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SCENARIO ANALYSIS TO DETERMINE TRANSFORMATION PATHS FOR IOT-BASED BUSINESS MODELS

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Anne Seegrün, Sonika Gogineni, Dr. Kai Lindow

Fraunhofer Institute for Production Systems and Design Technology IPK

in cooperation with Swissbit Germany AG

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Executive summary

The aim of the study was to explore IoT trends and, building on this, to develop scenarios for future IoT-based business models. For the analysis and identification of relevant future scenarios, the systematic methodology of scenario analysis by Gausemeier and Plass [GP14] was followed. In line with the scientific method of the scenario analysis, the first step is the analysis of the scenario field by identifying influence areas relevant to IoT-based business models. Based on initial research, key influencing factors within these influence areas were derived. This was followed by expert interviews, to identify possible transformation paths of the influencing factors over the next 5 years. By analyzing the consistency of these development options, corresponding future projections were clustered to develop future scenarios for IoT-based business models.

The first scenario reflects the uncertainty of future developments due to the lack of overarching standards and the absence of major innovations. According to this scenario, only streamlining of internal processes and systems is recommended. The second scenario projects a future with advanced technological developments related to IoT and data-driven innovations. If this scenario occurs, it is advisable in the context of business model adaptation to establish new product, service, or product-service-system opportunities. In the third scenario, a major technology leap with disruptive innovations is expected. For companies, the occurrence of this scenario would mean accelerating the development process and increasing their responsiveness to new business field developments.

Based on the probability of occurrence indicated by the experts and the results of the cluster analysis, Scenario 2 has the highest significance for the development of a strategy for IoT-based business models. Nevertheless, in the event that Scenario 3 occurs, alternative strategies must be agreed upon in order to prepare future IoT-based business models for the changes and development options expressed in the respective scenario.

We would like to thank Swissbit Germany AG for their support in enabling the study.

1 Structure of the study

The aim of the study was to examine IoT trends against the backdrop of digitalization and, building on this, to develop scenarios for future IoT-based business models. To this end, influencing factors that have a major impact on the design of future IoT-based business models were identified in workshops using the methodological approach of scenario analysis. By clustering development options of these influencing factors, relevant future scenarios could be derived. Figure 1 provides a schematic overview of the overall procedure of scenario analysis as the methodological basis for the present study. The respective sub-steps and the generated results arising from them are examined in more detail in the following chapter.

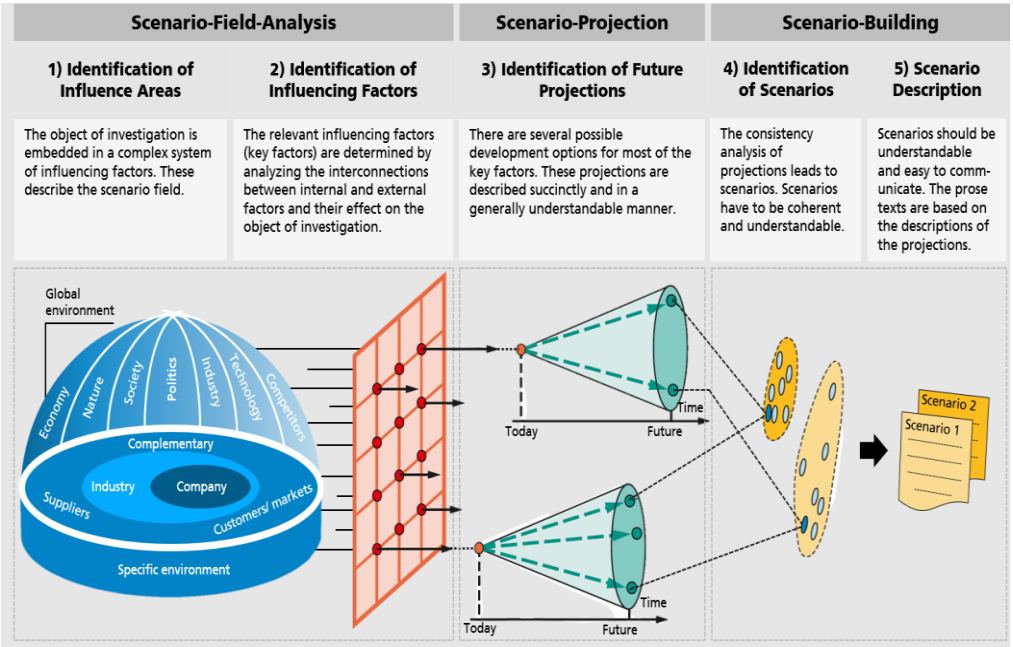


Figure 1: Procedure of scenario analysis [GP14]

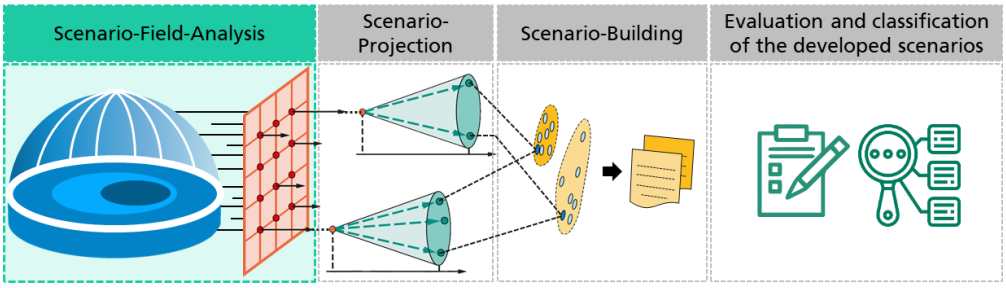
The study was divided into the following three steps (Table 1). A more detailed description of these steps with the corresponding objectives, applied methods, and achieved work results can be found in the following sections.

Table 1: Steps of the project with description

Steps	Description	Results
Step A	Identification of influencing factors (Key factors) within influence areas of the scenario field	Key factors for scenario analysis (Input for Step B)
Step B	Development of future projections of key factors via expert interviews and questionnaires and development of future scenarios.	Future scenarios (Input for Step C)
Step C	Classification of developed scenarios with regards to the significance for IoT-based business models	Classification of the scenarios regarding their probability of occurrence and their significance

2 Step A | Scenario-Field-Analysis

2.1 Overview



Aim

The main objective of Step A was to identify relevant key factors according to global trends and development directions for IoT-based business models. This in turn forms the basis for the scenario-projection and the scenario-building in Step B. The corresponding references for deriving the key factors can be found in Appendix 5.1.

Structure

Step A consists of three sub-steps as depicted in Table 2. The first step is to identify initial influence areas followed by identification of particular influencing factors in these areas. The last step is to prioritize and identify the key factors among the influencing factors.

Table 2: Structure and key contents of Step A

Step A: Identification of key factors
Step A.1: Identification of influence areas
- Identification of initial influence areas - Detailing and identification of further influence areas - Workshop on defining final influence areas
Step A.2: Identification of influencing factors
- Conduction of semi-structured interviews in industry and academia - Evaluation of interviews - Elaboration of influencing factors
Step A.3: Identification of key factors
- Conduction of workshops to evaluate influencing factors - Validation of identified key factors

2.2 Step A.1: Identification of influence areas

In the first step, the scenario field was divided into so-called **influence areas**. These are areas that directly surround the object of study as well as areas of the global environment in which companies that are interested in IoT-based business models operate. The validation and expansion of an initial collection of influence areas by experts resulted in the identification of the following final influence areas [Aun12]:

1. Economy
2. Nature
3. Society
4. Politics
5. Industry
6. Technology
7. Competition
8. Business models

2.3 Step A.2: Identification of influencing factors

Within these 7 influence areas, so-called influencing factors were identified. The initially compiled catalog of influencing factors within the respective influence areas was verified and expanded with experts. A total of 51 influencing factors were identified. The complete list of all influencing factors can be found in Appendix A. From the 51 identified influencing factors, those had to be determined that particularly shape the scenario field and exert a particularly high influence on the industrial environment. As part of the direct influence analysis, the direct relationships between the influencing factors were first considered. Subsequently, indirect relationships between the influencing factors were also included in the indirect influence analysis. The relevance analysis was used to determine the significance of the influencing factors for the object of study. For this purpose, an influence matrix and a relevance matrix were compiled and filled. The row sums of the influence matrix indicate the active sum and the column sum indicates the passive sum of the respective influencing factor. The active sum corresponds to the degree of influence that an influencing factor exerts on all other factors in total. The passive sum, on the other hand, indicates the degree to which an influencing factor is influenced by all other factors in the sum. Overall, these two sums provide a measure of which influencing factors are most relevant and thus may represent **key factors** that particularly shape the scenario field. The key factors form the basis for the further analysis steps. Table 3 shows all key factors and the corresponding active and passive sums as well as the relevance values. The active sum contains values between 16 and 79, the passive sum contains values between 1 and 77, and the relevance contains values between 1 and 48. A more detailed description of the key factors can be found in Appendix B.

Table 3: List of key factors with the active sum, passive sum, and relevance value

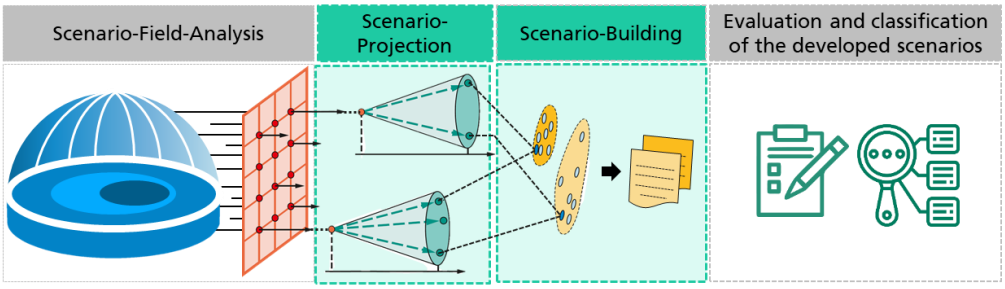
No.	Key factors	Active sum	Passive sum	Relevance
1	Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization	*79*	*51*	*32*
2	Infrastructure strategy for the IT network from politics	78	52	35
3	Netcom (network communication) & mobile communication	77	63	48
4	Regulation of data protection and data security from politics	73	38	36
5	Information technologies	69	61	37
6	Secure data storage solutions in embedded applications	61	75	24
7	Mobility solutions	68	71	43
8	Smart Infrastructure / Building / Home	52	71	40
9	Manufacturing (IIoT) / Industry 4.0	78	77	40
10	Service concepts: data business models (customers, partners)	47	69	39
11	Sensor and detection systems	73	60	46
12	Hybrid solutions (cooperation between cloud and local devices)	53	62	26
13	Surveillance (including dash and body cameras)	40	50	48
14	Devices and solutions for medicine and healthcare	41	61	46
15	Micro integration / miniaturization	52	62	38

2.4 Results

The variety and diversity of the identified key factors reflect the broad spectrum of influences that companies face when designing and establishing IoT-based business models. In the following chapter, the future projections of the respective key factors, as well as the future scenarios, are developed based on the findings of the previous sections.

3 Step B | Scenario-Projection and Scenario-Building

3.1 Overview



Aim

The steps of scenario-projection and scenario-building aim at taking a look into the future. In line with the methodological approach of scenario analysis, several future development paths are first described for each key factor. These development paths of the corresponding key factors, the so-called **future projections**, were developed with the help of expert interviews and form the essential basis for deriving future scenarios. By evaluating the projections in terms of their consistency and clustering those according to their compatibility to one another, future projections were finally combined into scenarios.

Structure

Table 4 shows the structure and the key contents of Step B. In a first step, suitable experts were identified, contacted, and interviewed concerning the key factors listed in Table 3 (Chapter 2.3). In individual cases, questionnaires were also distributed and evaluated. The analysis of the interviews enabled the derivation of future projections for each key factor (Chapter 3.3). These future projections were evaluated with regard to their consistency with one another in order to prevent the depiction of contrary developments within a scenario. Based on this consistency analysis, all possible future projection bundles were created and clustered. The analysis results are highly consistent, mutually delimited clusters of future projection bundles that can be combined into scenarios.

Step B: Scenario-Projection and Scenario-Building
Step B.1: Development of future projections with the help of expert interviews
- Preparation of interview guidelines and questionnaires - Identification of possible interview partners - Contacting interview partners and scheduling interview appointments - Conduction of interviews
Step B.2: Development of future scenarios
- Transcribing conducted interviews - Mapping future projections - Conduction of cluster analysis of future projections - Derivation of future scenarios

Table 4: Structure and key contents of Step B

3.2 Step B.1: Development of future projections with the help of expert interviews

As a first step, a template for a questionnaire and an interview guideline for the expert surveys were created. Subsequently, suitable experts were identified, contacted, and interviewed according to their expertise within the individual key factors. In individual cases, questionnaires were also distributed to the respective experts. The following table provides an overview of the number of conducted interviews or completed questionnaires per key factor.

Table 5: Number of interviews/ questionnaires per key factor

No.	Key factor	Questionnaires	Interviews
1	Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization [OEC14]	1	1
2	Infrastructure strategy for the IT network from politics	0	2
3	Netcom (network communication) & mobile communication [Fro20]	1	2
4	Regulation of data protection and data security from politics [Kah20]	4	-
5	Information technologies [OC19]	4	-
6	Secure data storage solutions in embedded applications [SUL20]	3	-
7	Mobility solutions [Pla20]	3	-
8	Smart Infrastructure / Building / Home [Gum21]	5	-
9	Manufacturing (IIoT) / Industry 4.0 [LKT19]	-	1
10	Service concepts: data business models (customers, partners) [Mou+18]	1	2
11	Sensor and detection systems [Moh+21]	3	2
12	Hybrid solutions (cooperation between cloud and local devices) [Sch+18]	2	-
13	Surveillance (including dash and body cameras) [Yan19]	5	1
14	Devices and solutions for medicine and healthcare [RTR21]	1	1
15	Micro integration / miniaturization	1	0

A total of 27 experts from different areas of expertise were interviewed. Table 6 shows the industry affiliation of the respondents.

Sector	Leadership position	Employee
Applied research	6	4
Mobility	2	2
Software company	4	1
Medical technology	2	-
IoT / Industry 4.0	2	2
Associations	2	-

Table 6: Industry affiliation of the respondents

3.3 Step B.2: Development of future scenarios

From the expert interviews, three future projections were developed for each key factor. Each of the projections are described in detail in Appendix C. The following table contains brief descriptions of the respective projections per key factor:

No.	Key factors and their Projections	
1	**Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization**	
	Projection A	Digitalization is lagging behind, no uniform standards
	Projection B	Bottom-up digitalization and defacto vs. public standards
	Projection C	Global networking and standards for maximum interoperability
2	**Infrastructure strategy for the IT network from politics**	
	Projection A	Digital (Infrastructure-) Beginner
	Projection B	Digital (Infrastructure-) Follower
	Projection C	Digital (Infrastructure-) Expert
3	**Netcom (network communication) & mobile communication**	
	Projection A	5G is introduced slowly
	Projection B	5G is standard in metropolitan areas
	Projection C	5G as a nationwide standard
4	**Regulation of data protection and data security from politics**	
	Projection A	Easing of data protection leads to a lack of trust
	Projection B	Data security leads to liberal data traffic
	Projection C	United Europe in data protection regulations
5	**Information technologies**	
	Projection A	New digital territory
	Projection B	Digital exploration
	Projection C	Digital transformation
6	**Secure data storage solutions in embedded applications**	
	Projection A	Secure data storage as a novelty
	Projection B	Secure data storage as a standard
	Projection C	Secure data storage as the rule

Table 7: Short description of projections per key factor

No.	Key factors and their Projections	
7	**Mobility solutions**	
	Projection A	New mobility concepts being tested
	Projection B	New mobility concepts suggest suitability for everyday use
	Projection C	New mobility concepts prove their suitability for the masses
8	**Smart Infrastructure / Building / Home**	
	Projection A	Smart City 4.0 a long way off
	Projection B	Smart City 4.0 within reach
	Projection C	Smart City 4.0 widespread
9	**Manufacturing (IIoT) / Industry 4.0**	
	Projection A	Partial automation and retrofitting
	Projection B	Further development of partial automation
	Projection C	Full automation and smart factories
10	**Service concepts: data business models (customers, partners)**	
	Projection A	PSS is being implemented in some cases
	Projection B	PSS becomes marketable on a large scale
	Projection C	PSS as a natural necessity
11	**Sensor and detection systems**	
	Projection A	Sensor solutions as nice-to-have
	Projection B	Sensor solutions as should-have
	Projection C	Sensor solutions as must-Have
12	**Hybrid solutions (cooperation between cloud and local devices)**	
	Projection A	On-premise-solutions
	Projection B	Hybrid Cloud-/ on-premise-solutions
	Projection C	Cloud-solutions
13	**Surveillance (including dash and body cameras)**	
	Projection A	Large political and social barriers to expansion
	Projection B	Data protection-compliant expansion of monitoring
	Projection C	More surveillance means more security
14	**Devices and solutions for medicine and healthcare**	
	Projection A	Digital is fatal
	Projection B	Digital would be ideal
	Projection C	Digital becomes real
15	**Micro integration / miniaturization**	
	Projection A	Improvement existing solutions and systems
	Projection B	Development of new solutions and systems
	Projection C	Breakthrough in quantum technologies

A consistency analysis was conducted based on the projections listed in Table 7. This analysis assists in developing consistent future images, based on the compatibility among individual projection pairs. The pairwise consistency analysis is carried out using a consistency matrix. The matrix is filled with consistency values representing the scale of consistency, ranging from 1 (absolute inconsistency) to 5 (absolute consistency). For reasons of simplicity the consistency matrix is not presented in this report. Based on the consistency analysis of the projections listed in Table 7, a set of possible projection bundles were determined. Each projection bundle contains only one projection per key factor (KF). Projection bundles that contain projections that were previously rated as absolutely or partially inconsistent with one another are excluded from consideration.

The remaining projection bundles are clustered based on their similarity are combined into scenarios. The table below shows the evaluation of the cluster analysis. The percentage composition is shown based on projections A, B, and C. All values above 90% are highlighted in a darker shade of grey.

Table 8: Percentage composition of scenarios as a result of the cluster analysis

	Scenario 1			Scenario 2			Scenario 3		
	Projections								
	A	B	C	A	B	C	A	B	C
KF	%	%	%	%	%	%	%	%	%
1	67	33	0	0	59	41	0	0	100
2	100	0	0	0	76	24	0	8	92
3	83	17	0	6	71	24	0	16	84
4	100	0	0	0	65	35	0	18	82
5	100	0	0	0	100	0	0	8	92
6	100	0	0	18	76	6	0	8	92
7	100	0	0	0	88	12	0	8	92
8	100	0	0	18	82	0	0	8	92
9	100	0	0	6	94	0	0	8	92
10	100	0	0	0	100	0	0	15	85
11	83	17	0	0	88	12	0	21	79
12	100	0	0	18	71	11	0	23	77
13	100	0	0	0	100	0	0	10	90
14	100	0	0	0	100	0	0	8	92
15	67	33	0	29	71	0	0	30	70

Table 8 shows that the scenarios differ fundamentally from one another. **Scenario 1: Uncertainties in technology development and usage** mainly contains the less advanced A-projections. **Scenario 2: Increasing technology acceptance as a driver for innovation** is a mix of B- and C-projections with a focus on the former and thus combines slightly progressive and a few advanced projections. **Scenario 3: Secure and intelligent networking** includes a larger number of advanced projections and is, therefore, the most progressive scenario. These 3 different scenarios are described below in prose.

Scenario 1: „Uncertainties in technology development and usage"

Political developments

Structural obstacles, outdated administrative regulations, and low affinity for digital topics in politics stand in the way of digitalization, broadband expansion, and the creation of uniform standards and norms. The dilapidated, slow IT infrastructure leads to IT security gaps and hinders the creation of networked data infrastructures. Confidence in data and IT security declines dramatically. In order to remain internationally competitive, data protection regulations nonetheless will be liberated allowing companies considerable freedom in value creation.

Industry developments

High expectations on key technologies have not been met due to technical obstacles. Technology-oriented industries in the fields of „Manufacturing (IIoT) / Industry 4.0", "Smart Infrastructure / Building / Home" as well as "Devices and solutions for medicine and healthcare" have made little progress and shown low innovation capability. In general, respective industries do not go beyond partial automation and retrofitting, and come up with smart and innovative solutions only in some cases. In the field of "Monitoring", the lack of public acceptance for the expansion of surveillance systems leads to stringent requirements for regulatory approval. Hence, the overall deployment of surveillance solutions is limited.

Developments in technologies

Progress in technology remains limited and, apart from a few exceptions, no major technological leaps are made. Existing technologies will only be moderately expanded and developed. Especially in metropolitan areas, 5G will gradually establish itself. New mobility concepts, such as autonomous driving, are being tested but are not yet being used on a large scale. Data security will mainly be business-driven. However, there will be scarce technical or automated support in the implementation of legal requirements for data protection. On the storage level, on-premise solutions will remain predominant, since data security for sensitive data is not yet advanced in the case of cloud services. In the field of sensor technology, the achievements are mainly associated to solutions leading to savings in cost and energy consumption as well as an increase in robustness. Within the corporate context, outdated IT architectures are predominant and industrial applications are largely upgraded through retrofitting.

Developments in business models

In the area of business models, product service systems (PSS) and data-driven service concepts are only being implemented cautiously. The value and importance of PSS are not sufficiently understood, and a large number of customers fear the loss of control and data in the event of a failure in the PSS provider environment. Nevertheless, the range of PSS offerings will experience moderate but stable growth.

Scenario 2: "Increasing technology acceptance as a driver for innovation"

Political developments

The gap between de-facto-standards (industrial standards) and de-jure-standards (legal standards of formal standardization bodies) is steadily narrowing. This specifically means that digitalization is being driven by companies but complemented by official standardization activities. This development sets the fundamental political and legal framework for digital business processes. Furthermore, the IT infrastructure is being significantly improved with the expansion of fiber optics and 5G. With security enhancements, vulnerabilities are increasingly being closed and the networking of data infrastructures is being driven forward. Data protection is recognized as a political and economic success factor, and procedures for data anonymization create trust and increase the willingness to exchange data.

Industry developments

Key technologies progress in some areas and thus produce innovations in the fields of „Manufacturing (IIoT) / Industry 4.0", "Smart Infrastructure / Building / Home" as well as "Devices and solutions for medicine and healthcare". In the production context, digitalization is being promoted and routine tasks are steadily being carried out automatically. Digital factory twins are increasingly penetrating medium-sized businesses as data provision systems. Driven by the Covid-19 pandemic, solutions in the field of "Smart Infrastructure / Building / Home" and "Devices and solutions for medicine and healthcare" are becoming more intelligent and have proven successful in practice. The technological upswing is also opening up new possibilities in the area of "Monitoring". Data protection-compliant storage media and reliable encryption enable increased use of cameras and storage of personal data.

Developments in technologies

Already existing technologies are subject to continuous development and improvement. 5G is being established and applied primarily in metropolitan areas and will continuously spread to rural areas. New mobility concepts, such as autonomous driving on test tracks or the ban on motorized private transport in metropolitan areas, are increasingly being implemented. Attention will primarily be focused on electric mobility. Data security is politically motivated, encouraged, and promoted. Technical, automated support in the implementation of legal requirements for data protection is progressively establishing itself in industrial applications. Innovations in storage solutions allow advanced functions in the area of synchronization, archiving, cloud cache management as well as data security and promote the widespread use of hybrid cloud and on-premise solutions. In the field of sensor technology, the integration of multi-sensors is increasing significantly. These are cost-effective, energy-efficient, networked, and equipped with intelligent functionalities. In addition, data storage

solutions are becoming significantly smaller and thus enable the intermediate storage and processing of signals directly on the chip/ edge device. In the corporate context, IT architectures are renewed and improved. They enable the efficient organization of business processes, production, and resource consumption.

Developments in business models

In the area of business models, product service systems (PSS) and data-driven service concepts are increasingly becoming a driver of digitalization and automation. The value and importance of PSS are recognized, and modular ready-to-use software, tools, and services further promote partial automation. Digital factory twins are steadily penetrating medium-sized businesses as data provision systems.

Scenario 3: "Secure and intelligent networking"

Political developments

With the help of large funding programs, the development of uniform standards and norms are promoted. These include the creation of far-reaching political and legal frameworks for digital networking of supply chains and the formation of digital ecosystems and business models at EU-level. This promotes the establishment of innovation hubs and helps companies to achieve technological leaps. Thanks to the extensive fiber-optic expansion, a high-performance, area-wide IT infrastructure is developed, and protected with reliable data and IT security. This enables digital, networked solutions to be used also in critical infrastructures such as hospitals. The alliance of European countries working on digitalization also promotes European data protection regulations. Europe is developing into a competitive and strong player in data protection concerns and uses this as a political and economic success factor for the management and control of international relations.

Industry developments

Producing pioneering innovations in the fields of „Manufacturing (IIoT) / Industry 4.0", "Smart Infrastructure / Building / Home" as well as "Devices and solutions for medicine and healthcare", further development of key technologies is carried out continously. In the production context, advanced digitalization concepts enable the first fully automated, networked, self-controlling plants and machines. Modular, ready-to-use software, tools, and services as well as "plug & produce" approaches enable a fast, flexible response to changes and customer-specific wishes. Digital factory twins across different sites connect the real and digital production of the entire entrepreneurial value creation. Driven by the Covid-19 pandemic, extensive intelligent solutions are being developed and put into practice in the field of "Smart Infrastructure / Building / Home" and "Devices and solutions for medicine and healthcare". The massive upswing in technology is also opening up new possibilities in the area of "monitoring". Security is equated with increasing surveillance and is widely accepted by the population. Data protection-compliant storage media and reliable encryption enable increased use of cameras, enhanced storage of personal data, and the use of technologies for biometric facial recognition.

Developments in technologies

Already existing technologies are subject to vast investments and advancements. 5G is fully established and used extensively. New mobility concepts, such as autonomous driving on test tracks or the ban on motorized private transport in metropolitan areas, have been successfully implemented in many cities. In addition, a comprehensive conversion to environmentally friendly drives are being undertaken and priority is being given to the extensive utilization of alternative fuels for transport applications such as hydrogen and fuel cells. Data security is a political prerequisite. Technical, automated support in the implementation of legal requirements for data protection, as well as modern and highly secure (on-board) solutions for encryption, signature, authentication, and data recovery, make data protection more practicable and applicable on a large scale. Reliable IT infrastructure enables many companies to move data storage to the cloud, causing a decline in storage-intensive devices. Only for highly sensitive data, on-premise or hybrid data storage solutions will remain the best alternative. Sensor fusion, intelligence, and networking are becoming the standard in the field of sensor technology. Major technological advances allow the development of cost-effective, compact, reliable as well as extremely sensitive sensor principles. Further innovative solutions, for instance, include energy harvesting, self-learning AI algorithms as well as systems-on-chip components. Quantum photonic packaging to overcome technical limitations is also within reach. In the corporate context, IT architectures are being significantly improved and, through the networking and autonomation of industrial applications, enable the use of IoT for the more efficient organization of business processes, production, and resource consumption. Furthermore, European alternatives for IT security solutions are being developed.

Developments in business models

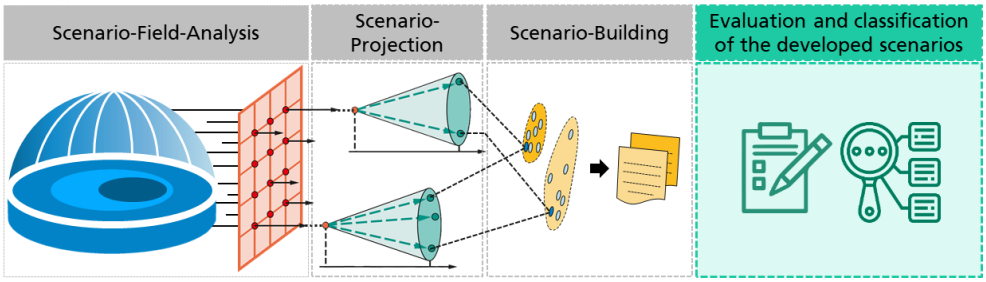
In the area of business models, product service systems (PSS) and data-driven service models have become key competencies for data-driven business management. Comprehensive, scalable, and easily manageable IoT technologies promote the acceptance and broad use of PSS. Companies implementing data-driven business models can clearly distinguish themselves from the competition. In addition, the power of data is widely understood, to the extent that data is used as a means of payment in some areas.

3.4 Results

Based on the findings of Step A (Chapter 2), the cluster analysis of the future projection bundles in Step B (Chapter 3) resulted in a total of 3 highly consistent, mutually delineating scenarios. **Scenario 1: Uncertainties in technology development and usage** describes the status quo with low innovation and weak progress. **Scenario 2: Increasing technology acceptance as a driver for innovation**, on the other hand, describes moderate progress and innovation in technologies and industries. **Scenario 3: Secure and intelligent networking** describes an innovation-driven future with major advances in technology as well as in the area of political measures and regulations. As part of Step C in the following Chapter 4, these scenarios are classified by the strength of their impact and their probability of occurrence.

4 Step C | Evaluation and classification of the developed scenarios

4.1 Overview



Aim

In this chapter, the scenarios developed in Step B are being evaluated and classified according to their strength of impact and probability of occurrence. The scenarios broaden the view on possible future development and therefore form a sound basis for a company's strategy development. In order to obtain indications of tomorrow's potential for success as well as possible threats to today's established business, respective scenarios need to be analyzed. This provides the foundation for the conception of a company-specific roadmap to determine transformation paths for IoT-based business models.

Structure

Table 9 shows the structure and the key contents of Step C.

Step C: Evaluation and classification of the developed scenarios
Step C.1: Analysis of developed scenario for strategy development
- Evaluation and classification of scenarios based on their strength of impact and probability of occurrence - Selection of reference scenario

Table 9: Structure and key contents of Step C

The evaluation was conducted in a workshop by considering the results of the interviews and questionnaires.

4.2 Step C.1: Analysis of developed scenario for strategy development

In order to identify the scenario (reference scenario) with the greatest significance for strategy development, the developed scenarios need to be analyzed according to their strength of impact and probability of occurrence. The strength of impact indicates the degree of change/modification for today's business. The probability of occurrence, however, indicates how likely the occurrence of a scenario is from today's perspective. The evaluation and classification of the three developed scenarios result in the following portfolio as shown in Figure 2.

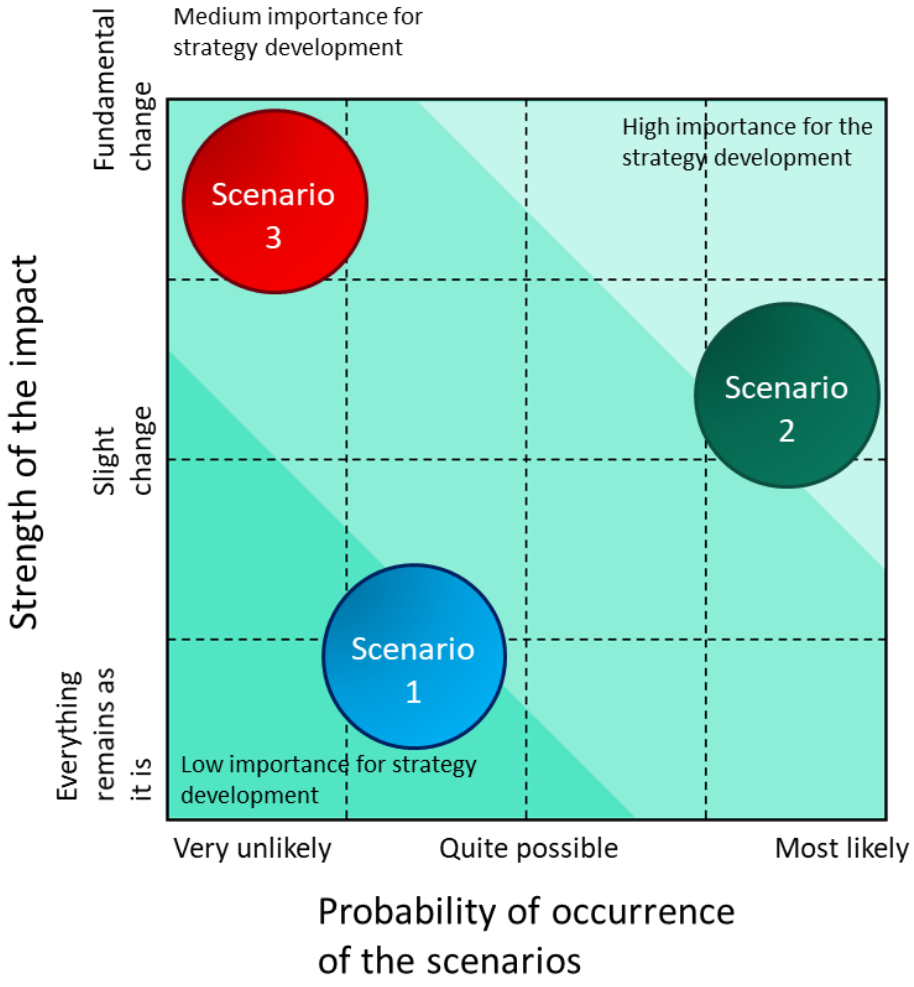


Figure 2: Evaluation and classification of scenarios based on their strength of impact and probability of occurrence

Scenario 1: Uncertainties in technology development and usage is located in the lower-left area of the portfolio and has a low significance for strategy development due to its low probability of occurrence combined with a low impact on the field of consideration.

Scenario 2: Increasing technology acceptance as a driver for innovation has a high significance for strategy development due to its relatively high probability of occurrence combined with a high impact on today's business.

Scenario 3: Secure and intelligent networking has a medium significance for strategy development due to the low probability of occurrence but at the same time fundamental changes in the boundary conditions.

Focused strategy development should be consistently geared to the occurrence of only one scenario. According to its strength of impact and probability of occurrence, **Scenario 2: Increasing technology acceptance as a driver for innovation** has the greatest significance for strategy development and therefore represents the reference scenario. In future-robust strategy development, companies gear themselves up for the occurrence of several scenarios. However, since this always involves a waste of resources, **Scenario 3: Secure and intelligent networking** should only be included as an alternative strategy in the derivation of development paths for future IoT-based business models.

4.3 Results and Outlook

The aim of the study was to explore IoT-trends and, building on this, to develop scenarios for future IoT-based business models. For the analysis and identification of relevant future scenarios, the systematic methodology of scenario analysis was followed. In line with the scientific method of the scenario analysis, the first step included the analysis of the scenario field by identifying influence areas relevant to IoT-based business models. Based on initial research, key influencing factors within these influence areas were derived. This was followed by expert interviews, to identify possible development options of the influencing factors over the next 5 years. By analyzing the consistency of these development options, corresponding future projections were clustered to develop future scenarios of possible transformation paths for IoT-based business models. By obtaining future-relevant information in the context of IoT trends, the scenario technique helps to anticipate opportunities and threats for the future as well as established business and to determine transformation paths for IoT-based business models. Accordingly, the scenarios developed can be used to assist companies in drawing up roadmaps and developing IoT-based business models.

Based on the probability of occurrence indicated by the experts and the results of the cluster analysis, Scenario 2 has the highest significance for the development of a strategy for IoT based business models. Nevertheless, if Scenario 3 occurs, alternative strategies must be agreed upon in order to prepare future IoT-based business models for the changes and development options presented in the respective scenario.

For further strategy development, it is also essential to conduct further investigations into suitable target markets, products, services, and product-service systems. With the help of detailed market studies, suitable industries and partners can be identified whose needs can be satisfied through entrepreneurial value creation. Based on these findings, appropriate business models are then derived and developed. However, making a well-founded decision in line with identified futures may always involve certain business risks.

IoT-based business models mostly contain data-driven processes. In order to transform data into valuable information and systematically integrate it into a company’s value proposition, a data-driven business model has to be established. A comprehensive approach for developing such business models is the Business Model Canvas as depicted in Figure 3.

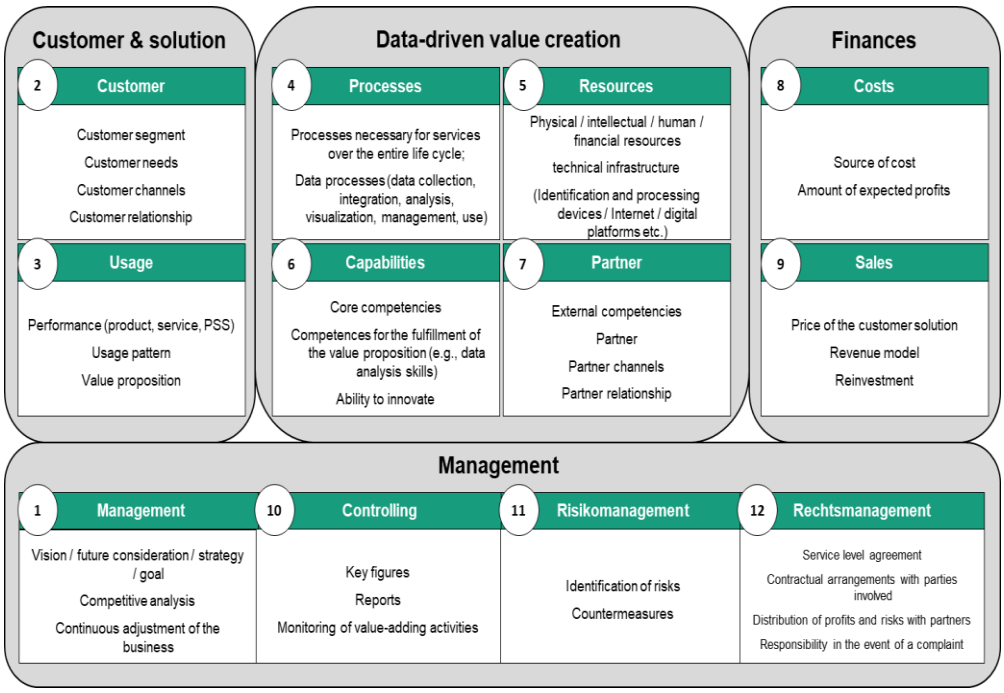


Figure 3: Data-driven business model canvas (EKS17)

With the help of a set of key questions for each of the 12 categories, companies using the method are guided through each aspect of the model. The systematic application of the model is supported by sequential steps as indicated by the numbering. The model provides guidance in designing data-driven business models and assists in detailing identified transformation paths for IoT-based value propositions.

5 Appendix

5.1 A: List of influencing factors

Table 10: List of influencing factors

Influence area	Influencing factor
Economy	Germany's attractiveness as a development location [Bun19]
	World trade
	Sectoral structural change [Klo18]
	Intersectoral structural change [Klo18]
	Deglobalization / Localization
Nature	Environmental goals / environmental agreements [Net19]
	Natural disasters
	Shortage of raw materials / resources
Society	Acceptance of new technologies
	Skilled workers
	Average age
	Change in working conditions
Politics	Regulation of data protection and data security from politics [Kah20]
	Infrastructure strategy for the IT network from politics
	Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization [OEC14]
	Sustainability strategy of the government
	Standardizations and norms from politics
	Research funding
	Subsidies
Industry	Manufacturing (IIoT) / Industry 4.0 [Fro20a, LKT19]
	Smart Infrastructure / Building / Home [Gum21]
	Mobility solutions (automotive, drones, electrification, ADAS including infrastructure [Pla20]
	Devices and solutions for medicine and healthcare [RTR21]
	Bionic & Robotic
	Point of Sale (POS)
	Surveillance (incl. Dash and Bodycams) [Yan19]
	Netcom (network communication) & mobile communication [Fro20a]
	Education (e-learning)
	Government and military applications
	Enterprise
	Data Centre / Data Management
	Energy industry

Influence area	Influencing factor
Technology	Low Power WAN / NB-IoT
	Sensor and detection systems [Moh+21]
	NFC/ BLE
	Microintegration / Miniaturization
	Materials
	Secure data storage solutions in embedded applications [Fro20b, Fro20c, SUL20]
	Lifecycle Monitoring
	Cloud & Data Analytics
	Human-Machine Interaction
	Cryptography
	Information Technologies [OC19]
	5G
Competition	Competitors - New suppliers and existing suppliers
	Customers - Buyers and users
	Competitive strategies
	Hybrid solutions (cooperation between cloud and local devices) [Sch+18]
Business models	Cooperation
	Service concepts: Data business models (customers, partners) [Mou+18]
	Supply chain & strategic suppliers

5.2 B: Description of key factors

Table 11: Description of key factors

#	Key Factor	Description
1	Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization	The key factor considers the development of specifications, standards, and norms in the context of digitalization as well as strategies at the federal and state level that deal with the political control and implementation of the digital transformation.
2	Infrastructure strategy for the IT network from politics	The key factor considers relevant strategies for the IT network at the political level, which are directed in particular at the development and expansion of the IT infrastructure.
3	Netcom (network communication) & mobile communication	The key factor refers to relevant developments in the NetCom and mobile communications sector and considers both the technologies and the infrastructure necessary for the communication with the end devices.
4	Regulation of data protection and data security from politics	The key factor refers to the influences of political regulations considering data protection and data security.
5	Information technologies	The key factor considers relevant developments in information technologies (e.g. edge computing / gateways, operational data collection (Big Data) and license / IP protection).
6	Secure data storage solutions in embedded applications	The key factor covers developments with regard to secure data storage in embedded applications and refers to properties such as access protection, durability, and availability. In addition, it considers corresponding functionalities for encryption and secure exchange and deletion of data.
7	Mobility solutions	The key factor relates to relevant developments in the mobility sector (e.g. electrification of automotive transport, autonomous driving, mobility services, alternative drives, expansion of the necessary infrastructure, use of drones, etc.).
8	Smart Infrastructure / Building / Home	The key factor considers developments in the Smart Infrastructure, Smart Building, Smart Home sector and includes concepts for transforming and connecting infrastructure units, monitoring and optimizing buildings as well as automating and improving the quality of living.
9	Manufacturing (IIoT) / Industry 4.0	The key factor "Manufacturing (IIoT) / Industry 4.0" considers developments to transform production facilities into factories of the future using modern information and communication technologies to drive automation, smart manufacturing, and flexible production.
10	Service concepts: Data business models (customers, partners)	The key factor considers future developments to expand only hardware solutions with service offerings (product-service systems (PSS)).
11	Sensor and detection systems	The key factor considers technologies in the area of sensor and detection systems as a core component of Industry 4.0, which use optical, acoustic, electrical, and chemical signals.

#	Key Factor	Description
12	Hybrid solutions (cooperation between cloud and local devices)	The key factor considers the various combinations of local and cloud data storage, processing, and access, as well as secure authentication.
13	Surveillance (incl. Dash and Bodycams)	The key factor relates to relevant developments in surveillance technologies and includes both audio and video surveillance, as well as biometrics.
14	Devices and solutions for medicine and healthcare	The key factor considers devices and solutions for medicine and healthcare, and refers in particular to the digitalization and networking of corresponding solutions and procedures.
15	Microintegration / Miniaturization	The key factor considers technologies in the field of microintegration / miniaturization and covers the entire life cycle of miniaturized devices from design to manufacturing to packaging.

5.3 C: Description of projections per key factor

1) Digitalization strategies of the federal and state governments / standardizations and norms in the field of digitalization

Projection A: Digitalization is lagging behind, no uniform standards

- Standards and norms are developed and disseminated by the open-source community
- Federal, state and industry associations adopt standards but do not develop them
- No uniform standards, many individualized standardization efforts
- Structural obstacles, outdated administrative regulations, or low affinity to digital issues in politics continue to stand in the way of digitalization
- Funding programmes are not being used due to complicated application processes, voluntary efforts to standardized regulations are not effective, progressive legislation is being prevented by lobbyists of conventional industries and eroded business models.

Projection B: Bottom-up digitalization and defacto- vs. public-standards

- Standards are defined by large technology companies with existing ecosystems
- Defacto-standards emerge
- Open-source solutions complement each other
- Legislators try to change the legal framework to reduce the monopolistic market power of large suppliers.
- Raising disparity between defacto-standards and publicly available standards
- Due to a lack of coordination in an overall system, no coherent application and market performance available
- Digitalization is driven through the bottom-up approach by companies

Projection C: Global networking and standards for maximum interoperability

- Far-reaching political/legal framework for digital business processes
- Large funding programs for the development of uniform standards and norms
- Lighthouse initiatives such as GAIA-X promote extensive digital networking of supply chains and the formation of digital ecosystems and business models
- Standardization bodies are being formed at the federal and EU level
- Establishment of innovation hubs to help large companies make technological leaps
- Coordination with international parties and companies supporting large-scale interoperability
- E-government with a uniform look and feel

2) Infrastructure strategy for the IT network from politics

Projection A: Digital (Infrastructure-) Beginner

- Slow fiber roll-out and slow closure of white spots (connections below 30 Mbit/s).
- Slow mobile phone coverage and elimination of mobile phone gaps and slow expansion of 5G
- Lack of IT security in critical infrastructures (e.g. hospitals, outpatient facilities) and hardly any investment in IT equipment.
- Data strategy: Expandable, poorly networked data infrastructures, lack of trust regarding data and IT security
- State as a service provider: online accessibility of basic administrative services

Projection B: Digital (Infrastructure-) Follower

- Gigabit-capable infrastructure through fiber-optic expansion, primarily in the private sector and in schools, hospitals, and commercial areas
- Advancing mobile phone coverage and expansion of 5G (railway lines, motorways, federal and state roads)
- Improvement in IT security of critical infrastructures (e.g. hospitals, outpatient facilities) and investment in IT equipment.
- Data strategy: Expansion and networking of data infrastructures, measures for responsible data use, and strengthening of data and IT security
- State as a service provider: Online accessibility of all federal administrative services

Projection C: Digital (Infrastructure-) Expert

- Comprehensive availability of gigabit-capable infrastructure through fiber-optic expansion
- Comprehensive mobile phone coverage and expansion of 5G in metropolitan areas and rural regions
- Solid IT security of critical infrastructures (e.g. hospitals, outpatient facilities) and large investments in IT equipment
- Data strategy: Efficient, networked data infrastructures, responsible data use, strengthening of data and IT security
- State as a service provider: Online accessibility of all administrative services of the federal states and municipalities

3) Netcom (network communication) & mobile communication

Projection A: 5G is introduced slowly

- Gaps in mobile coverage exist due to economic aspects
- Devices are becoming increasingly intelligent and equipped with communication technologies
- Smartphones remain the main application to use netcom
- Network slicing enables the distribution of resources according to the demand
- Network slicing acts as a key technology for 5G mobile technology
- 5G will be introduced slowly

Projection B: 5G is standard in metropolitan areas

- Full 5G network coverage in metropolitan areas
- Functionality in mobile devices acts as a driving factor for 5G
- The use of 5G will increase
- New cars will be connected with 5G
- Smart cars need a reliable network and high bandwidth

Projection C: 5G as nationwide standard

- Complete 5G network coverage in Germany
- 5G will largely replace the 4G standard
- 5G is the basis for autonomous driving
- Autonomous driving and intelligent cars will be the main applications
- The next standard (6G) is already being heavily researched and prepared

4) Regulation of data protection and data security from politics

Projection A: Easing of data protection leads to lack of trust

- National data protection has loop-holes
- Uniform guidelines at the EU level have a representative character
- The loose approach to data protection compliance and control
- Germany relies on mild data protection regulations (competitiveness)
- Lack of trust in data security

Projection B: Data security leads to liberal data traffic

- Data protection as a political and economic success factor
- Increased implementation of EU-wide controls for data protection compliance
- Data protection for the management and control of international relations
- Procedures for data anonymization create trust and increase willingness to exchange data
- Easing of regulations on a case-by-case basis (e.g. law enforcement, smart city, big data)
- Increased exchange of data with third parties (suppliers, sub-developers, consultants, etc.)
- Data security is a basic requirement for customers

Projection C: United Europe in data protection regulations

- Europe as a competitive and steadfast player in data protection subjects
- Strengthened data protection guidelines
- Systematic recording and tracking of data attacks
- Closing legal security gaps
- Sanctioning of data privacy violations
- Establishment of trust concepts and modern encryption procedures at the company and individual user level

5) Information technologies

Projection A: New digital territory

- Slow-moving digital transformation
- Outdated IT architectures in the corporate context
- Criminal network attacks of a on production facilities
- Germany lags behind

Projection B: Digital exploration

- Large companies are making headway
- Medium-sized companies are trailing
- Standard mechanisms for IT security are politically motivated
- Security mechanisms as a driving factor in the selection of information technologies
- Prevention of network attacks
- Expansion of IoT to make business processes, production, and resource consumption more efficient
- Spread of edge computing for applications with high computing requirements

Projection C: Digital transformation

- Digitalization in the advance
- Networking and automation in industrial applications
- Quantum computing for solving complex problems
- High-security standards in business software solutions
- Successful defense against network attacks
- Re-Europeanisation of IT security solutions

6) Secure data storage solutions in embedded applications

Projection A: Secure data storage as a novelty

- Data security is primarily business-driven (protection against cyber-attacks)
- Hardly any technical and automated support in the implementation of legal requirements for data protection
- New business models being tested (e.g. subscription-based security-as-a-service offers, data trust concepts)
- New encryption, signature, authentication, and data recovery solutions
- Lack of security measures among cloud operators (clinging to storage-intensive end devices)

Projection B: Secure data storage as a standard

- Data security is politically motivated (e.g. fines for non-compliance with legal requirements)
- Increasing technical and automated support in the implementation of legal requirements for data protection (e.g. automated, periodic deletion of data, cleansing technologies/services)
- New business models on the rise (e.g. data escrow concept, insurance for data loss)

- Technically mature encryption, signature, authentication, and data recovery solutions
- Development and offer of protective measures by cloud operators (decline of storage-intensive end devices)

Projection C: Secure data storage as the rule

- Data protection guidelines set clear rules for the collection, processing, storage, and transfer of data.
- Comprehensive technical and automated support for the implementation of legal data protection requirements
- Wide use of new business models (e.g. data trustees, mandatory insurance for data preservation and loss, payment models for data anonymization)
- Modern and highly secure (on-board) encryption, signature, authentication, and data recovery solutions
- Obligation of cloud operators to prove data security

7) Mobility solutions

Projection A: New mobility concepts are being tested

- Mobility services focus on customizing concepts (e.g. "over-the-air" customized infotainment services)
- Slow development of electrification and urban infrastructure
- Internal combustion engines as main drive technology
- Autonomous driving limited to pilot projects
- Expansion of rail transport as a counteroffer to air transport (e.g. revitalization of old railway lines, expansion of night trains, fuel cell drives)

Projection B: New mobility concepts suggest suitability for everyday use

- No motorized individual transport in metropolitan areas
- Mobility replacement through expansion of bicycle lanes, public transport, or car-sharing services
- Increasing number of private electric vehicles in urban and rural areas
- Urban infrastructure development more difficult than in rural areas
- Autonomous driving in specific traffic zones as test launches
- Further development of fuel cell and hydrogen fuel technologies

Projection C: New mobility concepts prove their suitability for the masses

- Autonomous driving in controlled areas
- Expansion of bicycle lanes in metropolitan areas (e.g. disused underground tunnels)
- Vehicle ownership is being replaced by vehicle use
- Widespread conversion to environmentally friendly drive systems
- Substitution of fossil fuels by man-made fuels
- Autonomous driving in freight transport fully established

8) Smart Infrastructure / Building / Home

This key factor covers the following areas:

- **Smart Living:** Intelligent Buildings, Smart Home, Digital Health and Care
- **Smart Environment**: Environmental protection, photovoltaic systems, smart grid, smart metering, environmental sensors, resource management (waste, energy, water)
- **Smart Government:** Digital citizen and business services, smart street lighting, public safety, broadband, waste management, free WiFi, open data
- **Smart Economy:** Industry 4.0, last-mile logistics, smart agriculture, circular economy
- **Smart Mobility:** Electromobility, transport, bicycle infrastructure, car/bike-sharing, public transport optimization, smart parking, road safety
- **Smart People:** Digital inclusion and education, digitalization of the labor market

The projections are as follows:

Projection A: Smart City 4.0 a long way off

- Technological feasibility of individual components tested in the 6 fields of action

Projection B: Smart City 4.0 within reach

- Demonstrated technological feasibility of individual components in the 6 fields of action

Projection C: Smart City 4.0 widespread

- Individual components are well established in the 6 fields of action

9) Manufacturing (IIoT) / Industry 4.0

Projection A: Partial automation and retrofitting

- Partially automated plants
- Large companies are making progress in digital transformation (e.g. digital factory twins)
- Medium-sized companies lag behind
- Data acquisition without data utilization
- Outdated sensor technology, machines, and software
- Retrofitting solutions on the advance
- Plant networking
- Protective mechanisms against production downtimes due to network attacks

Projection B: Further development of partial automation

- Advancing digitalization and automation in the production context
- Automating non-creative routine tasks
- Modular ready-to-use software, tools, and services facilitate partial automation of production processes
- Interoperability and standardized data (plant networking, predictive maintenance)
- Digital factory twins as data-providing systems are also entering SMEs (Small and Mid-sized Enterprises)

Projection C: Full automation and smart factories

- Fully automated, networked, self-controlling plants and machines through the use of AI
- Service providers provide new business models/ service offerings (e.g. real-time monitoring of machines) based on maintenance and evaluation of machine data
- "Plug & produce" through increasing demand for personalized and mass customized goods
- Global, cross-company digital twins connect real and digital production across the supply chain

10) Service concepts: Data-driven business models (customers, partners)

Projection A: PSS is implemented in some cases

- Offerings of product-service systems will increase continuously but moderately
- Value and importance of PSS is not yet fully understood
- Customers fear the loss of control and data in the event of a failure in the PSS provider environment
- Lack of acceptance of PSS systems, as customers fear that they will be unable to act if the PSS provider fails

Projection B: PSS becomes marketable on a large scale

- Development of scalable and straightforward IoT connections promotes PSS
- Data-driven business management becomes a key competence in SME's
- New technologies work without internet/networking and enable a low-level fallback mode or "hidden operation"
- Some companies retain sovereignty over their data and the competence to deliver important services.
- These then rely on data-driven PSS

Projection C: PSS as a natural necessity

- Data-driven PSS are widely available and accepted
- Convenience (B2C) and business benefits (B2B) reach the rank of "natural necessity"
- Selling one's data serves as a means of payment
- Data-driven companies can focus on their core business and displace the competition

11) Sensor and detection systems

Projection A: Sensor solutions as a nice-to-have

- Retrofitting: upgrading activities in industrial applications with standard sensor technology
- Increasing demand for sensor fusion, intelligence, and networking
- Sensor networking: a hodgepodge of protocols and interfaces hinder data processing
- New developments focus on miniaturization, lower power consumption, and lower costs of sensor technology

Projection B: Sensor solutions as a should-have

- Sensor technology as a prerequisite (e.g. IoT, digitalization, new business models, factory of the future)
- Sensor fusion: integration of multi-sensors
- AI-based sensor intelligence for increased autonomy, self-diagnosis and self-calibration
- Sensor networking: efforts to standardize protocols and interfaces
- Miniaturization and low power consumption/cost of sensors open up new areas of application
- Multifunctional sensor technology (e.g. memory, radio, data pre-processing to relieve central processor units)
- Transmission technologies with higher data rates increase sensor use

Projection C: Sensor solutions as a must-have

- Sensor technology as a necessity
- Sensor fusion, intelligence, and networking as standard
- Sensor networking: standardized, unified protocols and interfaces, which simplify data processing
- Major technological advances: e.g. use of a new generation of low-cost, compact, and reliable lidar sensors in autonomous vehicles, use of nanomaterials, extremely sensitive sensor principles
- Modern technologies for sensor encryption

12) Hybrid solutions (cooperation between cloud and local devices)

Projection A: On-premise solutions

- On-premise storage solutions still seen as the-way-to-go
- Lack of trust in cloud services
- Measures to ensure network independence
- Managing data constructs from cloud services to ensure offline working
- Retention of storage-intensive end-user devices
- Networking local on-premise solutions via standardized APIs

Projection B: Hybrid cloud/ on-premise solutions

- Hybrid approaches: The more sensitive the data, the more local the storage.
- Security-relevant information/ intellectual property → on-premise/ edge-based
- Guarantee of independence from third parties and immediate operability (e.g. network failure)
- Advanced functionalities for synchronization, archiving, cloud cache management
- Security mechanisms of cloud solutions strengthen trust

Projection C: Cloud-solutions

- Cloud solutions largely displace on-premise solutions
- Nationwide 5G roll-out boosts trust in cloud services
- Massive expansion of security mechanisms for data security and protection against attacks
- On-premise solutions exclusively for sensitive data
- Decline in storage-intensive end devices

13) Surveillance (including dash and body cameras)

Projection A: Large political and social barriers to expansion

- Acceptance of surveillance recordings is lacking among the population
- Surveillance is not being significantly expanded in Germany
- Restrictions, requirements, and test criteria for recording systems and algorithms for public approval are being developed politically
- Security guards are increasingly replaced by automated systems
- Biometric facial recognition is introduced only sporadically
- The trust concept for personal data (everyone can decide what their data can be used for) makes it even more difficult to use this data for surveillance purposes

Projection B: Data protection-compliant expansion of monitoring

- Increased use of cameras in police operations
- Biometric facial recognition is used but not linked to databases
- Data memories that are automatically deleted after a certain period of time allow for more surveillance overall
- Video recordings are encrypted at the time of recording and can only be decrypted in cases of justified suspicion and with a court order
- Secure and reliable encryption of messages is available and is also used as standard
- Encryption of data and messages can be bypassed by judicial order in relation to prosecution

Projection C: More surveillance means more security

- More surveillance systems are set up for the prosecution of criminal offenses
- Linking biometric facial recognition with ID photos is made possible for criminal prosecution.
- Technical progress is equated with security
- Laws on surveillance on the internet, including personal data, are softened in favor of law enforcement
- Encryption of messages can be circumvented for the benefit of law enforcement without a court order
- Citizens get used to constant surveillance by lawmakers

14) Devices and solutions for medicine and healthcare

Projection A: Digital is fatal

- Protection of personal, sensitive data massively slows down innovations
- Requirements and medical device regulations pose major challenges for manufacturers
- Lack of acceptance of digital transformation by healthcare professionals
- Little use of AI and machine learning
- Lack of interconnected/ networked medical devices

Projection B: Digital would be ideal

- Corona as a driver for digitalization in the health sector
- Government investment in digital transformation
- New sensor technologies (non-invasive sensors, hybrid, digital, wearable sensors)
- Modern tools for medical care and nursing
- New data- or patient-centered business models (online diagnosis, digital doctors, mechanisms for pandemic monitoring)
- Data protection realisations and anonymization of patient data
- Partial networking of medical devices
- Central data management through digital networking of hospitals in preparation

Projection C: Digital becomes real

- Immense technological innovations (embedded sensor systems in artificial organs, 3D imaging, pattern recognition based on AI/ ML)
- Reliable use of robotic assistance in the operating theatre through nationwide 5G expansion
- Well-established use of services for online diagnosis and digital doctors will
- Comprehensive networking of hospitals, medical facilities, and medical equipment
- Widespread Open-source strategies for the evaluation and networking of medical data

15) Microintegration / Miniaturisation

Projection A: Improving existing solutions and systems

- The technical limitations of the miniaturization of today's devices and sensors cannot be overcome
- The systems and sensors become more resistant and remain functional in harsh environments
- More dimensions for predictive maintenance applications are emerging
- Systems are becoming interconnected

Projection B: Development of new solutions and systems

- Sensor systems have a unique ID
- Data storage devices become much smaller, allowing data to be cached for signal processing or systems in harsh environments without constant connectivity
- Signal processing is possible directly on chips
- Wireless communication functionality can be integrated directly
- Intelligent autonomous microcontrollers prototypes become reality
- Enabling technologies such as wafer bonding and through-hole plating enable 3D integration of future integrated circuits

Projection C: Breakthrough in quantum technologies

- On-chip energy harvesting solutions become possible and solve the problem of power supply to the components
- Quantum photonic packaging overcomes the technical limitations of today's devices
- Sensor/actuator integration
- Embedded systems regulate and control themselves autonomously
- SOC (System on a Chip) becomes possible
- Self-learning AI algorithms on-chip become possible
- Development of new bio-compatible systems enables a multitude of new medical diagnostic and implant possibilities

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