PDM systems and the full range of Industry 4.0 technologies will continue to evolve, and that these will also be used in the development and operation of Digital Twins.

The time horizon to a future use of Digital Twins

It also emerged that over one-quarter of the interviewees regard a time horizon of 20 years as too long. These companies predict a widespread use of Digital Twins much earlier – namely, within the next five years.

QUESTION *What are the prospects for Digital Twins in 20 years?*

Figure 64: The future of Digital Twins in 20 years: detailed breakdown of answers



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- Capabilities
- Business models
- Task / added value
- Content
- Use
- Path to the Digital Twin
- Time frame

Environmental and social sustainability boost

Today's Digital Twin concepts are expected to deliver things like greater knowledge, enhanced product quality, and increased efficiency in the production environment. At the same time, however, Digital Twins might also be used to improve the environmental and social sustainability of product systems and production systems – through, for example, the assessment and enhancement of a product's sustainability during its production, use and end-of-life phase.

A large proportion of the interviewees (62%) see major potential for the use of Digital Twins to assess the environmental and social sustainability of physical systems (cf. fig. 65). A further 12% of the interviewees see medium potential and 24% minor potential for Digital Twins in this area. None of the interviewees state that they see zero potential in the use of Digital Twins for sustainability assessments.

This shows that while a good portion of the added value attached to today's Digital Twin concepts is firmly located in improvements to internal processes and the development of new digital offerings for the end customer, it by no means exhausts the potential of Digital Twins. Indeed, 8% of companies say that selected sustainability considerations, such as energy consumption or ergonomics within the assembly environment, already feature in the implementation of their Digital Twins. Similarly, as many as 39% have initial concepts and ideas in this direction.

A comparison across the industry groups shows that this assessment is almost evenly distributed. It is only in the group of companies in sectors for mechanical and plant engineering and equipment technology that there is, on average, a tendency to see lower potential. This may well be due to the fact that sustainability assessments are conventionally conducted in greater proximity to the end customer.

An analysis of the sustainability indicators or strategies specifically named by the interviewees reveals a clear trend towards environmental considerations (cf. fig. 66). For 92% of the interviewees, the relevance of Digital Twins for sustainability assessments lies in this area. The following aspects are specifically named:

- Reducing carbon footprint (16%); i.e., the review and avoidance of emissions and the use of resources that impact CO_2 emissions.
- Optimizing resource efficiency (48%); i.e., the review and improvement of the use-to-benefit ratio of resources used – such as raw materials, energy and water – to the end result in the form of the product system.
- Optimizing energy efficiency (56%); i.e., improving the ratio of energy used to the benefits achieved as a subcategory of resource efficiency.

A few companies also described the possibility of assessing social sustainability, although it must be emphasized that this poses particular challenges. For a start, social indicators are difficult to define uniformly and are also difficult to measure. Moreover, in contrast to the indicators of environmental sustainability, they are rarely surveyed in an Industry 4.0 context, since they frequently relate to HR factors such as fair pay and employee health. A further 16% of the interviewees state that Digital Twins can help prolong the service life of products and systems as part of a sustainability strategy featuring improved maintenance and repair processes. This is a classic approach from the realm of the circular economy.

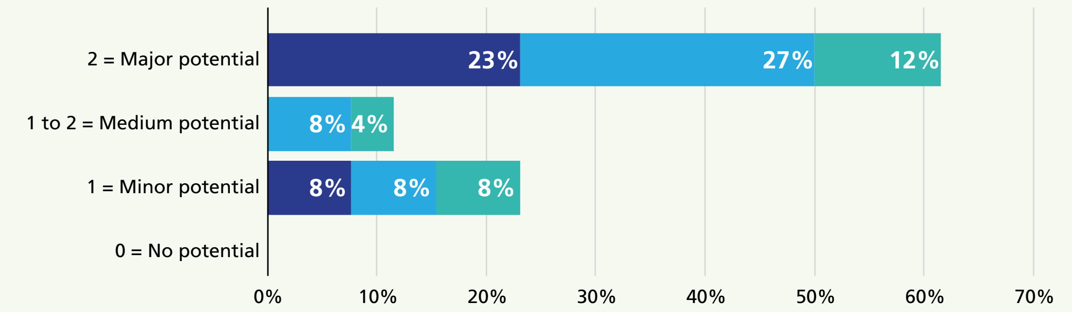
A breakdown according to the type of system represented by the Digital Twin (cf. fig. 67) shows that a very large proportion of companies with concepts designed to represent production systems (86%) see major potential in the area of sustainability assessment. Only 14% of companies developing production-related Digital Twins see minor potential here. There is a similar trend for companies with concepts designed to represent product systems. Here, however, the assessment is on average somewhat lower, with as many as 26% of companies with product-related Digital Twins seeing only minor potential here.

A common reason for this is that data collection is easier in production-related contexts and already well advanced as a result of Industry 4.0 systems. By contrast, companies developing product twins are still unsure as to what extent they will be able to collect genuinely qualitative data in the field. In particular, the ability to track material flows in the use phase implies access to inspection and maintenance information. However, it is rare that data from the use phase flows back to the companies who have developed or manufactured a product. Conversely, the energy consumption and emissions of product systems during the use phase often remain a mystery to end customers. Companies design their product systems for use in specific scenarios. In the long term, they could use field data in order to improve their simulations of energy consumption or emissions.

A lot of corporate sustainability initiatives are driven not by problems in operating procedures but rather by strategic decisions or regulatory requirements. Here, Digital Twins that are already in use for other applications might well contain information that could also be of use for assessing sustainability – for example, information on the materials used, energy consumption related to supply chain and procurement planning, and disposal contracts. In other words, when devising new Digital Twin concepts, it is well worth considering and incorporating sustainability factors at an early stage of the process.

QUESTION *How do companies rate the potential for a future use of Digital Twins to assess the environmental and social sustainability of their physical twins?*

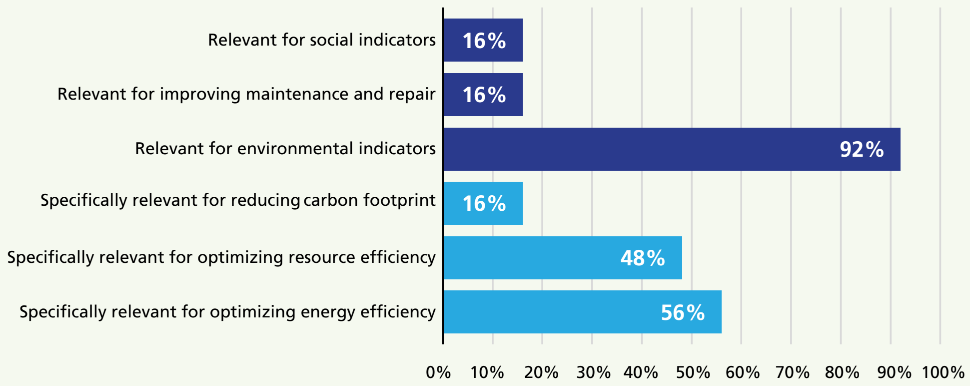
Figure 65: Sustainability assessment with Digital Twins – potential according to industry group



Legend for figure 65

- OEMs in mobility sector (road, rail, air)
- Suppliers in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices

Figure 66: Sustainability assessment with Digital Twins – relevance for specific aspects of sustainability



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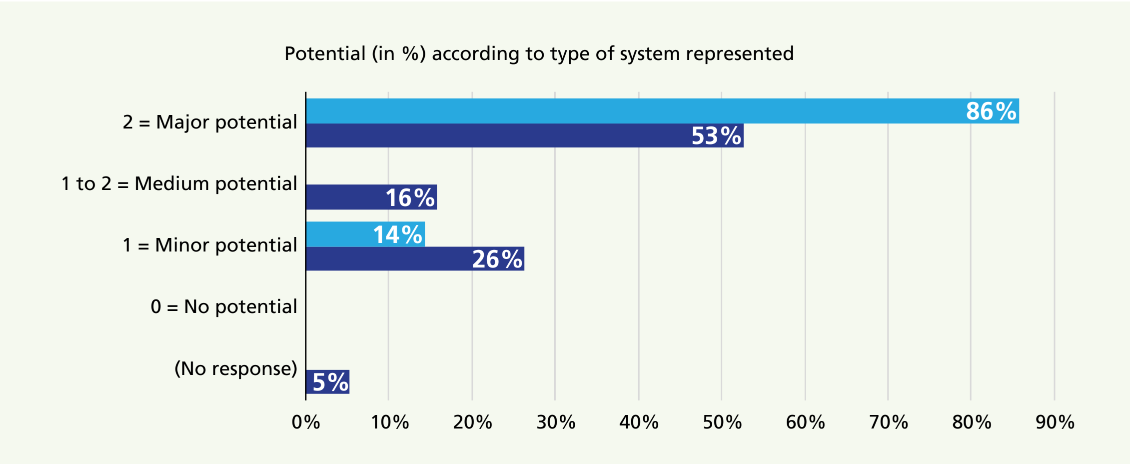
- Mentions in higher-level sustainability areas
- Specific mentions in the area of ecology

Figure 67: Sustainability assessment with Digital Twins – potential according to type of system represented



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Product context

Production / assembly context

Summary and conclusion

Our consideration of the future of Digital Twins over the next 20 years delivered diverse answers. For a large number of the interviewees, it is not merely a question of how advanced Digital Twins will be by 2040 and what they will be capable of; it is also about what measures will need to be implemented in companies and how this cultural change can best be managed. On the whole, however, the interviewees expect Digital Twins to be in full operative use well before the end of 20 years.

Expectations of enhanced productivity and efficiency as well as an expanded digital product range are fully justified by the potential of this technology. The amount of information represented in Digital Twins will continue to expand and eventually comprise the system environment and practically all of the parameters that describe that system. According to the interviewees, the continuous growth in information will mean that Digital Twins will also be able to take over some control and development tasks. This will take place either directly, in that Digital Twins will carry out some development activities by themselves, or indirectly, in that they will process information derived from a product's use in the field. The ability of Digital Twins to predict future behavior and the occurrence of certain events will also benefit companies and customers in many ways. Digital Twins will help companies make their internal processes more efficient as well as assist development engineers with current activities and improve their decision-making capabilities. They will enable the development of services tailored more closely to customers' specific needs and help deliver enhanced product quality on the basis of improved design and validation processes.

The new functions and services provided by systems are expected to improve interaction with customers and strengthen customer loyalty. The use of artificial intelligence will enhance various functions ranging from forecasting to autonomous decision-making. In particular, it will play an increasing role in prediction, even though not all of the companies interviewed seem to be aware of this fact. Of relevance in this context will be the degree of autonomy assigned to Digital Twins. At the same time, artificial intelligence may also assist with the development and operation of Digital Twins. Examples here include the automated development, automated administration and optimization as well as automated inspection and maintenance of Digital Twins. In view of the current state of implementation at companies and the degree of information exchange between them, it remains to be seen what added value Digital Twins will offer in the medium and long term.

As such, companies now face the challenge of choosing the right strategic priorities for the further development of their concept, as numerous goals can be achieved through the overall concept of Digital Twins. Other parameters to be considered here include market trends such as the increase in smart products, greater automation in the production environment and the ongoing rollout of digitalization. Furthermore, there is a clear gap between current concepts and future expectations in terms of the degree of communication between Digital Twins. Current concepts cover merely communication within the company itself. Future expectations, however, rest upon the assumption that there will also be data and information consistency between Digital Twins across company boundaries.

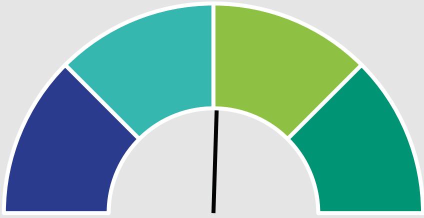
The concept of the Digital Twin displays another of its strengths in the area of sustainability assessment. The vast majority of the interviewees recognize its potential here, especially its use in the assessment of environmental sustainability. However, fewer companies agree that Digital Twins might also be used to track and assess social indicators of sustainability. This is understandable to a certain degree. The discrepancy and uncertainty regarding the assessment of social sustainability is a well-known issue in the sustainability community. It is considered extremely difficult to apply uniform standards for the purposes of assessing social sustainability.

In the area of environmental sustainability, by contrast, there is obvious potential, some of which is already being tapped. For example, energy consumption in production is already being monitored and optimized in terms of cost efficiency and emissions. Similarly, it is also possible to monitor material flows in terms of resource efficiency and emissions. In such cases, Digital Twins can provide a further source of detailed information and, by means of suitable algorithms, present, forecast and optimize the costs and emissions that occur over the product life cycle. In addition, it is important to take into account the environmental and social footprint of the hardware and software used to develop and operate Digital Twins. As we have seen, the cost and effort required to implement a Digital Twin must always be justified in terms of the envisaged benefit. The same applies to sustainability assessments: the expected benefit should always exceed the resources invested and the emissions thereby produced.

Looking to the future, Digital Twins will continue to be powerful enablers of internal improvements in companies, of new business models and of new digital offerings for end customers. At the same time, they will also help optimize the environmental and social sustainability of product and production systems.

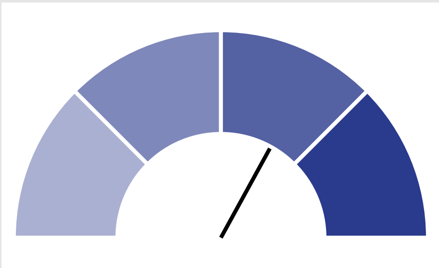
Consolidated readiness level of the companies interviewed

How do we assess a company's Digital Twin readiness?



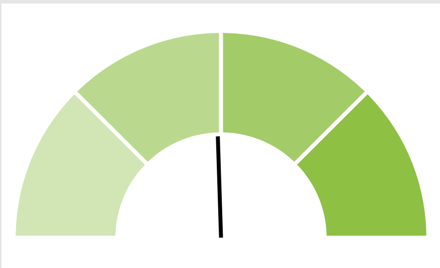
51% **consolidated overall readiness**

At the companies interviewed, Digital Twins are, by and large, in the conception phase.



66% **readiness in the area of "understanding and use"**

Companies already have a sound understanding of Digital Twins and initial experience in the use of Digital Twins.



49% **readiness in the area of "strategic goal and concept"**

The concepts submitted display a medium readiness level. Here, strategic goals are further advanced than concrete concepts.

39% **readiness in the area of "implementation"**

Readiness in the implementation of Digital Twins is still low, particularly for data and information models and IT systems.

Consolidated readiness level of companies interviewed

This chapter presents the overall results of the readiness assessment across all interviews. The assessment of the Digital Twin readiness of companies was conducted on the basis of the readiness model presented in the introduction *(see "Design and execution of the study" on page 30)*. As described, the readiness assessment is divided into three areas:

1. "Understanding and use"
2. "Strategic goal and concept," subdivided into:
   - Strategic goal
   - Concept
3. "Implementation," subdivided into:
   - Processes and organization
   - IT systems
   - Data and information models

These three areas are consolidated using the mean value for the overall readiness level. In the area of "understanding and use," it is the knowledge built up by the interviewees that was assessed along with the Digital Twin definition used in their company.

The area of "strategic goal and concept" is essentially strategic in nature. Here, questions have a medium/long-term time horizon.

In the area of "implementation," questions are operational in nature. Here, the implementation of Digital Twins and corresponding measures to realize the benefits envisaged in the concept are considered.

As initially presented, the readiness level is assessed on the basis of the responses provided and a summary of the areas presented above, so that an overall readiness assessment could be made across all interviews.

Readiness is presented according to an ordinal scale ranging from 0 (zero readiness) to 1 (full implementation):

Ordinal scale	Numerical scale
Zero readiness	0
Idea stage	0.25
Concept stage	0.5
Implementation underway	0.75
Full implementation	1

Figure 68 represents the ordinal scale as a dial with values converted into percentages for easier reading.

Figure 68: Overview of assessed readiness of the interviewees according to area of work

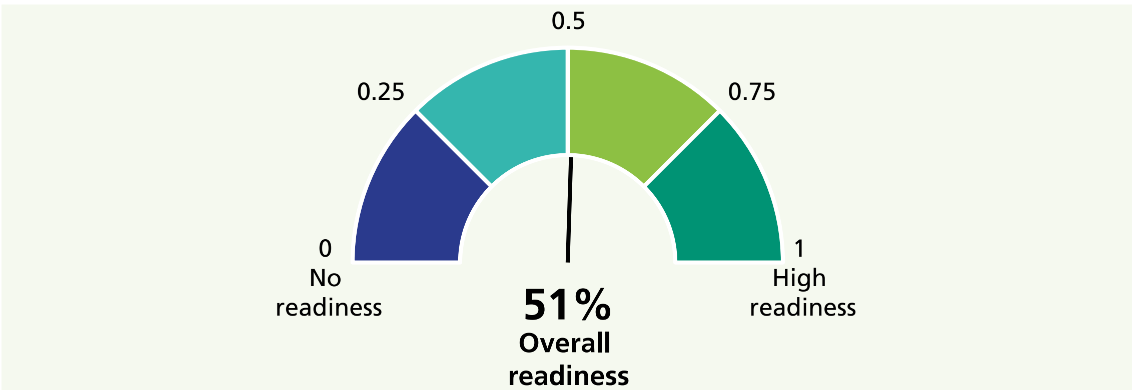
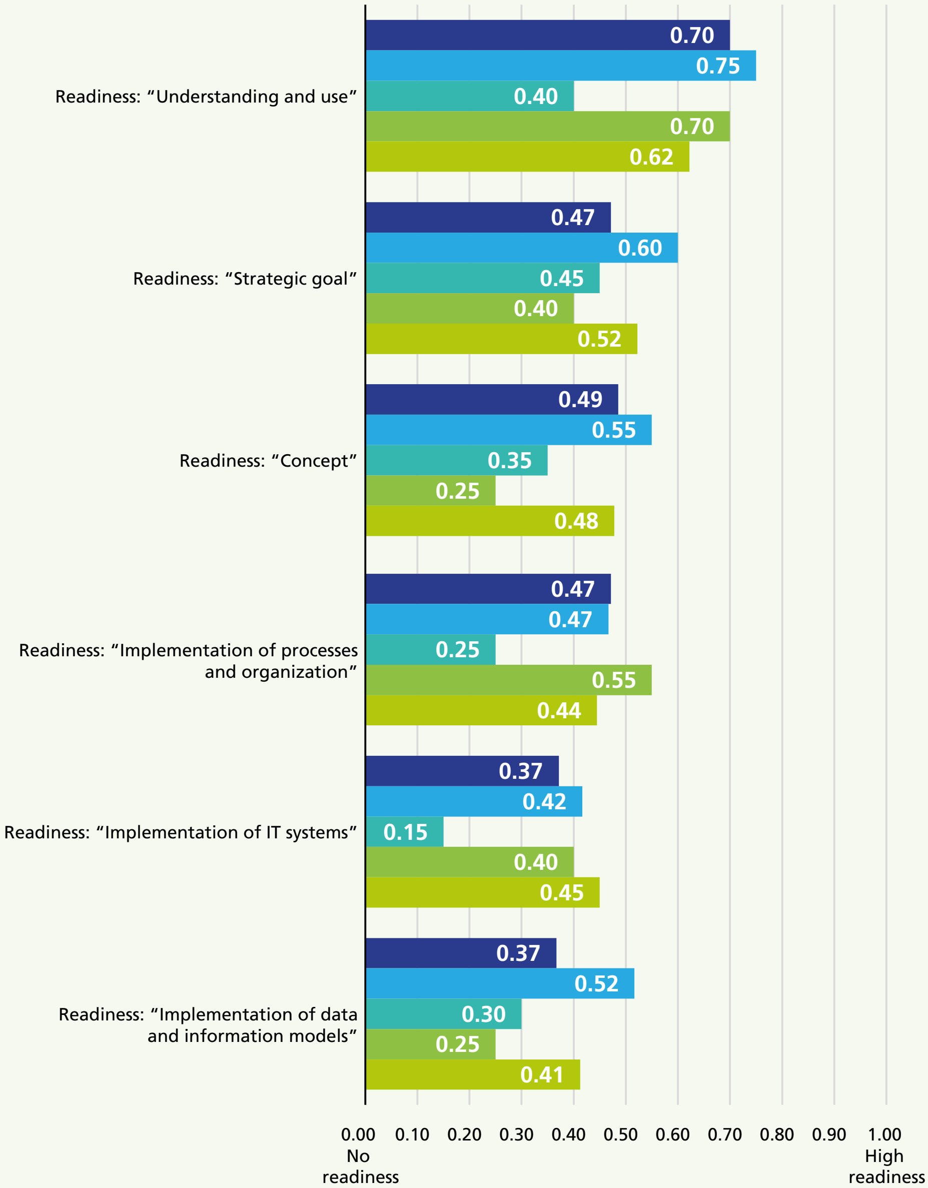


Figure 69: Overview of assessed readiness of the interviewees according to area of work



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Overall readiness

A basic comparison of the mean readiness of the companies interviewed shows they are still in the process of preparing for the introduction of Digital Twins (cf. fig. 68).

Overall, it can be concluded that readiness is at a medium level in strategic areas such as strategic goal (mean readiness of 0.51) and concept (mean readiness of 0.47), whereas readiness levels decline significantly in the direction of operational implementation. In the area of implementation, it is the subdivision of processes and organization that receives the highest assessment (mean readiness of 0.45). By contrast, implementation readiness in terms of IT systems (mean readiness of 0.39) and data and information models (mean readiness of 0.40) is relatively low.

A comparison according to the areas in which the interviewees work shows that the lowest level of readiness is in production (cf. fig. 69). By comparison, dedicated staff units display a high level of readiness in the implementation of Digital Twins. From an industry group perspective, no clear trend is discernible across all areas. Instead, different industry groups lead in the respective areas.

Readiness in the area of "understanding and use"

The highest level of readiness is in the area of "understanding and use" (mean readiness of 0.66; see fig. 70). This is due to the fact that all participants possess a medium-to-high level of prior knowledge and a relatively high level of experience in the use of Digital Twins.

The breakdown according to industry group (cf. fig. 71) shows that readiness in the area of "understanding and use" – i.e., accumulated know-how – is highest among suppliers in the mobility sector. OEMs in the mobility sector (0.61) and companies in sectors for mechanical and plant engineering and equipment technology (0.64) display a similar level of mean readiness in this area.

A comparison of the areas in which the interviewees work reveals the highest mean readiness (0.75) is to be found in dedicated staff units (cf. fig. 69). The areas of development and management also receive a high rating (0.7), followed by the interviewees working in IT (0.62). The area of production has a significantly lower rating, with a mean readiness of 0.4. The reasons for this could lie in the overlap with existing Industrie 4.0 initiatives. Follow-up research should seek to produce a more in-depth analysis here.

Figure 70: Mean readiness of all the interviewees in area of "understanding and use"

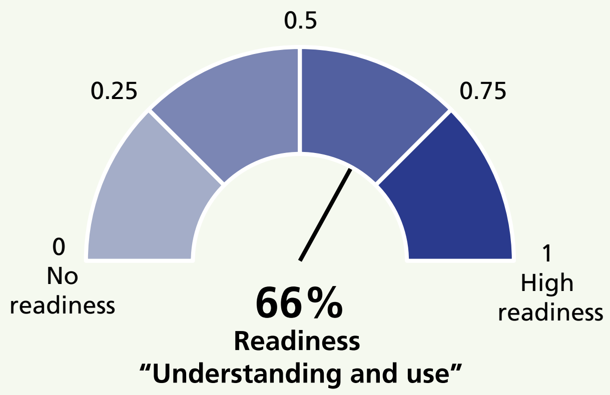
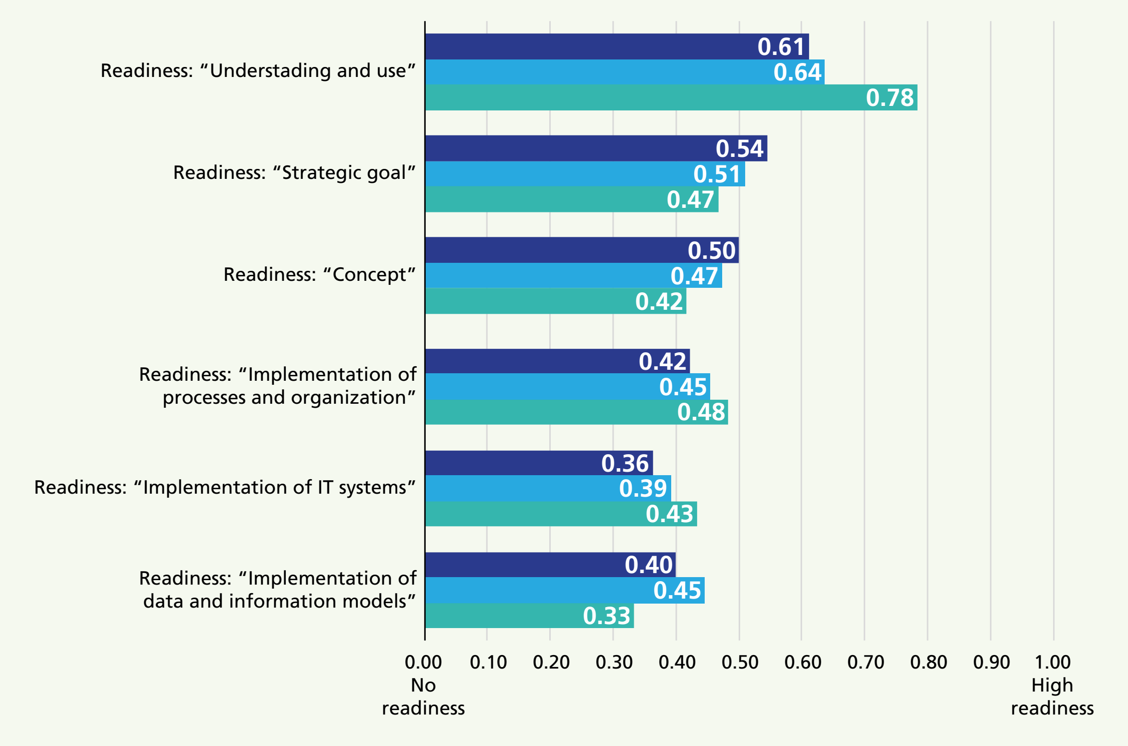


Figure 71: Overview of assessed readiness according to industry group



Legend for figure 71

- OEMs in mobility sector (road, rail, air)
- Mechanical and plant engineering and equipment and devices
- Suppliers in mobility sector (road, rail, air)

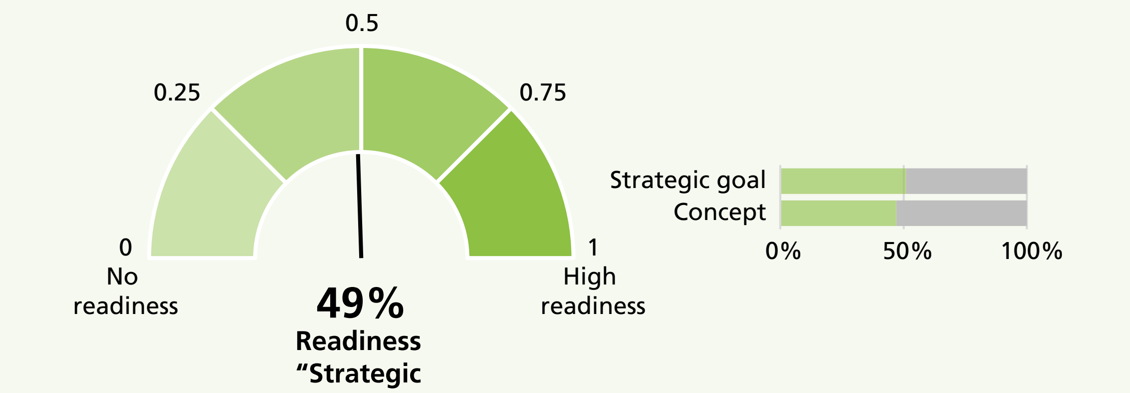
Readiness in the area of "strategic goal and concept"

Readiness in the area of "strategic goal and concept" is in the mid-range of "implementation" readiness (see fig. 72). On average, strategic goals and concepts have already been drafted, but are yet to be implemented. Companies are slightly further ahead in the area of strategic goals (mean readiness of 0.51) than of concepts (mean readiness of 0.47).

A comparison of industry groups shows a very similar readiness with respect to strategic goals (cf. fig. 71). Leading the way in this area are OEMs in the mobility sector (mean readiness of 0.54), with companies in sectors for mechanical and plant engineering and equipment technology following close behind with a mean rating of 0.51. The mean rating for suppliers in the mobility sector is somewhat lower (0.47). This may be due to the fact that suppliers are further away from the customer and their requirements – and therefore from the actual use of the product in the field.

In the area of concept readiness, there is a similar distribution according to industry group. Here, too, OEMs lead with a mean readiness of 0.5 – somewhat lower than was registered in the area of strategic goal readiness. Companies in sectors for mechanical and plant engineering and equipment technology have a similar mean readiness in this area (0.47). Here, too, it is suppliers in the mobility sector that display the lowest mean readiness (0.42).

Figure 72: Mean readiness of all the interviewees in area of "strategic goal and concept"



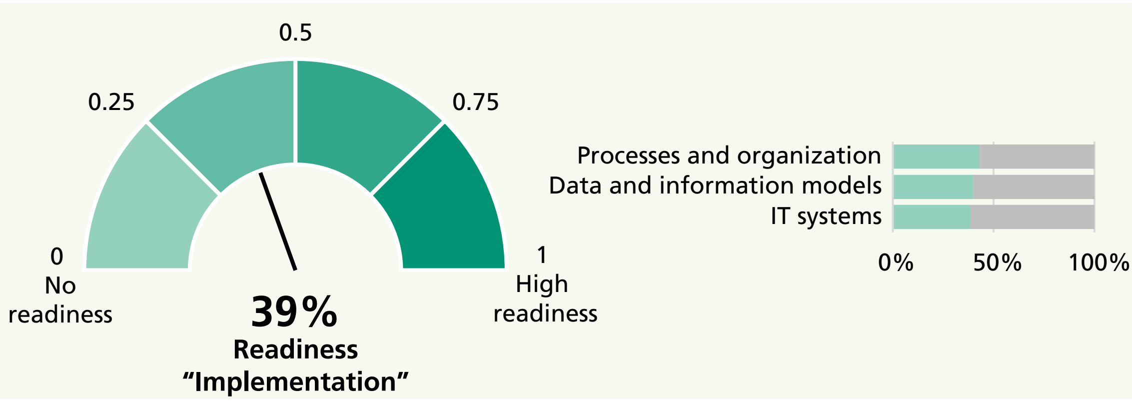
A comparison by area in which the interviewees work shows, once again, that dedicated staff units have the highest mean readiness in this area (0.6; cf. fig. 69). The interviewees working in IT receive a rating of 0.52. This is followed by development, with a mean readiness of 0.47, and production, with 0.45. In this area, management is only awarded a readiness rating of 0.4. This was contrary to expectations, since the basic assumption was that management departments would show strengths in strategic orientation. Here, too, follow-up research would seem advisable. Management also comes last in the area of concept readiness, with a mean rating of 0.25. The reason for this could lie in the lack of technical capabilities required for concept development. With a rating of 0.35, mean readiness in the area of production is higher – although here, too, not markedly advanced. IT, development and staff units are significantly further in terms of concept readiness, with mean ratings of 0.48 to 0.55.

Readiness in the area of "implementation"

The lowest level of readiness is in the area of "implementation", where companies are assessed with a mean readiness of 0.39 (see fig. 73). Implementation readiness is furthest advanced in the area of processes, organization and requisite skills, with a mean rating of 0.45. Here, however, mean readiness refers merely to concepts, whereas, for the most part, implementation has not yet commenced. The areas of IT systems (0.39) and data and information models (0.40) display a level of readiness that is even lower.

The breakdown by industry group shows that the order of implementation readiness

Figure 73: Mean readiness of all the interviewees in area of "implementation"



in the area of processes and organization is exactly the reverse of that observed in the area of concept readiness (see. fig. 71). In this case, it is suppliers in the mobility sector that lead the way, with a mean readiness of 0.48. This is followed by companies in sectors for mechanical and plant engineering and equipment technology, which display a mean readiness of 0.45, and OEMs in the mobility sector, with a mean readiness of only 0.42. With a mean rating of 0.4, implementation in the area of IT systems displays the lowest readiness of all three areas of implementation. Once again, as with processes and organization, it is suppliers in the mobility sector that display the highest readiness (0.43). Second in line are companies in sectors for mechanical and plant engineering and equipment technology, with 0.39, followed by OEMs in the mobility sector (0.36).

The third area of implementation – that of data and information models – receives a mean readiness rating of 0.4. Companies in sectors for mechanical and plant engineering and equipment technology perform best here, with a mean readiness of 0.45. One reason for this could be the advanced standardization of communication protocols for production machinery. OEMs in the mobility sector come second, with a rating of 0.4. This is followed by suppliers, with a readiness of 0.33. The low level of readiness on the part of suppliers could be due to their high dependency on OEMs. Initially, this data will be available from OEMs and has already been converted into suitable models.

The breakdown by area in which the interviewees work shows a varied picture (cf. fig. 69). As might be expected, it is management that displays the highest mean readiness in the area of processes and organization (0.55). Next come staff units and development, which perform almost as well, with readiness levels of 0.47 and 0.44 respectively. These are followed by production, with a mean readiness of 0.25. Reasons for this poor performance may lie in the focus on production systems. Ultimately, the implementation of Digital Twins in a production context necessitates changes to the entire product creation process.

The implementation readiness of IT systems in production is equally low (mean readiness of 0.15). This is substantially higher in other areas. As might be expected, IT performs best here (0.45) – this is, after all, its core competence – followed by management, staff units and development (0.42 to 0.37).

In the case of data and information models, it is once again dedicated staff units that perform best, with a mean readiness of 0.52 – significantly higher than the ratings for other areas. The reason for this may lie in the combination of IT and development-related knowledge in such departments. This is followed by the areas of IT and development, with a mean readiness of 0.41 and 0.37 respectively. It is here that production displays its highest mean readiness within the area of implementation, with a rating of 0.3. Here, too, this may be down to the advanced standardization and digitalization of manufacturing operations and the extensive use of digital control systems. Management displays the lowest level of readiness here, presumably due to a lack of detailed knowledge, with a mean readiness of 0.25.

Summary and conclusion

An assessment of all companies shows an average level of readiness with respect to the Digital Twin concepts considered. With an overall readiness of 0.51, companies are, by and large, still in the conception phase. In the area of "understanding and use" – including, therefore, experience in the use of Digital Twins – readiness is already well advanced (0.66). In the more operational areas, however, readiness tends to decline. In the areas of "strategic goal and concept," the consolidated readiness is 0.49, with a slightly higher rating in the area of strategic goals. The key considerations here are strategic objectives and the envisaged changes to business models. By far the least advanced level of readiness is in the area of "implementation," which comprises processes and organization, data and information models, and IT systems (0.39). On average, implementation measures are therefore still at the idea stage.

Overall, it must be emphasized that the introduction of Digital Twins will only succeed when a high level of readiness has been achieved across the areas specified of "understanding and use," "strategic goal and concept," and "implementation." It is only then that a Digital Twin will reliably generate the envisaged benefits.

The comparison of readiness between categories, industry groups and areas of work shows that the interviewees are still in the process of preparing for the implementation of Digital Twins. Here, it can be assumed that other industrial companies in the DACH region are to be rated somewhat below this mean readiness level, since participants for this study were specifically selected according to this criterion.

Although companies display overall a well-developed readiness in the areas of understanding and use, and strategic goal and theoretical concept, there are only a few actual implementations or isolated silo solutions already in operation.

A comparison according to industry groups reveals a difference between OEMs and suppliers in the mobility sector. At present, suppliers lack access to field data. Control over the product system and all the corresponding data lies with the OEM. Yet OEMs and suppliers alike have an interest in data consistency and data availability. Here, efforts to standardize product data across supply chains and industry sectors would be useful. In certain cases, IT system solutions, such as cloud systems or cross-company platforms, may also generate added value.

An analysis of all the concepts reveals that most companies are still working on individual solutions. However, added value for consumers will only emerge on a truly substantial scale through collaboration between different companies. In the actual implementation of Digital Twin concepts, greater consideration should therefore be given to accompa such as the development of smart products.

In a comparison of company departments, it is clear that staff units possess an advantage. In this form of organization, the knowledge required appears to be more readily available, with the result that companies display a higher level of readiness in the areas of strategic goal, concept and approaches to implementation.

SUMMARY AND CONCLUSIONS

Summary and conclusions

The study sought answers to the following key questions on the basis of expert interviews with 26 companies from the manufacturing industry in the DACH region:

- "How do Digital Twins impact business models?"
- "What added value should Digital Twins create?"
- "What defines today's Digital Twin concepts?"
- "What measures are required for the implementation of Digital Twins?"
- "What skills and capabilities are required for the implementation of Digital Twins?"

The study begins with a scientific introduction to the topic of Digital Twins. This is followed by a presentation of the design and execution of the study. The aggregated findings in each area of questioning were examined in detail: the understanding and actual use of Digital Twins in industry; business models; strategic goals and added value; Digital Twin concepts along with implementation methods and required skills. In addition, the future of Digital Twins and their potential to boost sustainability was discussed. Each interview was then assessed in terms of the readiness of the Digital Twin concept under consideration and these findings presented in the study. Below, the essential findings for each of these key questions are presented.

How do Digital Twins impact business models?

There are numerous expectations associated with the introduction of Digital Twins. Across the wide range of possible use cases, of Digital Twins, no common motive or impact on business models could be determined. In principle, however, 35% of companies expect that Digital Twins will change their business model and 27% hope to be able to offer new products. It is striking how many of the interviewees say that their prime goal is to tackle classic problems in the field of product life cycle management. On the one hand, the idea of the Digital Twin derives from the ideal image of a product life cycle management system that considers a product across its entire life cycle, reusing and updating data and models from the development phase. On the other hand, Digital Twins can be used to feed information back into the product life cycle and thereby help companies learn how to enhance the design of new products. This presupposes data consistency and a development and operational environment optimized for this purpose. The added value of Digital Twins is therefore often seen in classic life cycle management scenarios and not just primarily in the development of new business models.

A particular challenge arises from the need for collaboration across companies. It is therefore vital to think about topics such as information and data consistency, processes and organization and IT systems on a cross-company basis. In many use cases, Digital Twins cannot be implemented by individual companies. In fact, it is likely that in the future a number of Digital Twins will cooperate within a single product system. This will require a standardization of platforms and ICT interfaces. With regard to these external changes, more companies are now saying they want to offer services based on Digital Twins – which also corresponds to accompanying trends such as the introduction of smart products.

At the same time, many of the companies interviewed are focusing more on internal goals such as reducing costs, enhancing quality or increasing efficiency. All of these rely on the feedback of information derived from field data. This poses a challenge for suppliers, who usually do not have access to the actual product systems. We can therefore assume that a market for field data will emerge, which in turn may indirectly give rise to new business models.

Overall, the anticipated changes to business models are assessed as disruptive. While Digital Twin models are not regarded in themselves as new products, companies do believe that they will lead to new products and add new service components to their business model. As such, Digital Twins can be understood as a key technology in future value creation.

What added value should Digital Twins create?

The expected added value of Digital Twins among the interviewees is as diverse as the expected impact on business models. In general, companies are looking to realize added value both internally and externally. Inside companies, the focus is on improving processes, products and economic factors. Digital Twins will therefore take on a central, value-creating role within companies. In particular, it will be necessary to adapt internal working methods – specifically those in product development and production planning – to this new source of information and to amend and augment existing processes and infrastructure accordingly. By contrast, external value is to be generated in the area of services and by means of greater customer loyalty.

This growing range of value-added services will be based, on the one hand, on the platform that the Digital Twin creates for the provision of such services, and, on the other hand, on newly available information on potential consumer needs and consumer behavior.

Stronger ties to customers arise in two ways. Firstly, the use of product systems will also embed their Digital Twins within a larger context. This applies especially to companies in sectors for mechanical and plant engineering and equipment technology. Here, components will be linked to large mechanical or plant systems with their own Digital Twins. This integration results in a dependency on the value-added services offered in conjunction with the product and via the interfaces created for this purpose. Secondly, the improved availability of data will mean that Digital Twins can be adapted to user requirements. The new knowledge generated by Digital Twins linked to products or systems will tie customers closer to the supplier of the Digital Twin services. At the same time, we may see the emergence of neutral platforms that provide such services independently of hardware suppliers. Overall, the focus on benefits is evident in the alignment and expectations of the added value through Digital Twins.

What defines today's Digital Twin concepts?

By and large, the concepts submitted for this study reflect the many different expectations that companies have regarding the added value that might be realized with Digital Twins and the envisaged changes to business models.

A comparison of the concepts submitted shows that a lot of Digital Twins are intended for simple tasks. Examples of such tasks include the collection and processing of information in order to represent current system status. In such cases, it is striking how wide the gap is between such concepts and companies' envisaged goals. Very few concepts also consider automated valued-added services and autonomous or adaptive systems. Here, too, it is clear that the first step must be to achieve data and information consistency. As noted above, some of the concepts do not meet the actual definition of a Digital Twin. This shows the importance of Digital Twins for company competitiveness.

Viewed over the entire product life cycle, Digital Twins are used primarily in development, production planning, and service. In line with its definition, the digital shadow arises primarily in the use phase and production phase. On closer inspection, however, it is clear that there is still a lack of data and information models for the Digital Twin, both for the requisite master models and for representing the system in the digital shadow. For the purposes of interaction, most concepts envisage a human interface, which is itself in accordance with the notion that the primary task of a Digital Twin should be to provide information. None of the concepts really envisage the idea of an autonomous Digital Twin that can directly control product systems via suitable interfaces. Similarly, there is no clear picture of how Digital Twins might cooperate with one another, particularly across company boundaries. However, progress is needed in this area in order to generate added value for customers.

Digital Twins for product development

Here, the focus is on the provision of information – in particular, the support of fault analyses. The idea is to use available system data to generate a deeper understanding of the product system and the way in which it is actually used. At the same time, product data collected in the field is to be used to further develop simulation models. The aim here is to represent the operating environment of subsequent product generations as accurately as possible and thereby make validation processes more reliable. In the future, product features will be validated by means of simulation, especially when they are to be introduced by means of software updates to products already on the market.

One feature that still attracts far too little attention is the use of Digital Twins in the automation of development activities.

Digital Twins for production and production planning

In the area of production planning, Digital Twins perform value stream optimization and help streamline assembly operations. In particular, this includes the challenge of replanning during ongoing production operations or for brownfield scenarios, when current or new machinery and plant has to be integrated in legacy systems. In such cases, the chief purpose is to provide digital representations of such legacy machinery or plant. First and foremost, this means maintaining high-quality, up-to-date geometric models of production systems to ensure reliable scheduling of material and information flows and to avoid any disruptions to ongoing production. At the same time, Digital Twins can be used to validate various production scenarios. This ensures that capacity utilization and production of different variants can be validated in advance and compared to current production operations.

As previously mentioned, unlike their use in development, Digital Twins in production planning undertake basic planning tasks such as value stream optimization, although they are not yet entrusted with the responsibility for controlling production operations. This is because of a lingering skepticism about the use of autonomous systems to control what are, in some cases, safety-critical processes in the production environment. Confidence in Digital Twins and their ability to perform reliably is still relatively weak, and this continues to hinder their use as autonomous systems. In particular, a lack of experience in this area means that Digital Twins are not yet trusted to make independent decisions in the production environment.

Digital Twins for inspection, maintenance and services

The ability to offer value-added services on the basis of Digital Twins is one of the goals of new business models and one of the benefits that companies hope to achieve. However, this is not reflected in the concepts examined. Initial approaches in this area focus on the use of Digital Twins to monitor system behavior and identify any divergence from normal operation. In this instance, the Digital Twin takes over some of the communication with consumers and offers these functions directly. Certain concepts envisage a system with additional features that can be activated as needed – as already practiced in other industries.

In other concepts, Digital Twins play a key role in the supply of spare parts and offer great potential in the after-sales market. Here, Digital Twins are used to monitor components of product systems and to identify any divergence from normal operation or to notify when they are approaching the end of their service life. In addition, the Digital Twin informs the spares department that a new part is required and initiates the necessary maintenance work. This ensures that spare parts are supplied and installed on time, thereby reducing machine downtime.

In this case, the Digital Twin – unlike in development and more fully so than in production planning – takes on core activities in the area of maintenance.

The future of Digital Twins

First and foremost, the future will see Digital Twins take on more activities and also greater responsibility. This will rely heavily on the use of artificial intelligence and machine learning. Companies have a variety of goals here ranging from enhanced simulation, more precise forecasting and greater interaction and communication with customers to using Digital Twins for value-creating activities in development and production.

What measures are required for the implementation of Digital Twins?

To prepare for the introduction of Digital Twins, companies will need to implement a range of measures across all the relevant areas of the development and operational environment, including processes and organization, data and information models and IT systems. In general, this will require a transformation of corporate culture and company organization, especially when significant changes to the business model are required. Any such changes should be comprehensively planned and implemented. Companies often opt to optimize their processes, IT systems and data models on an individual basis. In the context of Digital Twins, however, this leads to very high costs, meaning that a holistic approach should be adopted from the outset.

With regard to company organization, the interviewees expect new positions to be established in the new areas of responsibility for development and operation of Digital Twins. As a result of the partly parallel, partly serial development of Digital Twins, increasingly agile structures can be expected. Collaboration between the various disciplines – electrical engineering and electronics, mechanical engineering, software and services – will play a key role in ensuring a fully integrated system. At the same time, systems engineering needs to become the standard procedure in the area of product development.

As yet, such modifications have not been planned in detail. Similarly, changes to existing processes – the use of Digital Twins in development, in enabling system functions, as new sources of information, in operations and maintenance – must also be addressed. The assignment of responsibilities is still unclear, especially between the two areas of product development and IT. This is where dedicated staff units, designed to introduce Digital Twins in a holistic way in companies, show their strengths. On the basis of this comprehensive approach, companies can then move on to further challenges of developing Digital Twins: the identification of existing models for digital masters and digital shadows, the creation of new ones, and their connection to one another. The ongoing digitalization of product development means that master models are already available in many instances. However, these still require processing and classification for use with the concept in question, and they must also be connected to one another.

In some cases, the data for the digital shadow has to be collected manually – i.e., without an automated process and without data consistency. In part, this procedure is highly unreliable. In certain cases, asynchronous communication between the product system and Digital Twin can significantly diminish the potential of a use case. This could be due to a lack of effective communication between a product and its twin. At the same time, legal uncertainties and national legislation can hinder the rapid implementation of solutions. Companies have been using new technologies to collect product-specific data for a number of years now. Here, however, the need to pay attention to data semantics is very often neglected. This makes it more difficult to process the data for use with a Digital Twin.

Simulations play a key role when it comes to Digital Twins. For example, the ongoing comparison of predicted and actual product behavior creates a basis upon which additional added value can be generated.

What skills and capabilities are required for the implementation of Digital Twins?

As a rule, a Digital Twin is a complex system that involves a wide combination of skills and capabilities. These include not only IT skills (the development of architectures, frameworks, communication systems and data-storage systems) but also technical skills (defining information needs; conception and modeling of services and system behavior). Disciplines such as systems engineering have always explored ways of integrating different domains and therefore provide a good starting point for the development of Digital Twins. Alongside an expansion of specialist knowledge in IT and engineering, this also requires further education and training for people in how to think about systems in a holistic way.

Key findings

Digital Twins must always have a purpose.

By way of summary, it can be said that Digital Twins and their use are not an end in themselves. Whatever the concept and whatever the implementation, there must always be a clear link to added value and, at the same time, a high degree of future viability with regard to additional applications. Only fully transparent motives based on business requirements can justify the great expense and effort needed to implement Digital Twins.

In terms of prior knowledge and understanding, industry is ready for the use of Digital Twins.

The interviewees display a good understanding with regard to Digital Twins. This shows that the knowledge provided by expert committees, consultants, research institutes and scientific bodies provides a good basis upon which to develop a sound and comprehensive understanding of Digital Twins. The knowledge acquired in this way can then be extended through experience in the practical use of Digital Twins.

The connection of existing models for Digital Twins still poses a major challenge.

This is particularly evident when examining the definitions of Digital Twins provided by the interviewees. For all the interviewees, the core function of a Digital Twin is to represent a product or production system on the basis of data collected in the field. However, the need to relate such field data to other data describing the product or production system is rarely mentioned. These master models are often neglected and the need to prepare them for further use with a Digital Twin forgotten.

Digital Twins are still frequently developed and used as isolated solutions.

There is clear gap between planned changes to business models and the operative implementations that companies envisage. This is presumably due to the need to make necessary enhancements to existing product life cycle management systems. In some cases, the concepts show that isolated solutions have been established for highly specific use cases but, at the same time, a highly global approach to general data collection and storage has been designed. Doubtless, both these approaches represent a legitimate entry into the world of Digital Twins – provided that they each offer scope to expand either specifically or globally, in line with company strategy.

Digital Twins have so far been used for basic tasks.

At present, Digital Twins are largely used for the basic tasks of information provision and compression. As yet, they have not been assigned responsibility for decision-making or coordinating processes. The reason for this seems to be a lack of trust in the models and algorithms used.

Digital Twins will be in widespread use within the next 20 years.

A lot of hope is being invested in Digital Twins. At the same time, the prospect of being able to generate added value both internally and externally means that companies are more than ready to press ahead with the implementation of Digital Twins. Here, the focus falls on greater automation and increased provision of information, especially with regard to sustainability indicators.

Digital Twins hold great potential to assess environmental sustainability.

Many of the interviewees see major potential for the use of Digital Twins in the area of sustainability. In their view, Digital Twins offer a sound basis for the analysis of material and energy flows. In fact, they are already being used in energy monitoring. Digital Twins may well provide the digital foundation for an increasingly sustainable value creation. Likewise, there are plans to use Digital Twins to represent the ergonomics of manual activities in the production environment, for example.

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For many companies, Digital Twins provide an opportunity to gather direct information on how their products are used in the field. This knowledge can form the basis for the user-centric optimization of successor products or new business models.

By taking data from production into account, it becomes possible to assess individual components or systems and forecast the length of their service life or likelihood of failure with increasing precision. By the same token, Digital Twins can also be used to represent elements of the supply chain in an effort to optimize production and supply processes. This in turn leads to products that can be used in a more sustainable way.

As a rule, companies have a clear vision of where Digital Twins should take them. But where do companies stand in the development and introduction of Digital Twins in regard to this vision?

Im Rahmen dieser Studie wird mithilfe des innovativen Reifegradmodells, welches von der msg und dem Fraunhofer IPK entwickelt wurde, ermittelt, wie weit die fertigende Industrie in der DACH-Region auf dem Weg zum Einsatz Digitaler Zwillinge ist. Folgende Kernfragen stehen in dieser Studie im Vordergrund:

- "How do Digital Twins impact business models?"
- "What added value should Digital Twins create?"
- "What defines today's Digital Twin concepts?"
- "What measures are required for the implementation of Digital Twins?"
- "What skills and capabilities are required for the implementation of Digital Twins?"

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