PLATTFORM INDUSTRIE 4.0

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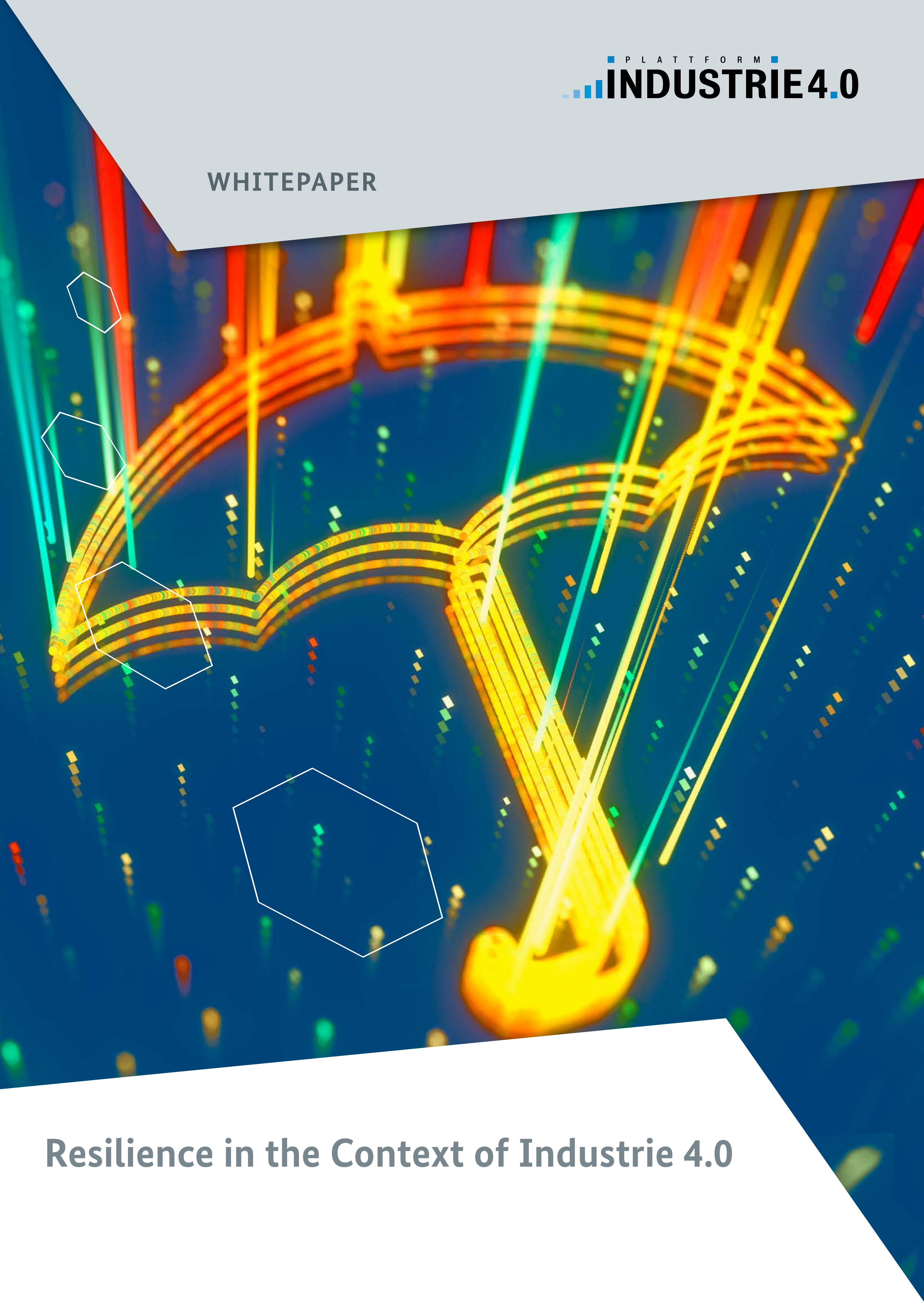

Resilience in the Context of Industrie 4.0

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Email: publikationen@bundesregierung.de
Tel.: +49 30 182722721
Fax: +49 30 18102722721

Contents

Executive Summary 3

1 Introduction 4
1.1 Resilience in the context of Industrie 4.0 4
1.2 Strategic action fields of Industrie 4.0 4
1.3 “Resilience and Industrie 4.0” classification scheme 5

2 Focus topics of resilience in the context of Industrie 4.0 7
2.1 Autonomy 7
2.2 Security of supply 9
2.3 Robust & flexible supply chains 9
2.4 Production systems and the role of people 11
2.5 Education, competence and work organisation 13
2.6 Standardisation and legal frameworks 15

3 Conclusion 18
3.1 Overarching fields of action 18
3.1.1 Autonomy through open, interoperable and secure data ecosystems 18
3.1.2 Security of supply 19
3.1.3 Flexibility and adaptability with the use of new technologies 19
3.2 Implementation 20

4 Annex – Exemplary activities of the focus topics 21
4.1 Examples of autonomy 21
4.2 Examples of security of supply 23
4.3 Examples of robust & flexible supply chains 24
4.4 Examples of production systems and the role of people 26
4.5 Examples of education, competence and work organisation 29

Executive Summary

Inspired by the steering committee, Plattform Industrie 4.0 participants have investigated the importance of resilience in the context of 4.0.

Resilience is seen as a supporting pillar of the Plattform Industrie 4.0 strategic action field of autonomy due to its significant contribution to the ability to withstand external shocks or upheavals in the social, economic or political frameworks, and to adapt to new conditions. Thereby, companies can withstand external influences and strengthen their competitiveness.

The authors identified three overarching fields of action:

- autonomy via open, interoperable and secure data ecosystems,
- security of supply and
- flexibility and adaptability through the use of new technologies.

They propose that stakeholders from industry and politics share equally in contributing to the overarching action fields conducive to resilient industry and society.

In their view, future work on the topic should take place accompanied by ethical guidance and in the setting of a specified committee via discourse between industry, politics, relevant federal authorities, research and development, and management level representatives of civil society.

The strategic goals developed in the proposed committee should be broken down into operational instruments and concrete measures by auxiliary, topic-specific working groups and task forces which would receive guidance up to the point of implementation.

1 Introduction

1.1 Resilience in the context of Industrie 4.0

Entrepreneurial resilience is the ability of a company to withstand external shocks or disruptions in the social, economic or political environment and to adapt to new conditions. To do this, companies must maintain their stability despite external influences, be able to return to their initial state, or adopt a new equilibrium. Consequently, they can withstand external influences and survive in the market over the long term. In contrast to robustness, whereby companies face change without adapting their structure, resilience means adjusting quickly to maintain the ability to act and, if necessary, to fundamentally redesign structures and processes. Anyone who believes that the current crises have been largely overcome and that a return to the pre-crisis system is the order of the day is fundamentally mistaken and inadequately prepared for the next crisis. Resilience is not a one-time measure to solve a problem, but an ongoing strategic task for corporate management to ensure long-term viability. Only companies that are resilient are prepared for the coming crisis.

1.2 Strategic action fields of Industrie 4.0

Industrie 4.0 transforms value creation, entrepreneurial success and work. Value chains become flexible, agile and globally networked value creation systems. Data and its use are here core elements of digital business models. Cooperation partners will, in the future, in addition to networking internally, connect to form cross-company, dynamic value creation networks within the Industrie 4.0 data space[1].

Hence, Industrie 4.0 can extend to the complete data integration of all industrial processes, from needs assessment to development, production, delivery, installation, service for the customer, and disposal and reuse, i.e., it can encompass the entire life cycle of a product or production system.

1 The Industrie 4.0 data space refers to the meta-level on which the various solutions for cross-organisational data use interact. The various solutions can themselves represent individual data spaces.

Three strategic fields of action are central to the implementation of Industrie 4.0:

- **Autonomy:** Room for creativity and self-determination guarantee competitiveness in digital business models.
- **Interoperability:** Cooperation and open ecosystems enable plurality and flexibility.
- **Sustainability:** Key aspects of sustainability in the I40-ecosystems of the future are good jobs and education, climate protection and the circular economy, as well as social participation.

These fields of action are the subject of the Plattform Industrie 4.0 vision statement.[2] They are based on a broad social consensus and provide long-term orientation for further initiatives.

In the event of a crisis, resilience, as it is properly understood, aims at the flexible or even anticipatory redesign of corporate structures or entire value networks. A key prerequisite for successful implementation is an in-depth understanding of one's own system. This includes the business processes, the critical role of individual components within the system, and their interdependencies vis-à-vis external stakeholders and other factors.

Companies around the world are continually confronted with abrupt changes, in particular such as extremely short-term, far-reaching disruptions like the global financial crisis, the trade crisis or, most recently, the Corona pandemic or war. However, long-term changes such as climate change or necessary transformation processes like digitisation also represent special dimensions of change that impact not only individual companies, but value networks as a whole.

To ensure economic success or continued existence, companies need to be prepared to change. The key, therefore, is to recognise resilience as a strategic competitive factor and to make it a strategic task of corporate management. Therein lies an enormous opportunity: companies that learn to manage crises effectively, or bypass them completely, open up entirely new market opportunities for the future. Companies that are truly resilient strengthen their international competitiveness in crises and even emerge as winners in the end.

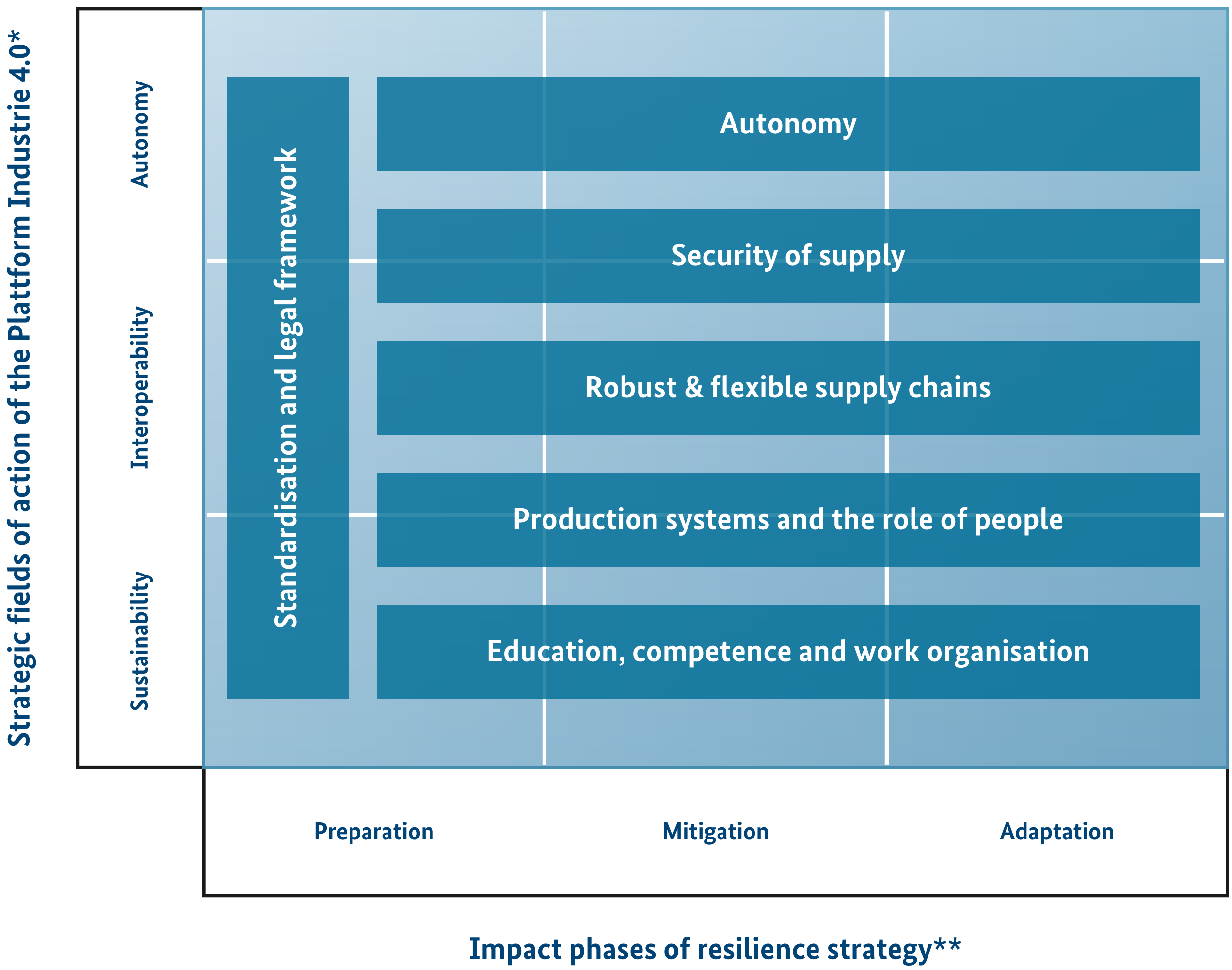
1.3 "Resilience and Industrie 4.0" classification scheme

The "Resilience and Industrie 4.0" classification scheme sorts the focus topics horizontally into the resilience phases and vertically into the Plattform Industrie 4.0 strategic fields of action. The focus topics serve here to structure the fields of action for resilience in terms of Industrie 4.0. The classification scheme based on the Plattform Industrie 4.0 strategic fields of action can be used to identify and characterize existing activities, programs and projects. Moreover, the classification scheme can be used to identify blank spots in the thematic areas and locate potential for individual stakeholder groups to act.

In the following sections, the focus topics of resilience in the context of Industrie 4.0 are described, starting with a clarification of the issues, through to their placement within the classification scheme and the presentation of known ongoing or completed activities, up to specific recommendations for action. In the final chapter of the document, the recommendations for action are compiled and an overview of possible next steps are identified.

2 More information at: https://www.plattform-i40.de/IP/Navigation/EN/Industrie40/Vision/vision.html, accessed: 04.11.2022.

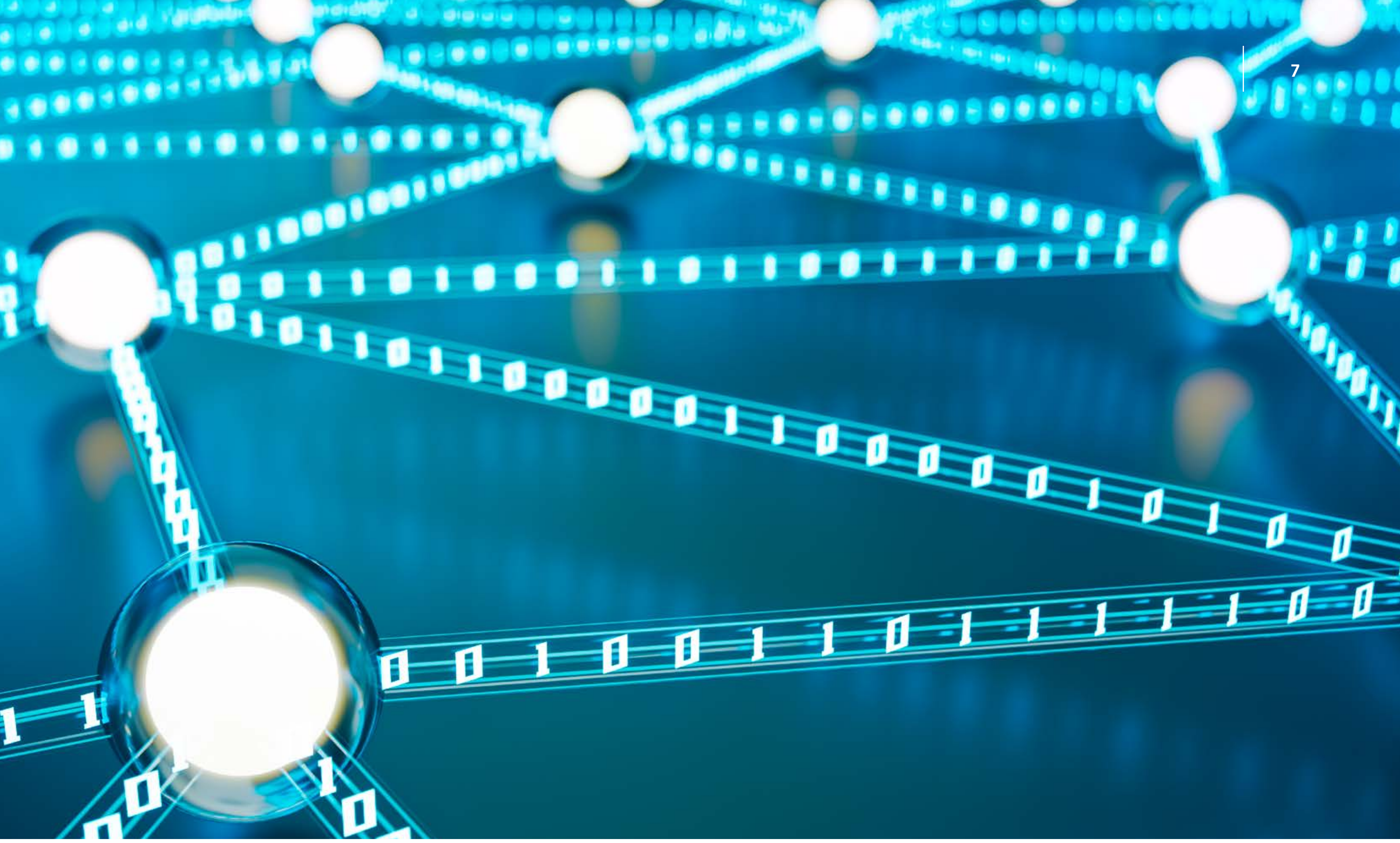
Figure 1: Resilience strategy



* **The 2030 mission statement of the Plattform Industrie 4.0** formulates a holistic approach to the design of digital ecosystems and realigns the development of Industrie 4.0. Central to the design of digital ecosystems are the three strategic fields of action.

** **A resiliance strategy** comprises the ability of an economy to take preparatory measures to overcome a crisis, to mitigate the immediate consequences of a crisis and to adapt to changing conditions.

Source: Based on: Bertelsmann Stiftung: Resilienz von Staaten gegen Außenwirtschaftskrisen, Schriftenreihe: Inklusives Wachstum für Deutschland, No. 22, 2018



2 Focus topics of resilience in the context of Industrie 4.0

2.1 Autonomy

Topic clarification – aspects of autonomy in the context of resilience

Autonomy as a guiding principle emphasizes the freedom of all market players to make self-determined, independent decisions and to act in fair competition with each other across all business phases.

Within the Industrie 4.0 data space, multilateral data exchange takes place on the basis of trust in digital collaboration between cooperation partners while they maintain their individual autonomy.

Digital collaboration requires digital infrastructures. Digital infrastructures comprise technical and data infrastructures. While technical infrastructures include data centres, edge devices, and nationwide broadband and mobile communications infrastructures; data infrastructures describe the technical and organisational approaches to exchanging data between value chain participants within the Industrie 4.0 data space in a competent and interoperable manner. The digital infrastructure thus defines access to the Industrie 4.0 ecosystems and guarantees pluralistic action and market diversity. A resilient digital infrastructure bundles all the requirements and services needed to collect, exchange, analyse and apply data across borders and sectors. Some examples of such approaches can be found in Gaia-X[3] and Catena-X[4].

To ensure autonomy, the digital infrastructure must be equally open to all participants and provide the technical and organisational conditions for data exchange which fulfil individual security requirements of availability, integrity and confidentiality.

In addition to shaping the digital infrastructure, the development of new technologies is also particularly important for securing autonomy. Microelectronics is a specific example of this.

3 More information at: https://www.gaia-x.eu/, accessed: 03.16.2022.

4 More information at: https://catena-x.net/en/, accessed: 03.16.2022.

Allocation of autonomy in connection to resilience within the classification scheme

Autonomy is one of the strategic action fields of Industrie 4.0. In addition, autonomous digital collaboration is to be regarded as a transversal aspect of resilience, since the digital infrastructure as an axiom requires open access for all participants, thereby providing the basis for the lasting transformation of value networks. The individual phases of the resilience cycle correspond also to those of security. Beginning with the development of a comprehensive understanding of current and emerging risk scenarios, capability is developed to compensate for events with as little loss of performance as possible and to continue with all critical functions despite an interruption or critical failure, as well as to limit impact and downtime. This includes prioritizing data availability and integrity during and after a disruptive event. As described in the introduction, the system is designed in the context of resilience from a security perspective to be flexible enough to allow for permanent adaptation. Knowledge gained from previous disruptions is used to improve resilience processes and reduce negative impacts in the future.

Against this backdrop, autonomy is positioned as a resilience-spanning focus topic in the ordering scheme.

Reference points for further activities with relevant stakeholder groups

Open and flexible production value chains are dynamically used on the basis of bilateral agreements to achieve specific business goals. However, the bilateral nature of the value chain hinders integrative collaboration among all stakeholders along the entire end-2-end value chain, making it difficult to modernize cross-company business processes and meet new regulatory requirements.

Examples that depend on complete digital transparency and an integrated “autonomous data flow” throughout the entire data ecosystem include the following:

- efficient supply chain traceability and quality management (especially in light of the Supply Chain Act),
- modular production and manufacturing as a service to increase the efficiency of the OEM or,
- a sustainable, environmentally positive[5] circular economy to achieve the internationally agreed climate protection targets.

To meet future business needs, companies must improve their business relationships along the entire value chain. This requires multilateral collaboration that enables comprehensive data exchange in a fully interoperable and autonomous data-oriented ecosystem while protecting the autonomy of the contributors. Synonymous with these requirements is the Industrie 4.0 data space. This end-to-end data space, equally accessible to all participants, must be established with the involvement of the entire relevant heterogeneous field of actors.

Safe spaces for purpose-driven collaboration

Within the data space, the opportunity to establish a safe space for building trust relationships between collaborators must exist. An Industrie 4.0 safe space enables governance for the requirements of trustworthy, purpose-driven collaboration within Industrie 4.0 scenarios. Governance is used by participants to establish and maintain their trust relationship. Among other things, an Industrie 4.0 safe space meets the requirements for the trustworthy identification of actors, linking them to respective credentials, as well as providing evidence of quality standards, e.g., ISO 9000, ISO 27000 certificates. Actors within the safe space are all entities, e.g., people, companies, machines, industrial components, processes, digital twins/AASs, etc. Standardisation of the requirements for these actors supports autonomy and the freedom to act, as well as self-determination, for market participants in protected data spaces.

5 CO_2 neutrality or climate neutrality is fundamentally not possible, but only approximate and realistically achievable up to a certain level of reduction. In this regard, we use the term ‘environmentally positive’ to indicate more resilient economic activities that contribute to improvement rather than making the existing business model and value creation structures less burdensome.

2.2 Security of supply

Topic clarification – Aspects of supply security in the context of resilience

In the current public debate, security of supply for industry is associated with the energy transition and a **stable energy supply** for industrial plants. Other aspects of supply security in the context of industrial value creation also include the importance of **stable modes of road and rail transport** and the supply for industry with **secure and stable communications networks**. But also, **raw materials and technologies** (e.g., microelectronics) are part of this topic. Broader aspects of supply security can be identified in the area of industrial use for **secure and sustainable water and gas supply**, and for innovation capability of industrial sectors in **education and digital competencies of skilled workers and managers**.

Allocation of supply security within the classification scheme

Aspects of supply security are found in the classification scheme for all three impact phases of a resilience strategy. Since aspects of supply security include basic infrastructures outside the sphere of influence of companies, supply security must be considered both in the preparatory phase of a resilience strategy to increase the robustness of the existing system, as well as the adaptability of supply routes and corresponding infrastructures after the occurrence of unforeseeable risks or crises.

With regard to the strategic action fields of Plattform Industrie 4.0, security of supply is primarily aimed at autonomy and secondarily at interoperability (e.g., common, open standards and architectures), as well as having sporadic, indirect references to sustainability (e.g., energy supply).

Reference points for further activities with relevant stakeholder groups

The aspects "energy supply", "communication networks", as well as "education and digital skills" are rated as high priorities. These aspects are therefore the focus of this document. The aspect "education and digital skills" is discussed in the section on the focus topic **education, skills and work organisation**.

2.3 Robust & flexible supply chains

Topic clarification – aspects of supply chains in the context of resilience

As a result of the increasing globalisation of value networks, the complexity of supply chains and flows of goods continues to grow, whereby also the susceptibility to disruptions increases. According to a survey by the Association for Supply Chain Management, Procurement and Logistics, every second company surveyed was affected by at least five disruptions in its own supply chain in 2020.[6]

Since the availability of materials is a key prerequisite for the broad value networks of Industrie 4.0, disruptions to this very prerequisite also have a significant impact on companies. In light of this, it appears evident that the resilience of supply chains is of strategic importance for Germany's suitability as a place to do business.

Allocation of robust & flexible supply chains within the classification scheme

Supply chains play an important role in all phases of a resilience strategy. Supply chains are often cross-company and international transport and production networks. **Preparation** is therefore the effectiveness phase with the highest potential for influencing impending crisis situations. This is where **risk and crisis management solutions** can already be used which make supply chains transparent and thus identify weak points and alternatives at an early stage.

6 Cf. Bundesverband Materialwirtschaft, Einkauf und Logistik (2020): Mehr Störungen in der Lieferkette: Schwachstelle Risikoprävention (More supply chain disruptions: risk prevention vulnerability), https://www.bme.de/mehr-stoerungen-in-der-lieferkette-schwachstelle-risikopraevention-3688/, accessed: 25.01.2022, German only.

If the effects of the crisis can already be felt, well-prepared supply chains that are as flexible as possible help to **mitigate them**. Important steps for this are the reliable identification of causes and their effects, as well as the flexible switch to alternatives. However, it is usually the best ad-hoc solutions that are implemented in this phase. To enable a long-term increase in resilience, these must be continuously evaluated so that the existing resilience strategy can be regularly adjusted on this basis. Suppliers, transport routes and warehouse locations can be re-evaluated and supplemented, or new production sites can be created, up to and including in-house solutions.

Keeping a supply chain flexible and robust at the same time requires various prerequisites. The individual components of the supply chain should interlock efficiently while still ensuring the greatest possible flexibility.

Reference points for further activities with relevant stakeholder groups

Based on the above, there are numerous points of reference for increasing resilience in the focus topic "Robust and flexible supply chains". Probably the most central aspect is transparency. Only with transparent supply chains can preparatory measures be taken; and mitigation, as well as adaptation of supply chains, are most effective when there is a sufficient basis of information. Since this requires sharing data, the willingness of companies to do so must be increased. After all, the synergies created by sharing do not cause the sharing companies to lose or give up any value. Rather, sharing a dataset created from separate data is much more likely to generate greater value than the sum of its parts. At this point, documentation systems that use Digital Product Passports can increase adoption, as can shared access to, for example, design, analysis or sales data (so-called data pools). The prerequisites for this are shared data exchange standards, which already exist in individual areas (e.g., in finance), but can be given greater consideration in the production/sales area, as well as a custom-fit and adaptable legal framework that regulates the automated transfer of data and responsibility. These are areas of action in which political decision-makers must become active.

One factor that contributes to reducing the resilience of value networks is dependency, which can, for example, manifest itself in oligopolies or even monopolies. If an actor in the supply chain is the sole supplier of a material, this may be efficient, but it is questionable, at least with regard to robustness. A good example of this is the geopolitical dependencies on rare commodities and materials (such as nickel, cobalt, and lithium). To avoid supply chain disruptions and dependence on few suppliers, reuse and recycling must be a viable part of a procurement culture that is both dynamic and responsible. With lithium-ion batteries for example, up to 80% of the cathode material used for battery production could technologically be recycled from old batteries.[7] The foundations for efficient reuse and recycling are an integrated life cycle management system and the linking of existing standards for products with life cycle assessment standards, as well as supply chain transparency. A major opportunity arises from the use of digital technologies for overall documentation of material use. This allows for systems engineering which by design considers the reuse of parts and reprocessed materials while managing supply chains of complex value networks and strengthening independence through the use of fallback technologies. For example, the otherwise hidden potential of products for recycling and recirculating can lead to mitigating dependencies on suppliers. Since policymakers are already working on creating the framework conditions, here it is the companies which need to act. They must consistently apply the existing standards for life cycle assessment and should drive the further development of these very standards. In this context, it is also important to create life cycle assessment which encompasses entire value networks.

With regard to the specific use of recycled materials, there is a need for consistent transfer of current research results. Last but not least, this point hides the heretofore largely untapped value creation potential which should be conducive to the promotion of these new business areas. On the other hand, political decision-makers should promote the use of recycled materials by creating the necessary legal framework. There is a need for action, among other things, in the allocation and transition of ownership and possession structures, as well as the responsibility for further recycling or sustainable disposal.

7 See Leonard Kurz et al, "Global Warming Potential of a New Waterjet-Based Recycling Process for Cathode Materials of Lithium-Ion Batteries," Batteries 2021, 7, 29. https://doi.org/10.3390/batteries7020029, accessed 03.16.2022.

However, dependencies do not only exist with rare raw materials. In the context of modern engineering processes, specifications for components – so-called CAD data – are essential. Since there are currently many different formats for such data sets, and the changeover to other formats is very cost-intensive in terms of money and time, this form of lock-in effect represents an obstacle to achieving resilient supply chains. In order for a supply chain with many different producers to be flexible and agile – i.e., to be able to rely on different producers – CAD data must be interoperable so that rapid and cost-effective adaptation to disruptions is possible.

2.4 Production systems and the role of people

Topic clarification – Aspects of production in the context of resilience

In the course of the progressive digitisation of industry, production systems have undergone massive development and change. New forms of production organisation such as matrix production, but also the use of technologies such as the digital twin, are good examples of this. However, in addition to these technical aspects, the role of people in production has also changed. Furthermore, the increase in the efficiency of production systems has increased their complexity and susceptibility to disruptions.

As modern production is nowadays digitised and networked, it forms a meaningful data basis as a foundation for resilient production and the use of innovative technologies, which should also cover systematic early detection of potential disruptions. Resilient production requires linking available resources and technological innovations in an adaptable and versatile manner.

Allocation of production systems and the role of people within the classification scheme

With regard to the location of production in the phases 'preparation', 'mitigation' and 'adaptation' to disruptions, it is easy to see that production plays an important role in them all. As preparatory measures, for example, anticipatory management and predictive maintenance are of central importance. In the event of an acute disruption, well-integrated alternative process chains contribute to mitigation; and after production has overcome the disruption, the experience gained must lead to adaptation of production, which at the same time means improving production in terms of its ability to act in the event of future disruptions.

Since both technical systems and people play central roles in production, this focus topic was allocated to the action fields of interoperability and sustainability. The link to interoperability seems evident simply from the fact that the intelligent interlinking of the systems of a production facility or even several production facilities[8] is unavoidable in order to establish resilient production. However, collaboration will only succeed if plants – and the standards under which these plants operate – are interoperable. Interoperability is not just to be understood between technical plants. The growth of human-machine interfaces is also relevant. Resilient production will continue to rely on humans. Even if algorithms monitor the status of production, ultimately a trained specialist must still make the final decisions.

Reference points for further activities with relevant stakeholder groups

Central with regard to increasing resilience in production and people in production is the factor that we must be involved with implementation. The identified connecting factors relate to standardisation (more details can be found in the focus topic **"Standardisation and legal framework"**), data sharing, people and process design.

Standardisation

An important basis for more resilient production is standardisation. More resilient production involves a high degree of flexibility and the ability to adapt production systems and processes. This places high demands on the interoperability of systems both on the hardware side and in digital networking, as well as for software. The availability of specifications and standards is elementary for the aforementioned requirements, but the process for developing guidelines and standards is very lengthy. In the future, it will be

8 See also the chapter "Robust & flexible supply chains".

crucial that innovative technologies can be tested, installed and utilized quickly. In addition to classic standardisation, the development and application of open source and open standards can contribute to acceleration. For this, acceptance and willingness for greater cooperation and openness are required from industry. Politicians must ensure through framework legislation that secure and faster certification of products and processes is made possible (for more details, see the focus topic **"Standardisation and legal framework"**).

Data sharing

Building a more resilient production landscape requires sufficient and good data as an essential raw material. This data is available in many cases but should be shared in a much more meaningful way than before in order to anticipate and avoid disruptions or mitigate their consequences.

To achieve this, the willingness to share data must be motivated in large parts of the business community; the creation of corresponding technical standards must be driven forward quickly and straightforwardly; and participation in safe data spaces for the autonomous sharing of data (see above) must become the norm. Building on these foundations, integrated resilience management systems should be jointly established and intensively used across corporate boundaries.

This requires a secure framework that supports the development of data-driven resilience ecosystems with the necessary political guard rails in an uncomplicated, unbureaucratic and internationally compatible manner. Global production and supply chains, as well as sales markets, urgently require an overall solution beyond particular regulations, for example, on data protection.

Finally, an overall social dialog must be conducted that considers the opportunities arising from the more extensive use of data. Securing a competitive production location in the long term requires both autonomous and fear-free handling of one's own data on the one hand, but on the other, an awareness of the joint responsibility for the sensible utilisation of this data in the interest of the entire location.

People

Digitalisation topics are generally interdisciplinary issues. This also applies to the area of resilience, for which a strengthening of corporate networking and collaboration in the sense of orchestrated joint action is necessary. From the employees' point of view, this requires an understanding of tasks, processes and interrelationships in production and other areas of the company that go beyond their own field of action. This is particularly true when considering service and supply chains. Resilience requires more knowledge and more flexible collaboration, for which the foundations should be laid in personal training and development. To ensure that people can continue to play their role in resilient production in the future, the "human factor" should be taken into account as a central aspect in technically oriented research projects (for more details, see the focus topic **"Education, competence and work organisation"**).

Process design

The goal of resilient, alternative process chains is to create flexibility at all levels of process design, production control, production equipment and process chain design. Companies need to consider alternative processes in terms of availability and plant capabilities in advance of disruptions. In particular, companies should always follow the developments of new types of production technologies or the extensions of already established production technologies and examine their use in their own company as a supplement or substitute to the existing portfolio.

Production and delivery stoppages or the meeting of urgent needs for necessary products and services call for swift and consistent action. On the other hand, procurement procedures can sometimes be costly or complicated. In order to unleash the necessary potential for agility and innovation despite this, temporarily accelerated procurement procedures should ensure the continuity of value-added systems, in particular to safeguard basic services – naturally, while complying with the necessary safety standards. Furthermore, the course must be set for collaborative and interdisciplinary resilience research at all levels and in political and social dialog. Only in this way can Germany's long-term competitiveness as a place to do business be ensured.

2.5 Education, competence and work organisation

Topic clarification – aspects of education, competence and work organisation in the context of resilience

The significant increase in complexity in the area of technology outlined in the previous remarks is leading to massive pressure for change and, as a result, to “change stress” for companies and their employees, and must be countered with new concepts in education, skills development and work organisation. Ultimately, it is the individual employees who determine a company’s ability to change and innovate.

For these to be able to do so, they must become resilient because the disruptive developments of Industrie 4.0 not only change methods, media and tools of work design; they change work content, work structures and cooperation between people, as well as between people and machines. These changes challenge us at all levels: the state, social partners, companies and individuals. In particular, this trend will lead to a significant shift in competencies: digitisation in companies is creating new activities and jobs; existing activities and jobs are changing and, in some cases, becoming significantly more demanding.

On the one hand, resilience is perhaps the meta-competence between making good use of and balancing our resources; on the other, it is a crucial basis for operating successfully in a dynamic system such as the Volatility, Uncertainty, Complexity, Ambiguity (VUCA)-world. Last but not least, resilience also plays a crucial role for the individual.

Resilient people have the ability to deal effectively with stress and uncertainty by being aware of their own resources and knowing how to use them (action competence). Individual resilience training, but also team training and organisational training, e.g., with a focus on mindfulness and error culture, should become a basic component of change.

Despite automation, people will continue to be at the centre of value creation. Adequately qualified employees are the most important resource and the greatest innovation driver of any company. This makes continuing vocational training a game changer in terms of securing skilled labour. Qualification is becoming a competitive advantage.

Allocation of education, competence and work organisation in the classification scheme

With regard to Industrie 4.0 resilience, (vocational) training and work organisation play a central role. With regard to the phases of a concrete resilience strategy, the first point of contact is preparation for the avoidance / elimination of disruptive incidents. It should be emphasized that precautionary measures should be given priority in all cases. Well-prepared employees ensure that disruptions cannot make the waves that lead to disturbances in operations in the first place. To establish a successful qualification strategy, qualification must be integrated into operational processes. Here, aligning the strategy with medium to long-term corporate goals, as well as corporate values, pays off and generates synergies with regard to strategic human resources planning. Functioning competence management is also important in this context.

As systems and processes become increasingly complex, employees need the ability to recognise causalities across departments and to derive the right decisions from them. An important cornerstone for interdisciplinary thinking must already be laid during training by also teaching technical content from other professional fields.

Basic digital skills and digital awareness are prerequisites for using hardware and software in various application scenarios and constellations. But informally acquired key skills, such as creative problem-solving competencies, sophisticated communication skills, and interdisciplinary thinking, also help mitigate in the event of a disruption. In this context, e-learning in particular plays a central role. The ability to use digital tools such as checklists, experiential knowledge in IT systems, dashboards for data presentation, IT tools for simple software configurations (by skilled workers), as well as an understanding of contexts and data, creates the basis for a confident response in the event of a disruption and ultimately contributes to the robustness of production.

In addition to preparation and mitigation, the adaptation phase is also central to a comprehensive resilience strategy. Experiences from disruptions that have occurred, as well as developments (incl. disruptive developments), can be evaluated and processes can be improved to promote resilience. Factors such as corporate culture, leadership and value orientation play an important role here. If resilience has already been experienced, this is also beneficial, as is the consideration of change and the transfer of knowledge for promoting success in the company. Maintaining a certain level of resilience is a lifelong process that is predominantly self-motivated / intrinsic. In addition to the previously mentioned factors, the existence of an error culture, good knowledge of processes and methods, as well as prepared checklists or a clear structure and communication can be helpful.

Starting points for further activities with relevant stakeholder groups

Promoting digital literacy

As shown not only by the comments on the focus topic "Education, skills and work organisation", the demands on employees continue to be immense. The key to mastering these challenges is to increase digital literacy. From a chronological point of view, the keys to promoting this competence are found first in primary education. Therefore, policymakers are called upon to design and further develop relevant modules for the curricula. Digital literacy must not, however, be regarded as an isolated skill. Rather, this competence affects all subject areas since they are all influenced by digitisation. The same applies to secondary education.

Chronologically later, but no less complex, are in-service training programs. Here, too, digital literacy must be understood as a general competence that addresses both accounting and manufacturing. For this reason, demands are placed upon players in the economy and politics for concrete programs and funding.

Health protection

This connecting factor must be pursued decisively by economic actors. In addition to the ability to deal confidently with digital tools of modern production, being resilient is also important at a personal level for employees. In order to achieve the highest possible level of resilience in the sense of coping strategies in particularly uncertain and stressful situations, it is crucial that employees experience their job requirements as transparent and comprehensible, manageable and meaningful (a sense of coherence). Work can be organized in this way by developing a mission statement that promotes employee participation and empowerment. It is essential to involve the workforce in this process. Mission statements should focus on the sustainability and social benefits of the company's products, the creation of working conditions that are conducive to learning and, with a view to new technologies, anchoring decision-making authority regarding processes in the hands of the people. Innovations in the company should be examined to determine whether they are in accordance with the goals anchored in the mission statement.

Creativity & learning culture

The aspect of "creativity & learning culture" also starts with corporate culture. Here, there is a need for action on the part of business and politics. Business must work on improving communal cooperation, e.g., by networking people locally, inviting them to discussions and by solving social issues together in order to actively bring about change or make (new) potential visible. Self-efficacy experiences of the workforce are conducive to such development. Policymakers should encourage the development of a vibrant error culture. Growth can also come from defeat. New forms of (lifelong) learning should be promoted so that the creativity of the workforce can unfold, and existing resources can be used successfully. Incentive systems within the company can also have a positive effect on creativity in this context.

2.6 Standardisation and legal frameworks

Topic clarification – Aspects of standardisation and legal frameworks in the context of resilience

Industrie 4.0 is also referred to as the industrial revolution because it has the potential to break apart and redefine the established structures of the industrial value chain. This affects the role of standardisation as well.

A standard is a comparatively uniform or unified, widely accepted, and usually applied (or at least aspired to) way of describing, making, or performing something that has prevailed over other ways or is at least considered a guideline.

Standards are market-initiated documents that are developed in a voluntary and consensus-based process. Their success is based on their orientation toward market relevance and practicality, as well as their legitimization through the participation of interested parties in the drafting process. Norms are therefore of outstanding importance for the functioning of the economy.

Standardisation is a tried and tested element for relieving the burden on legislators and promotes practical, lean, dynamic and thus innovation-friendly regulation. The European system of the New Legislative Framework (NLF), in which European specifications concretise the basic requirements of legislative acts, is an example of success. Crucial to this success is the trust placed in the European standardisation organisations (CEN, CENELEC and ETSI) by all those involved in the European standards creation process. These organisations operate according to European values while supporting European competitiveness in global trade through their strong links to international standards (ISO, IEC). Consistent application of the NLF in Europe helps European experts succeed in international standards creation. The argument that "if we formulate it this way, then it fits the EU legal framework in conjunction with the national delegation principle of "one country one voice" are often decisive success factors for the influence of European experts. Conversely, weakening the NLF through bureaucracy and lengthy processes weakens Europe's global influence.

Allocation of standardisation and legal frameworks in the classification scheme

Standardisation and legal frameworks can be assigned to the "preparation" and "adaptation" phases of a resilience strategy, whereby the adaptation phase is always seen as a preparatory phase. The development of standards and the creation of a legal framework always have a fundamental or preparatory character. They create the basis for cooperation and economic action by all participants according to uniform and recognised rules. Standards and legal frameworks always have an adaptation component due to their development and revision processes.

With a view to the strategic action fields of Plattform Industrie 4.0, the issues of standardisation and legal frameworks contribute equally to all three mission statement aspects (autonomy, interoperability and sustainability).

Reference points for further activities with relevant stakeholder groups

Technological autonomy as a strategic factor in global competition

Resilient digital infrastructures are a basic prerequisite for a successful digital transformation of the economy – without digital infrastructures, there is no Industrie 4.0. In contrast to "analog" infrastructures such as transport routes, digital infrastructures and their technologies are mostly developed, built and operated by the private sector. At the same time, there are numerous government requirements for the use of digital infrastructures, for example, DSGVO or KRITIS, as well as requirements under private law, such as the protection of intellectual property or trade secrets.

On the other hand, standardisation can bridge the gap between regulatory and technical requirements for the digital infrastructure. Suitable standards that describe cyber security requirements and form the basis for their testing help to make the debate about the use of products from abroad more objective. It follows that the ability to describe appropriate testing requirements for digital infrastructures can be understood as part of the provision of services of general interest.

Strategic relevance of standardisation

Standards and specifications are important instruments for spreading innovations throughout the market. Only with the help of specifications is a technological basis created on which companies can compete for the best product with a new technology.

Standards are found where a high level of stability is required, and broad stakeholder and cross-domain acceptance enables widespread application. This applies in particular to support for the fulfilment of legal technical requirements, but also for the establishment of long-term and internationally recognised principles.

Successful standardisation is an important instrument of global competition. This is particularly true in the context of the globalised economy. In addition to purely technological competition, there is also competition between political systems. Here, we are seeing rapidly increasing participation and the associated dominance of companies from Asia. China, in particular, regards the standardisation as a geostrategic factor and is driving forward, with government support, standardisation activities on a massive scale at the national and international levels. Standards have paved the way for our current economic strength. But in recent years, other countries have followed suit. How resolutely we continue our success story here and represent our interests vis-à-vis our competitors is the central economic policy question for Europe in the 21st century.

Standardisation should be understood and used as an instrument of technological and economic autonomy.

Standards developed by consensus and international standardisation driven from Europe should be actively used as instruments:

- to define a "level playing field" where even an SME can assert its needs and requirements vis-à-vis a hyperscaler.
- to incorporate central points of the social agenda such as sustainability and data protection into international standardisation and thus into international digital business models.
- to be used systematically as a transfer instrument in the context of innovation projects. Standards and specifications should be considered here to describe the state of the art at the beginning of the project and/or the potential for developing a standard should be investigated at the start of the project.

Industry and politics should jointly identify the strategic key technologies for Industrie 4.0 that are relevant from a German and EU perspective and push standardisation work in these areas.

These key technologies and the associated challenges for standardisation should be addressed in the work on the Industrie 4.0 Standardization Roadmap[9] and described by means of corresponding recommendations for action. They provide a suitable framework for dialog between science, industry and politics and international partners.

In dialog with industry and the standards organisations, national and European policymakers should strive to create optimum framework conditions for internationally successful standardisation work.

This includes counteracting further fragmentation of technical rulemaking, which limits the participation opportunities of small and medium-sized enterprises and even small and medium-sized corporations and strengthens the opportunities of very large non-European corporations.

9 More information at: https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/standardization_roadmap_i40.html, accessed: 23.04.2022.

In consultation with industry and standards organisations, policymakers should:

- relate model funding criteria to the prioritized fields of action of the Industrie 4.0 Standardization Roadmap – both for the technical experts and the standards organisations.
- Consider other possible instruments, such as the introduction of a tax incentive for companies actively involved in standardisation, as well as financial support for German project management and participation in the identified areas.

Policymakers should aim for a consistent introduction of standardisation under the NLF for new areas of law in the context of digitalisation, sustainability and autonomy.

This requires:

- a critical review and adaptation of the framework conditions for the preparation of standardisation mandates to the European standards organisations by the European Commission, as well as the evaluation and citation of European-wide harmonised standards.
- the pilot application of the NLF for selected topics of digitisation, such as the Digital Nameplate, the Digital Product Passport and framework conditions for cloud services (Gaia-X).
- a clear separation between technical requirements and specifications (which should be described in standards) on the one hand, and legal requirements (which should be described in laws, directives, regulations, ...) on the other hand.

Sources:

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Bundesverband der Deutschen Industrie (BDI) [Federation of German Industries] (2021): Akut-Programm für mehr Normungspower (Acute program for more standardisation power), https://bdi.eu/publikation/news/akut-programm-fuer-mehr-normungspower/#:~:text=standardisation%20has%20f%C3%BCr%20the%20function%C3%A4hability%20to%20implement%20international%20standardisation%20, accessed: 11.04.2022.

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Deutsche Kommission Elektrotechnik Elektronik Informationstechnik (DKE) [Association for Electrical, Electronic & Information Technologies] (2021): Mit Normen und Standards das digitale Jahrzehnt gestalten (Shaping the digital decade with standards and specifications), https://www.dke.de/resource/blob/2090254/846ed1496e92f54817321d80049c1542/dke-positionspapier-politik---pdf-data.pdf, accessed: 11.04.2022.

3 Conclusion

3.1 Overarching fields of action

The particular challenge of resilience is that measures must take effect regardless of the reason for the crisis. This would be the case, for example, with pandemics, natural disasters and geopolitical developments of various kinds, etc.

Three fields of action for the development of a resilience strategy can therefore be derived from the identified focus topics for resilience in the context of Industrie 4.0: autonomy through open, interoperable and secure data ecosystems, security of supply, and flexibility and adaptability using new technologies.

3.1.1 Autonomy through open, interoperable and secure data ecosystems

Companies must be able to reshape their business relationships throughout the entire value network. This requires multilateral collaboration that enables comprehensive data exchange in a fully interoperable and autonomous data ecosystem while protecting the autonomy of the contributors. Synonymous with these requirements is the Industrie 4.0 data space, in which heterogeneous data ecosystems can collaborate across the board. This continuous data space, which is equally accessible to all participants, must be established with the involvement of the entire relevant heterogeneous field of actors. At the same time, the possibility of trustworthy, bilateral data exchange or data processing in the self-controlled security domain should remain unaffected.

Selected examples may include:

- design an end-to-end Industrie 4.0 data space with the participation of current initiatives and organisations as a reference framework,
- develop transferable concepts for the development of data ecosystems in the Industrie 4.0 data space,
- secure the connectivity of the Industrie 4.0 data space to data spaces in other sectors,
- abilities and capacities to develop and manufacture new technologies.

3.1.2 Security of supply

… for industrial interests

German industry, together with policymakers, should identify resources relevant to it, such as (data) raw materials, supplier products, (digital) infrastructures, critical technologies and competencies, as well as develop proactive strategies to secure them in sufficient availability.

Selected examples may include:

- implementing systems for transparent, cross-company monitoring of supply chains and networks, on the basis of which approaches to shared production and multiple sourcing can be realized,
- securing supplies by recycling raw materials, which can be done, for example, by extending the administration shell to include a lifecycle component model,
- securing a stable energy supply, both in terms of (renewable) energy sources and stable and secure energy networks,
- ensuring stable and fast communication infrastructures such as 5G networks.

… for societal purposes

Policymakers should identify relevant products and services that should be available to society for overcoming crisis situations such as natural disasters and pandemics. For these products and services, proactive strategies must be developed in close cooperation with the relevant industries to ensure their sufficient availability.

Operationalize minimum supply concepts through:

- determination of the status quo for minimum supply concepts,
- incentive systems for industry participation,
- transferable approaches to appropriate legal forms for implementing collaboration between private and public actors.

3.1.3 Flexibility and adaptability with the use of new technologies

… for production and services

German industry must always be able to flexibly adapt its own production processes, business models and services to new requirements and framework conditions and significantly increase the degree of adaptability.

Selected examples may include:

- support for interoperability through standards,
- implementation of approaches to expand production competencies and capacities, for example, through shared production and matrix production,
- use of the administration shell to support engineering and simulation to demonstrate process capability of alternative process routes.

… for education, competence and work

The fields of action for resilience in the context of Industrie 4.0 result in new demands on the competencies of employees. The social partners, together with political actors, must therefore specify these requirements and develop suitable offers of education and competence building, as well as establish new forms of work organisation in industry.

Selected examples may include:

- basic interdisciplinary understanding in education and training,
- consistent transfer of expertise from research to companies,
- taking stock of the status of digital skills in the workforce. Numerous “checks” already exist here, as shown in the appendix.
- continuing education programs supported by shop stewards or mentors to expand employees’ digital skills.

Economic interests are not always in harmony with state welfare. Therefore, the identified areas of action are part of a field of tension.

The action field digital autonomy, for example, is of particular interest for industry from the perspective of Plattform Industrie 4.0 and is already supported by politics. The action fields security of supply and flexibility and adaptability in using new technologies are in the interests of both stakeholders, although the focuses, as described above, are quite different.

3.2 Implementation

Contributions to the solutions for the overarching fields of action on the way to a resilient industry and society should be balanced between the stakeholders, politics and industry.

Future work on this issue should therefore take place with ethical guidance in discourse between industry, politics, relevant federal authorities, research and development, and representatives of civil society at management level. As a broad-based network, Plattform Industrie 4.0 can play a key role here.

This discourse could be incorporated into existing or planned activities of the federal government, for example, as part of the planned German Recovery and Resilience Plan.

The strategic goals and alliances developed in the proposed body should be broken down into operational tools and concrete measures via supporting, topic-specific working groups and task forces, and followed through to implementation.

In the event that it is not possible to integrate the proposed body into existing activities, it would seem advisable to continue working on the issue of resilience in the context of Industrie 4.0 in an independent body, such as a German Resilience Council Industrie 4.0, using the proposed approach.

4 Annex – Exemplary activities of the focus topics

4.1 Examples of autonomy

Cybersecurity

A survey conducted by the VDMA (Verband Deutscher Maschinen- und Anlagenbau e.V.)[10] [Association of German Mechanical and Plant Engineers] has shown that mechanical engineers consider the risk of intrusion by third parties via remote access to be rather unlikely. The biggest gateways for ransomware attacks are not malicious e-mails, but poorly secured remote access to machines and systems. Inadequate access protection means that only a username and password are required. That is why current projects aim to ensure that manufacturers can only access the machine remotely after prior consultation, that all employees have understood the absolute necessity for cybersecurity awareness, and that purchasing guidelines for remote access are created and supplier companies are obligated to follow them.

A functioning cybersecurity concept is an interplay of actors, both human and technical. Therefore, it is important to follow a systematic approach. Guidelines have been published by the Plattform Industrie 4.0[11], the ISACA Germany Chapter e.V.[12] and the American NIST[13]. It is important that review and follow-up take place regularly and are best incorporated into the daily operating routines.

In the case of networked devices and machines, IT security begins with the development and selection of the IT

10 Ibid. VDMA (2021): Umfrage Industrial Security in der Industrie gestartet (Survey Industrial Security in the industry started), https://www.vdma.org/viewer/-/v2article/render/18528055, accessed: 11.04.2022.

11 Ibid.: Plattform Industrie 4.0 (2016): IT-Security in der Industrie 4.0 – Handlungsfelder für Betreiber (IT-security in Industrie 4.0 – Action areas for providers), https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/guideline-it-security-i40-action-fields.html, accessed: 11.04.2022.

12 ISACA (2021): Leitfaden Cyber-Sicherheits-check OT (Guide to Cyber Security Check OT), https://www.isaca.de/sites/default/files/isaca_leitfaden_cyber-sicherheits-check_ot.pdf, accessed: 11.04.2022, for info in English see https://www.isaca.org/, accessed: 11.04.2022.

13 Computer Security Resource Center (2021): Operational Technology Security, https://csrc.nist.gov/projects/operational-technology-security, accessed: 04.11.2022.

architecture for devices and the overall system. This applies equally to industry and consumers. The international IEC 62443 series of standards supports this process with the aim of guaranteeing secure operation in the interactions between system operators and suppliers.

In addition to technical approaches, the simplification of value chains and future regulations will also play a key role in ensuring autonomous digital collaboration.

Secure communication in post-quantum times

Current cryptographic methods will not always remain secure: new attack methods are discovered over time; and continuously growing computing capacities make previously unthinkable attacks possible. It can be assumed that future quantum computers will break currently used cryptographic encryption and signature methods through their high performance. Especially for products with a long lifespan, such as industrial equipment, the early development of security technologies that resist attacks from quantum computers is urgently needed. Such new technologies are used for secure encryption and decryption, but they must also enable the easy use of digital signatures. Public-key infrastructures (PKIs), based on current cryptographic methods, serve this purpose. These must also be adapted for quantum computer-resistant processes. Therefore, so-called post-quantum cryptography (PQK) is needed.

The *FLOQI* (Full Lifecycle Post-Quantum PKI) research project aims to develop a quantum computer-resistant PKI. This must be compatible with current cryptographic procedures. For this purpose, PQK procedures are implemented on different platforms and tested in three demonstrators. Project developed procedures for the automotive industry, Industrie 4.0 and finance will be demonstrated. For these applications, durable and secure processes are necessary because products such as ATMs and production facilities are used for several decades. In order to make the transition from current to new procedures as free from interruption as possible, the project will develop ways that allow the parallel use of current and newly developed quantum computer-resistant procedures. The results will be incorporated into international standards.

The concepts designed will be used in demonstrators by leading industry partners from the automotive, Industrie 4.0 and government sectors.[14]

Overcoming the crisis with AI support

In order to effectively support crisis management using AI, it is important that the applications developed are able to predict the evolution of crisis situations and also anticipate the simultaneous reactions of the various actors (government, companies, etc.). Only by considering the reactions to an initial crisis in specific scenarios is dynamic crisis management be possible. The amount of data required by the AI application to forecast such highly complex scenarios is correspondingly high. The lack of data that is common in a Big Data scenario must be overcome, and existing data must be continuously kept up to date while ensuring data privacy and autonomy at all times. *PAIRS*[15] (short for: Privacy-Aware, Intelligent and Resilient CrisiS Management) solves these challenges through a platform architecture with federal services that can access a wealth of relevant data and collaboratively enable economic and political actors to anticipate mutual influences of individual actions and incorporate them into their own decisions. An important role in this is played above all by the ability to share data with trust, if necessary, even preserving data privacy.

The research project aims to create cross-domain transparency in supply chains in order to be able to derive targeted measures for anticipatory risk minimization.

To this end, a service-oriented, open data infrastructure is being developed that can be used to identify the emergence and impact of crisis situations and to forecast their effects. The AI hybrid technology of *PAIRS* will incorporate both the initial crisis event and the reactions of various actors in a cross-domain data space in order to generate targeted recommendations for action on this basis.

14 More information available at: https://floqi.org/; https://www.forschung-it-sicherheit-kommunikationssysteme.de/projekte/floqi, accessed: 08.04.2022, German only.

15 More information on *PAIRS* at: https://www.pairs-projekt.de/en/about-pairs-2/, accessed: 08.04.2022.

4.2 Examples of security of supply

Examples such as the need to scale back the power production at nuclear power plants due to low and warm water levels in adjacent rivers, as well as the restricted movement of goods such as coal by water due to the heat wave in 2018, are extreme events that illustrate the vulnerability of energy supply systems. Hence, there are many examples and activities which address the stable supply of energy to industry.

Examples of stable energy supply

Example *PAIRS* project: Energy supply application

The *PAIRS* (Privacy-Aware, Intelligent and Resilient CrisiS Management) project will provide an open and service-oriented infrastructure for data that can be used to predict the effects of crises. AI technologies are used to anticipate the occurrence of crises as well as possible reactions of participants in the respective crisis scenario. In the *PAIRS project*, various applications are being considered, including supply chains and logistics, healthcare, and energy supply. In the energy supply application, AI-based data analysis will make it possible to predict the impact of crises on energy demand.[16]

Example *EASY-RES* project

The EU project *EASY-RES*[17] (Enable Ancillary Services bY Renewable Energy Sources) investigates how the energy supply for Europe can be made secure with 100% renewable energy. For society as a whole, the project sets the course for further expansion of renewable energy necessary to achieve international climate targets and the progressive decarbonization of the economy. *EASY-RES* strengthens the position of prosumers who can feed their share of renewable energy into a future smart grid and contribute to further decentralization of the energy supply. *EASY-RES* was funded under Horizon 2020, the European Commission's framework program for innovation and research.[18]

Example: Fields of action for resilience of digitized energy systems

The National Academy of Sciences Leopoldina, acatech – German Academy of Science and Engineering, and the Union of the German Academies of Sciences and Humanities published a statement on the resilience of digitized energy systems in February 2021 as part of their science-based policy advice. The *recommendation paper* deals in particular with the question of how black-out risks can be limited and identifies seven fields of action for politics and industry.[19]

The energy flexible factory

Risk assessment with regard to resilient power supply in an industrial company aims to determine which measures must be taken to ensure the company's own power supply in the event of an external disruption. Conversely, measures that contribute to a self-sufficient and resilient energy supply of industrial companies correspond to the question of how these individual energy systems can add to the resilience of the entire external electrical energy system. Analogous to the concept of herd immunity, the question is therefore how the entire energy network with individually flexibly operated factories can be made resilient.

In this context, the *DC Industry* initiative is worth mentioning. Since October 2019, 39 partners – 33 of them companies and 6 research institutions – have been working on the seamless, efficient integration of renewable energies (e.g., solar panels on factory roofs) and storage systems to balance electricity supply and demand in factories. The focus of *DC Industry* is the DC power supply of an entire production hall, following up the industry's 2016 achievement of DC power supply for a production cell. The DC infrastructure is being implemented and extensively tested in

16 Source: https://www.pairs-projekt.de/en/about-pairs-2/, accessed: 08.04.2022.

17 More information on *EASY-RES* at: https://openems.io/research/easy-res-enable-ancillary-services-by-renewable-energy-sources/, accessed: 11.04.2022.

18 Sources: https://www.bayern-innovativ.de/en/page/research-project-easy-res-key-results; www.easyres-project.eu, accessed: 08.04.2022.

19 Source: https://www.leopoldina.org/uploads/tx_leopublication/2021_ESYS_Stellungnahme_Resilienz_Energiesystem.pdf, accessed: 08.04.2022.

nine model plants and transfer centres at various partners. The output of these plants ranges from several kilowatts to 2 megawatts.

The VDI has published recommendations on the subject of energy-flexible factories, and the *VDI guideline VDI 5207 Part 3 – Energy-flexible factory – IT infrastructure for operating energy-flexible factories* is planned for October 2022. Regarding the topic "Key figures for energy flexibility" in the planned part 3 of VDI 5207, there are commonalities with ISO 22400 and DKE-AK 931.0.10 "Energy efficiency in industrial automation".

There is also the *SynErgie* project[20] (Synchronized and energy-adaptive production technology for the flexible alignment of industrial processes to a fluctuating energy supply), funded by the BMBF [Federal Ministry of Education and Research] as part of the Copernicus project, the Future of our Energy. The *SynErgie* project aims to align all technical and market conditions with legal and social aspects by 2026 in order to effectively synchronize the energy demand of German industry with the volatile energy supply.[21]

Examples of secure and stable communication networks

5G technology and campus networks for Industrie 4.0

5G technology and related applications will exist primarily in the industrial sector. They will enable automated and efficient production processes. Campus networks are versatile for use at industrial sites of all sizes. For versatility, 5G technology has the necessary characteristics such as extremely high bandwidth, short latencies and improved availability. Campus networks are entirely mobile networks for a defined local company site, a university, or individual buildings, such as an office tower. They are tailored to the individual needs of users and meet future requirements from the Industrie 4.0 environment.[22]

4.3 Examples of robust & flexible supply chains

In order to be able to react flexibly and agilely to changes and crises in their environment, companies no longer organize themselves along rigid supply chains but in **dynamic business networks**. Within such a network, a manufacturing company maintains relationships with several suppliers of the same material (**"multiple sourcing"**) and can, for example, switch quickly from one supplier to another, possibly located in a completely different region of the world, if necessary. In the meantime, platforms already exist (**"matching platform"**) that can dynamically match supply and demand to one another. The goals of **shared production** are similar.

A good example of a platform is the research project *Service for Integrated Trading of Production Capacities (DiHP)*[23]. Within the framework of this project, such a market platform was designed and conceptualized to safeguard against production downtime through the automated and inter-company trading of production capacities in the context of additive manufacturing. In the research project, *Platform for the Integrated Management of Collaboration in Value Networks (PIMKoWe)*[24], a cooperative platform was developed on the basis of blockchain technology for secure data exchange in the context of inter-company collaboration.

Another strategy for responding to increasing complexity is the use of resilience ecosystems, which anticipate potential disruptions via advanced (AI) technology and mitigate their impact through a coordinated response from relevant partners. Resilience ecosystems can be used at the store floor level as well as for entire production networks and industries. The goal is to increase the resilience of associated companies (which are not necessarily connected in direct production chains). A prototype of an AI resilience network for manufacturing companies is currently being developed by RWTH Aachen University and DFKI, among others, in

20 More information on *SynErgie* at: https://wupperinst.org/en/p/wi/p/s/pd/713, accessed: 04.11.2022.

21 Sources: https://dc-industrie.zvei.org/en/; https://www.vdi.de/news/detail/die-energieflexible-fabrik; https://www.vdi.de/richtlinien/details/vdi-5207-blatt-3-energieflexible-fabrik-it-infrastruktur-zum-betrieb-energieflexibler-fabriken; https://synergie-projekt.de/ueber-synergie/projektziel; https://www.kopernikus-projekte.de/en/home; https://www.iso.org/standard/54497.html; https://www.dke.de/de/ueber-uns/dke-organisation-auftrag/dke-fachbereiche/dke-gremium?id=3002810&type=dke%7Cgremium, accessed: 08.04.2022.

22 Sources: https://www.telekom.com/en/company/details/5g-technology-in-campus-networks-556692 and https://5g-acia.org/, accessed: 08.04.2022.

23 More information on *DiHP* at: https://projekt-dihp.de/sample-page/, accessed: 08.04.2022, German only.

24 More information about *PIMKoWe* at: https://projekt-pimkowe.de/, accessed: 08.04.2022, German only.

the research program *Scalable Adaptive Production Systems through AI-based Resilience Optimization (SPAICER)*[25].

Shared production can be described as a production system of decentralized, networked companies and locations which are joined in a flexible and agile manner. Networking which extends into the companies can link resilience not only at the supply chain level, but also combine other resilience approaches within the companies. The strengths of this system are brought into play in Germany's fragmented industrial landscape with its many hidden champions among small and medium-sized enterprises[26].

The cross-company integration of data, based on interoperability, is important for the functioning of business networks. The prerequisite is the creation of **trust spaces** (cf. focus topic above "Autonomy") like those in **Gaia-X** and **Catena-X**.

In addition, the question of the interoperability of IT systems and the exchanged and shared data arises – both on syntactic and semantic levels. Approaches and solutions, like those resulting from the Gaia-X and Catena-X Automotive Network initiatives, create trust and data spaces. To achieve greater flexibility in supply chain management, marketplaces and corresponding Manufacturing-as-a-Service (MaaS) platforms have an increasing importance. The risk of newly emerging dependencies (platform vendor lock-in) should be reduced by open MaaS services, such as those proposed by the *Smart Factory Web architecture*[27]. MaaS networks can then also be established on the basis of data spaces with the integration of existing operational delivery portals.

The Internet of Things provides the necessary sensor technology to supply these data spaces with real-time information about conditions and events from the supply chains. Artificial intelligence processes can use this **real-time transparency** to detect and avoid crisis situations at an early stage or to develop solution strategies quickly and semi-automatically when a crisis occurs.

The *PAIRS* research project[28] (Privacy-Aware, Intelligent and Resilient Crisis Management) presents the first outlines of solutions for this. Its goal is to create cross-domain transparency in supply chains in order to be able to derive targeted measures for anticipatory risk minimization.

In the Interreg project, New Business Models with 3D Printing[29] (ABH081), the partners involved are looking at the role of additive manufacturing in cross-border supply chains. Specifically, the project is investigating which business models can be used by SMEs in cross-border supply chains in which physical products are produced via additive manufacturing located directly in the target market close to the end customer, thus contributing to more resilient supply chains. In addition to legal and tax aspects, the project focuses on the role of print licenses for print service providers as well as print handling via digital encryption from the licensor to the licensee and digital monitoring of the printing process.[30]

The example of BAM GmbH shows how companies can easily make their production capacities available to other players in the value chain, making it possible for them to quickly change suppliers if necessary. Via the company's online store "mipart", customers can, for example, have cut steel

25 Project *SPAICER* (https://www.spaicer.de/en/) develops a data-driven ecosystem based on lifelong, collaborative and low-threshold Smarter Resilience Services by using leading AI technologies and Industrie 4.0 standards with the aim of anticipating disruptions (anticipation) and optimally adapting production plans to active disruptions at any time (reaction). This will strengthen the ability of companies to better manage the business risks arising from production disruptions, including the disruption of supply chains, as well as a significant increase in complexity in production due to Industrie 4.0 in a globalized and networked economic world.

26 More information available at: https://www.bmwk.de/Redaktion/EN/Artikel/Digital-World/GAIA-X-Use-Cases/shared-production.html; https://smartfactory.de/en/, accessed: 11.04.2022.

27 More information at: https://www.smartfactoryweb.de and https://www.mdpi.com/2076-3417/11/14/6585, accessed: 08.04.2022.

28 More information on *PAIRS* at: https://www.pairs-projekt.de/en/startpage-en/, accessed: 08.04.2022.

29 More information on *New Business Models with 3D Printing* at: https://www.bayern-innovativ.de/en/page/interreg-project-abh081-of-the-alpenrhein-bodensee-hochrhein-region, accessed: 08.04.2022.

30 Source: https://www.bayern-innovativ.de/suchergebnisse/seite/interreg-projekt-abh081-der-alpenrhein-bodensee-hochrhein-region, accessed: 08.04.2022, German only.

plates calculated and order them fully automatically as part of an AI-based process, without the need for a 2D drawing. This means that thanks to the use of state-of-the-art robotics and additive manufacturing, customers can easily obtain information around the clock, seven days a week, on the price and production time of the parts they need and receive them as promptly as required.[31]

4.4 Examples of production systems and the role of people

The qualified human being plays the decisive role for resilient production, even if it is strongly autonomous. In the future as well, decisions will be made by people – be they the use of knowledge management for maintenance, or the preparation and presentation of production data from the various roles from the store floor up through to company management.

The use of assistance systems is an important building block here. Simulation solutions, for example, enable workflows to be tested on the basis of the administration shell before they are actually transferred to the machine. **Assistance systems** based on **artificial intelligence techniques** will adequately support humans in production decision-making and increase flexibility, ultimately strengthening the robustness of production. Concepts such as **condition monitoring**, predictive analytics and early warning systems are further examples of systems that enable workers to have control over the process and make decisions. These approaches increase the robustness of production against disturbances.

The use of control rooms, control stations and mobile operating systems such as tablets and smartphones for multi-machine operation will further increase the number of **human-machine interfaces**. While this opens up new possibilities in terms of monitoring, control, maintenance and repair of machines, these interfaces must be designed to ensure correct operation in order to achieve resilient production. This can be achieved, for example, by designing different user interfaces for different employees (e.g., blue-collar worker & white-collar worker).

In addition to people, technology also plays a central role in resilient production.

The basis for resilient production is a reliable and relevant database. Therefore, in the future, the linking of data – by which is also meant the breaking up of data silos, the general use of data in IT solutions and software services for production, intralogistics and quality assurance, as well as the provision of specific supporting technologies – will play an essential role.

The field of **artificial intelligence** plays a key role together with data that will be available in the future. For example, machine learning processes enable machines to perform repetitive tasks ever better. With so-called cognitive systems, it is possible to come to decisions and recommendations for action through digital information from sensor data and networks on the basis of learning algorithms, as well as to design generally more resilient production systems.

In addition to the linking and utilization of data, however, the cross-manufacturer exchange of data, e.g., from involved machines, components, material, software, and documents (also called assets or objects), is a prerequisite for value creation within Industrie 4.0.

A **digital twin** is the data image of an object and contains all the information that characterizes the object and its behaviour. These digital images can be used to document the life cycle of products, devices and documents.[32, 33]

For production, in addition to a data basis, material resources and energy are required to manufacture a part, component or product. Designing **alternative process chains** based on alternative materials, semi-finished products, etc., enables rescheduling when resources are scarce. Here too, the **digital twin** plays a decisive role: A digital product twin can be used in the evaluation or suitability of **process chains** with regard to the requirements for component properties, while the **digital process twin** can be used in the evaluation of the effects on processes and machines. Digitally supported engineering and simulation signifi-

31 Source: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/Factsheets/Fallstudie_Industrie40_BAM_OnePager.pdf?__blob=publicationFile&v=8, accessed: 08.04.2022, German only.

32 See summary after remarks by IDTA at: https://industrialdigitaltwin.org/en/technology, accessed: 08.04.2022.

33 A practical example can be found here: https://www.produktion.fraunhofer.de/en/research/futuretopics.html, accessed: 08.04.2022.

cantly support the verification of the process capability of alternative process routes.

To control changeable production within companies, production management can be set up as a sort of flexible network of production factors in the sense of a modular matrix production system. Examples of this include the work of the Fraunhofer IPA[34], which was developed by *SEW Eurodrive*[35] as part of the Industrie 4.0 analyses.

Participation in such a resilience ecosystem requires participating companies to overcome barriers, some of which are considerable. Relevant challenges here are, for example, the willingness to invest their own data on production, supply network or utilization of their own facilities in such a network. The acceptance and rapid implementation of recommendations from this AI resilience system also require trust in the performance of the algorithm and the correctness of the data. Among other things, data worthy of protection, such as from the domain of employees, must also be considered. Overcoming these and other barriers will be critical to the effective use of available technologies for increasing industrial resilience.

Through the research of the *RESYST – Resilient Value Creation Systems*[36] project, companies are supported in the implementation of holistic yet efficient systems for increasing resilience to known and unknown events. From adaptive strategies and processes up to their technical and organisational realization, as well as the selection and development of specific key technologies, solutions are created at all company levels. Concrete examples include the development of technological management support (interactive situation picture, matching platforms), digital models for implementation support and proof of process capability of alternative process routes, or fall-back technologies. In a follow-up project, *SE.MA.K*[37], design options for a flexible and resilient production system, matrix production, are being created for companies so that they remain able to function in the face of fluctuations in the number of units, the increasing diversity of product variants and varying challenges such as supply chain interruptions.

Smart Maintenance means the development of maintenance in the age of Industrie 4.0 and addresses the strategic, tactical and operational management of industrial production facilities (i.e., plants, buildings, technical infrastructure). The *Smart Maintenance Community* of the Fraunhofer-Gesellschaft supports the sustainable improvement of value creation in production systems. Continuous plant availability represents a decisive competitive advantage in securing and expanding production sites. This directly influences the success factors of time, cost, quality and the resilience of a production system. These approaches strengthen the robustness of the system.[38]

Members of the AI Production Network Augsburg are working on a vision of AI-based production. Essentially, a distributed, modular and self-organizing production network is being built in the form of a technological research infrastructure on an industrial scale. Based on this, some examples of future research for resilient production will be done on learning and self-adaptive manufacturing processes, as well as on self-configuring and modular production systems. These processes should also safeguard the autonomy of humans and ensure that their expertise is used optimally. Additionally, companies are supported in implementing AI applications.

Assistance systems for human decision-making support in production, based on machine learning methods, are being researched through BMBF [Federal Ministry of Education and Research] funding under *"Learning Production Technology – Use of Artificial Intelligence (AI) in Production (ProLern)"*. One example that should be mentioned is the research project *"Self-learning machine tools for highly efficient production (AutoLern)"*, which started in June 2021.

34 More information on modular matrix assembly at: https://www.ipa.fraunhofer.de/en/expertise/factory-planning-and-production-management/assembly-planning/modular_matrix_assembly.html, accessed: 08.04.2022.

35 More information on *SEW-EURODRIVE* at: https://www.sew-eurodrive.de/automation/factory-automation/industry-40/industry-40.html, accessed: 08.04.2022.

36 More information on *RESYST* at: https://www.imw.fraunhofer.de/content/dam/moez/en/documents/project-sheets/201218_Projektblatt_RESYST_Englisch_%C3%B6ffentlich.pdf, accessed: 08.04.2022.

37 More information on *SE.MA.KI* at; https://www.ipt.fraunhofer.de/en/projects/semaki.html, accessed: 04.11.2022.

38 More information at; https://www.produktion.fraunhofer.de/en/research/futuretopics/SMC.html, accessed: 08.04.2022.

In AutoLern, a common development platform is being built which will provide analysis methods for data collected during operation of various machine tools. Based on this, it can be determined when AI-models no longer achieve the specified accuracy and need adjustment. This should happen automatically so that AI algorithms can be used flexibly under a wide range of conditions in the industrial environment. Two exemplary applications are planned in the joint project: "Worker Assistance" for setting up the machine or troubleshooting, and "Real-time Control of Processes" for significantly improving process control. For this purpose, models are trained with data from production machines of participating machine and plant manufacturers and then implemented on the machines.[39]

SmartFactory-KL is working on the implementation of the *Production Level 4* vision. The vision is of resilience, flexibility and sustainability in production and is also the basis for the Gaia-X project SmartMA-X. SmartMA-X covers the establishment of shared production in Kaiserslautern, as well as the implementation of innovative AI methods in human-centred production architecture. The project includes work on key technologies and concepts such as industrial edge cloud, skill-based production, multi-agent systems, as well as the implementation of an administration shell.[40, 41]

The Austrian-German project *EuProGiant*[42] is aimed at supporting companies in developing self-organisation skills and stabilisation methods in case of disruptive events. To this end, learning ecosystems are being designed as experimental spaces for employees. A resilience concept for technology at the store floor level based on Gaia-X self-descriptions will be developed. Resilience mechanisms are defined and tested in experimental spaces using stress tests which have been developed. *EuProGigant* works with SmartMA-X projects on edge computing developments and Gaia-X functionalities, as well as with *SPAICER*[43] on a common understanding of resilience and strategy for European industry. *EuProGiant* developed its own resilience concept in connection with the Gaia-X functionalities, which will be presented at the CIRP Conference on Manufacturing Systems in summer 2022.

The *SimProve* project[44] links simulation, which forms the basis of digital twins, and the data-driven approach of process mining for the design of production and logistics systems. The analysis of dynamic "what-if" scenarios of real-time and actual process information can also be used for experimental simulation-based risk analyses. Companies are thereby able to assess the impact of disruptive events before they occur in the real system. The expert knowledge of those responsible is increased, simulation-assessable process alternatives can be played out, and resilience-enhancing solutions can be developed and implemented by management.[45]

In the research project *MoSyS* – Human-oriented Design of Complex System of Systems – new methods, aids and IT tools for the design of complex technical systems and the associated value creation networks as elements of complex System of Systems (SoS) are being researched. SoS refers to an overall system that is composed of various individual systems depending on time and location. Furthermore, guidelines for the design of change are created, which serve companies on their way to a digital and collaborative working environment as well as for clear and comprehensible decision-making processes. All areas involved in product

39 More information at: https://www.wbk.kit.edu/wbkintern/Forschung/Projekte/AutoLern/index.php?site=home, accessed: 08.04.2022, German only.

40 More information at: https://www.bmwk.de/Redaktion/EN/Artikel/Digital-World/GAIA-X-Use-Cases/shared-production.html, accessed: 08.04.2022.

41 The University of Augsburg also outlines a vision of tomorrow's production systems with its "AI Production Network" and emphasizes interdisciplinarity. Further information at: https://www.uni-augsburg.de/de/forschung/einrichtungen/institute/ki-produktionsnetzwerk/, accessed: 11.04.2022, German only.

42 More information on *EuProGiant* at: https://euprogigant.com/en/, accessed: 08.04.2022.

43 See the section "Robust & flexible supply chains" for more information.

44 More information on *SimProve* at: https://www.uni-kassel.de/forschung/simprove/startseite, accessed 04.11.2022, German only.

45 See also the *Platform dataPro* project, which, in addition to data-driven production, also highlights the role of people in the resilient production of the future. Further information on the project at: https://plattform-datapro.de/, accessed: 08.04.2022, German only.

creation (product, production and service development) are included. Aspects such as interdisciplinary collaboration between employees and stakeholders, thinking in terms of product generations, and modeling concepts and methods for mapping SoS are taken into account.[46]

4.5 Examples of education, competence and work organisation

The research project *"Union Workplace Representatives as Training Mentors"*, which is embedded in the national continuing education strategy, addresses the subjective hurdles of continuing education decisions. The trained mentors focus on confidential meetings with employees who have reservations about learning and support them in recognizing their personal resources, in pursuing suitable internal or external paths of professional qualification, in promoting their strengths and in developing themselves personally. The training mentors enable their colleagues to cope with uncertain work situations by acting proactively.

IG Metall's *digital company map* offers company partners the opportunity to create through dialog with employees a systematic overview of the effects of digitisation on individual parts of the company. A traffic light system records changes in qualification requirements and working conditions, as well as the effects on employment. A company map clearly shows which parts of the company are likely to experience extensive change. The employees working there are exposed to particular stress situations, especially psychological stress. Resilience-building measures should accompany the change processes in the long term.

With the online self-tests *"DIGI-Check"* and *"DigiCheck Competencies"*, the state of Hesse is strengthening digital competencies in business and society. The tests determine the current status, provide tailored recommendations for action, and list consulting, funding, and educational opportunities. *The DIGI-Check for companies* of the Hessian Ministry of Economics considers digital competencies of personnel as a component of a digitisation strategy. Its basis is an extensive further development of the VDMA's Industrie 4.0 Readiness Level developed by IW Consult. The *"DigiCheck Competencies"*[47] of the Hessian Digital Minister on the platform *"How digital am I?"*[48] promotes digital competencies as lifelong learning among pupils, trainees, employees, and others. It was created on the basis of the EU *"DigiComp"*[49] model.

Competence transfer from science to praxis provides employees with skills and knowledge and enables companies to utilize the latest know-how and technologies. The following projects in the field of artificial intelligence (AI) and cyber security help to improve the resilience of SMEs in the context of Industrie 4.0. *KompAKI*[50] – Competence Centre for Work and Artificial Intelligence – provides information on the latest AI developments and supports companies in the introduction of AI solutions. In doing so, AI issues from the world of work are researched and directly implemented. Centre for the Future *ZUKIPRO*[51], takes a new, practical and human-centred approach to using AI and digitalisation to make work in production and the skilled trades better. The ZUKIPRO team offers partnership-based support through information, consulting and qualification for production and craft enterprises and their employees in Hesse. *ATHENE*[52] – National Research Centre for Applied Cyber Security – accompanies and supports the digital transformation of the economy to improve cyber

46 More information on *MoSyS* at: https://community.advanced-systems-engineering.de/projects/368, accessed 10.04.2022.

47 More information on *DigiCheck* competencies at: https://www.wie-digital-bin-ich.de/DigiCheck-Kompetenzen, accessed 08.04.2022, German only.

48 More information on the *"How digital am I?"* platform at: https://www.wie-digital-bin-ich.de/, accessed: 08.04.2022, German only

49 More information on *Digi-Comp* at: https://joint-research-centre.ec.europa.eu/digcomp/digital-competence-framework-20_en, accessed: 08.04.2022.

50 More information on K*ompAKI* at: https://kompaki.de/, accessed: 08.04.2022, German only.

51 More information on *ZUKIPRO* at: https://zukipro.de/, accessed: 08.04.2022, German only.

52 More information on *ATHENE* at: https://www.athene-center.de/en/, accessed: 08.04.2022.

security and data protection. Among other things, it offers training and continuing education in the challenging field of cyber security.

In the *EPICSAVE* project[53], a serious game simulation approach based on virtual reality technology was implemented to recreate situations that are difficult to train. This strengthens both the technical competencies as well as the social and communicative skills of the trainees, thus achieving the goal of comprehensive professional competence. With the help of such a system, a wide variety of scenarios in the field of Industrie 4.0 can be simulated. For example, various production lines and assembly workstations are possible in order to train concrete work steps as well as to convey basic concepts of digitisation and allow them to be experienced in a hazard-free environment. Since errors have no consequences in virtual reality, participants can try out new things without risk.

In the joint project *RePASE* – Reflexive Process Development and Adaptation in Advanced Systems Engineering – scientists from product development and industrial- and organizational psychology are working together with companies from plant and mechanical engineering, the automotive industry and rail vehicle technology to anchor structured reflection in the development process. The results of the interdisciplinary collaboration are adapted procedures and IT tools for system-oriented product development, as well as reflection methods and digital tools for competence recording and training concepts for competence development. For this purpose, company-specific development activities are analyzed with regard to work and organizational psychology as well as engineering criteria and designed in a goal-oriented manner. Methods for interdisciplinary activity-oriented process modelling and evaluation are developed and tools for method provision and -adaptation in system-oriented development are tested. For the goal-oriented development of competencies, requirements for methodological competencies are to be recorded – including through interviews – and role-specific competency models are to be developed.[54]

In the project *Strong Employees and Strong Companies through Strengthening the Ability to Change with Resilience Concepts (STÄRKE)*, an overall concept of individual and organisational resilience was developed and tested in several pilot companies. For this, approaches from the fields of occupational science, business management and psychology were combined. A key result of *STÄRKE* is the so-called resilience compass. This is a praxis-oriented guide that enables companies to independently analyse their adaptability to current and future economic and social conditions, and to derive and implement suitable development measures.[55]

The rapid spread of the SARS-CoV-2 coronavirus and the accompanying measures adopted by the government have a strong impact on international and national social life. The working world, too, has to comply with strict and changing regulations and measures, and is also faced with collapsed supply chains in some cases. To nevertheless remain functional, many companies and businesses have had to make far-reaching adjustments to their work structures and processes that did not seem feasible or sensible before the crisis. For the subsequent use of the knowledge acquired through the forced learning process, a detailed, systematic analysis of the resulting conversion and change processes is necessary. In the project *Using Good Solutions for the Future – COVID-19 Lessons Learned (COVID19LL)*, a cross-sectoral and systematic stocktaking of the operational measures and changes was carried out first. This was done with the involvement of representatives from trade unions, companies, employees and employers. Based on a subsequent analysis of best practices in selected activities, suggestions for transfer potential for the period after COVID-19 were identified and recommendations for similar activities in other sectors were inferred.[56]

53 More information on *EPICSAVE* at: https://epicsave.de/, accessed 08.04.2022.

54 For more information on *RePASE* see: https://community.advanced-systems-engineering.de/projects/436, accessed: 11.04.2022.

55 For more information on *STÄRKE* see: https://staerke-projekt.de/, accessed: 11.04.2022, German only.

56 For more information *COVID19LL* see: https://www.mw.tum.de/lfe/forschung/projekte/covid-19-ll/, accessed: 04.11.2022, German only.

AUTHORS:

Volker Ahrens, Advaneo GmbH | Prof. Dr.-Ing. Thomas Bauernhansl, Fraunhofer Institute for Manufacturing Engineering and Automation IPA | Dipl. Ing. Maria Christina Bienek, SEF Smart Electronic Factory e.V. | Nadine Blechinger, Siemens Energy Global GmbH & Co. KG | Dr. Maximilian Bock, Bayern lnnovativ GmbH | Jürgen Bretfeld, Advaneo GmbH | Dr.-lng. Robert Couronné, Bayem Innovativ GmbH | Johannes Diemer, ARENA2036 e.V. | Dr. Jens Gayko, Standardization Council Industrie 4.0 – VDE e.V. | Julia Görlitz, IG Metall | Christian Gülpen, RWTH Aachen | Stephan Hamm, Technology Initiative SmartFactory KL e.V. | Dr. Thomas Helfer, Bayern lnnovativ GmbH | Alexandra Horn, DIN e.V. | Dr. Svantje Hüwel, Hessen Trade & Invest GmbH | Peter Klement, MIT Club Germany | Prof. Dr.-Ing. Holger Kohl, Fraunhofer Institute for Production Systems and Design Technology IPK | Dr. Uwe Kubach, SAP SE | Dr.-Ing. Thomas Kuhn, Fraunhofer Institute for Experimental Software Engineering IESE | Prof. Dr. Frank T. Piller, RWTH Aachen | Stefan Pollmeier, ESR Pollmeier GmbH Servo-Antriebstechnik | M. Sc. Brandon K. Sai, Fraunhofer Institute for Manufacturing Engineering and Automation IPA | M. Sc. Niels Schmidtke, Fraunhofer Group for Production & Fraunhofer Institute for Factory Operation and Automation IFF | Thomas Schulz, GE Digital | Dennis Weber, Advaneo GmbH

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