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Industry 5.0 implementation barriers for manufacturing companies

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Abstract

The advent of the fifth industrial revolution (Industry 5.0) has brought a new era of transformation for manufacturing companies (MCs), intending to achieve human-centered, sustainable, and resilient production. However, the change accompanying this transformation also presents a number of implementation barriers that companies must fully consider in order to prevent the establishment of Industry 5.0 from failing. The aim of this paper is, firstly, to provide an overview of the industrial situation of Industry 5.0 and, secondly, to identify and transparently present the existing implementation barriers for MCs on the way to a sustainable, human-centered, and resilient production. The research process starts with a literature review to identify the influencing factors, which are then further developed and structured in an Axiomatic Design. The relevance of the identified influencing factors was then assessed in an international survey with more than 200 participants. Finally, all global implementation barriers are visualized using an Ishikawa diagram. Future research should focus on local implementation barriers and implementation guidelines.

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Keywords: Industry 5.0; Change; Implementation; Manufacturing; Challenges

1. Introduction

Over the last decades, production has significantly transformed within industrial revolutions in response to various challenges. In the 18th and 19th centuries, manual production processes were initially revolutionized by the first industrial revolution, which introduced the mechanization of production through water and steam power within the factory. However, harsh working conditions without support systems led to Industry 2.0 in the late 19th and early 20th centuries. This era introduced electricity, internal combustion engines, assembly lines, mass production techniques, and labor division (Taylorism). To further improve the efficiency and precision of production, Industry 3.0 emerged in the 1970s with the automation of repetitive tasks using computers and programmable controllers. Driven by the growing need for digitalization and connectivity, industries began to focus on networking and communication between machines, systems, and people to create smarter, more integrated production environments. The fourth industrial revolution (Industry 4.0), from the 1980s to the 2000s, introduced technologies such as virtual reality, big data, and the Internet of Things to enable real-time data exchange and digital production monitoring. [1, 2]

However, Industry 4.0 (I4.0) has revealed several limitations, including insufficient attention to human factors (such as well-being and collaborative robots), a lack of sustainable responsibility (such as linear production models and resource inefficiency), and a slow response to complex or unforeseen events (such as supply chain delays and machine breakdowns). Therefore, Industry 5.0 (I5.0) has been aiming at a sustainable, human-centered, and resilient production from

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the beginning of the early 21st century onwards [3], thus counteracting these limitations.

With the introduction of new production approaches, technologies, or regulatory requirements, manufacturing companies (MCs) are facing transformation processes. The implementation of concepts such as the Toyota Production System [4, 5], Lean 4.0 [6, 7], sustainability [8, 9], or I5.0 represents a substantial change process for companies. As change processes are accompanied by challenges that can lead to the failure of the transformation [10], it is important to identify the barriers and sensitize those affected by the change to manage it successfully. Due to the novelty of the I5.0 concept, it is still unclear which aspects are already implemented in MCs and which ones represent an implementation challenge. Therefore, this paper provides insights into the industrial perspective on I5.0 and identifies and presents barriers to I5.0 implementation for MCs, based on an international survey of more than 200 participants.

2. Moving towards Industry 5.0

I5.0 represents the next evolution in industrial development, focusing on the synergy between humans and machines. It aims to enhance human creativity and innovation by leveraging advanced technologies such as artificial intelligence, robotics, and big data from I4.0. The key pillars of I5.0 are resilience, sustainability, and human-centration (see Figure 1). Resilience enables production companies to quickly respond to disruptions with flexible and adaptable technologies. Sustainability leads a company to respect planetary boundaries, thereby focusing environmental sustainability, and human-centration aims for the promotion of talents, diversity, empowerment, and respect for the workers. [3]

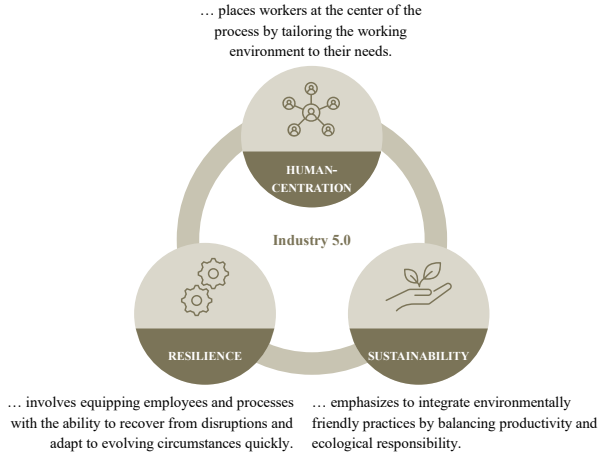

Figure 1: Industry 5.0 concept

To gain insights into MCs in times of disruptive change, particularly in the context of I5.0, an international online survey was conducted in 2024 with 214 respondents. The questionnaire was developed according to Döring [11], by considering the four research design quality criteria *construct validity*, *internal validity*, *external validity*, and *reliability* [12]. External validity, for example, refers to the generalization of a study's findings. Slovin's formula can be used to determine the number of data points necessary to allow statistical statements to a certain level of confidence. A 90 % confidence interval can be met by having 69 data samples (assuming an unlimited population size). The questionnaire of this study had more than 200 data samples from companies of different international locations (e.g., Germany, United States, Italy, Argentina), industries (e.g., Automotive, Eletronics, Food and beverages), and sizes (almost 45 % large, 22 % medium, 33 % small). Thus, statistical statements with a high level of statistical significance are possible. The first step of the survey was to gain insight into the establishment of the I5.0 paradigm and its implications for MCs, presented in Section 2.1 and Section 2.2.

2.1. Industry 5.0 current and target situation

Although the term I5.0 was introduced by the European Commission in 2021, the participants' responses confirm the novelty of the I5.0 paradigm: Over 35 % of the respondents indicated that they currently have no plans to implement I5.0, and a further 40 % of the participants have only reached the 'partially implemented' stage (see Figure 2). This contrasts with over 30 % who plan to reach at least the 'mostly implemented' stage in 5 to 7 years, and a further 18 % who plan to achieve full implementation of I5.0 in this period.

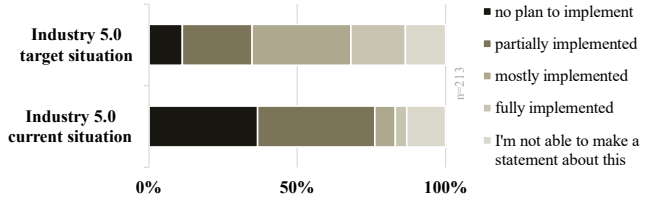

Figure 2: Current and target situation regarding Industry 5.0

In terms of current performance in the three pillars of I5.0, 30 % or more of the respondents said that they were at least above average in terms of proficiency, but less than 15 % said that they were 'highly proficient' in all three pillars. In contrast, more than 20 % rated themselves as below average in all pillars (see Figure 3). This indicates that while individual actions are being taken in the areas of human-centration, environmental sustainability, and resilience, comprehensive proficiency in these three pillars has yet to be achieved.

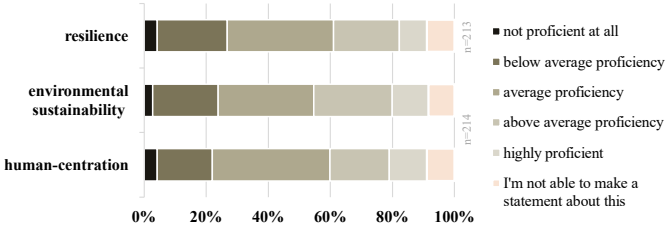

Figure 3: Company's current proficiency

2.2. Industry 5.0 awareness and importance

Familiarity with the pillars of I5.0 varies across the study participants. While almost 70 % of the respondents reported being familiar or very familiar with environmental sustainability, only around 50 % were familiar with human-centration and resilience. This is also confirmed by the number of participants who were not at all familiar with the pillars. While less than 3 % of the respondents stated this for environmental sustainability, it was just under 6 % for

resilience and around 11 % for human-centration. Figure 4 therefore shows that most of the respondents are already familiar with the pillars of I5.0, with only a few participants stated that they do not know the meaning of the pillars at all. The largest need for clarification is in the human-centration pillar.

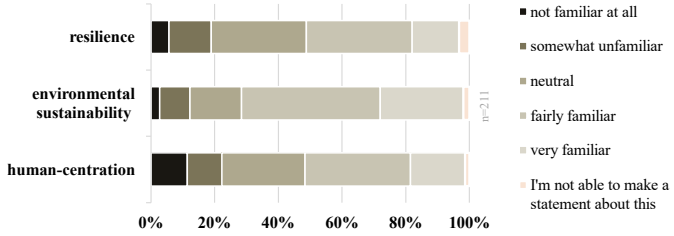

Figure 4: Familiarity with the pillars of Industry 5.0

The importance of the pillars of I5.0 for companies is shown in Figure 5. It shows that over 70 % of the respondents stated that all pillars are relevant. In the case of environmental sustainability, more than 75 % of the respondents indicated that this is 'relevant' or 'very relevant' to their company. This is confirmed by the number of respondents who rated the pillars as 'not relevant at all' (less than 3 %) or 'not relevant' (less than 5 %).

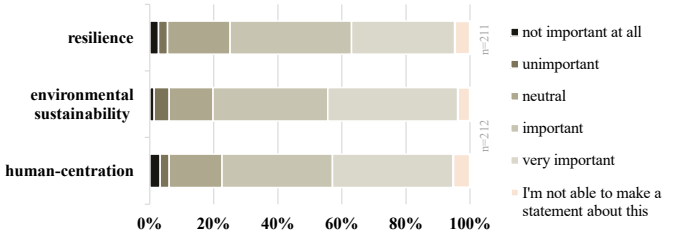

Figure 5: Importance of the Industry 5.0 pillars

3. Literature review

The previous sections show that there is a growing attention to the implementation of I5.0 and that companies recognize the need to make progress in this area. As the implementation has stalled so far, it is important to identify potential barriers at an early stage to support a successful transformation to I5.0.

A systematic literature search based on Webster and Watson [13] was conducted to capture the state of research on the barriers to the implementation of I5.0. The search was carried out in the Scopus database, including all publications up to the end of 2023, using a search code consisting of the three terms 'I5.0', 'Production', and 'Barriers'. While the terms were linked with AND, relevant synonyms within the terms were linked with OR. The initial search returned 567 results. To ensure the accessibility and relevance of the publications, only publicly available publications ('all open access'), English literature assigned to the research field of 'Engineering' were considered, resulting in 101 documents. After the title and abstract screening, the number of publications was reduced to 11 publications whose content was relevant for full-text screening. The full-text screening resulted in 8 publications relevant to the state of the art, which are presented below.

Santhi & Muthuswamy [14] outlined the need to develop I5.0, as it represents an improvement towards focusing on human and environmental aspects, and presented the main technologies of I5.0. However, the authors focused their work on the main technologies of I4.0 as well as the socio-economic challenges of I4.0 and did not present specific challenges for the implementation of I5.0.

The authors Pizoń et al. [15] examined in their publication the challenges of I5.0 on the way to a human-centered production system. They conducted a literature review and categorized their key findings (i.e. challenges) into the *social*, *technical*, *security*, and *legal and ethical dimensions*. However, they did not consider the sustainability or the resilience challenges holistically.

In their approach, Maddikunta et al. [16] looked at the relevant technologies and the application of the I5.0 paradigm. They also discussed the challenges of I5.0. However, they focused on selected challenges related to, e.g., security, or collaborative activities between humans and robots in a factory.

Cotta et al. [17] discussed in their publication the development and implementation of a cognitive cell factory in I5.0. They presented challenges related to the transition to I5.0 and to cognitive factories, such as *cost*, *data privacy and security*, and *training efforts*. However, the challenges shown are limited and do not consider the I5.0 concept holistically.

In their work, Mourtzis et al. [18] presented a framework to support the transition from I4.0 to Society 5.0 (S5.0) and identified the key issues that need to be addressed to make the movement successful. Although the authors focused mainly on S5.0, they also identified challenges and opportunities that are common to both I5.0 and S5.0, such as an *aging population* or *resource scarcity*. However, the presentation of the I5.0 challenges is limited, as this was not the focus of their work.

Khan et al. [19] elaborated an approach to overcome the challenges of I4.0 by presenting the changes and improvements of I5.0. However, they focused on presenting challenges related to I4.0, such as *data and information security* or *human resource issues,* and investigated on how I5.0 can be used to address these challenges.

In their work, Trstenjak et al. [20] focused on the elaboration of key enablers for the I5.0 that can be used to support the transition from I4.0 to I5.0. As a result, five key enablers (e.g., Flexibility and Modularity) are presented. However, the authors divided these enablers into two groups, the *human-centered approach* and the *environmental impact awareness*, and thus did not consider the concept of I5.0 holistically.

In their paper, Gladysz et al. [21] presented their findings on the transition from the Operator 4.0 to the Operator 5.0. They used the PDCA cycle to assign drivers (e.g., well-designed human-machine interaction) and restraints (e.g., lack of disciplinary knowledge) to Operator 5.0. However, they did not address the common challenges associated with the I5.0 change.

As a result, it can be said that, although some approaches have considered the I5.0 paradigm, none of them have elaborated on the related factors that pose a barrier or a challenge to a successful implementation of I5.0 holistically, considering both the literature and the industry perspective. Therefore, the following section presents the methodological approach to identify the factors influencing the transformation towards I5.0.

4. Methodological procedure

A four-step process was used to identify barriers to I5.0 adoption (see Figure 6). In the first step, a literature search was conducted using the methodology described in Section 3 to identify factors influencing the progress of I5.0. A search code was therefore defined, consisting of keywords related to production and linked to the pillars of I5.0 or I5.0 itself. The search was carried out in the Scopus and Web of Science databases, and the influencing factors were captured qualitatively and mapped to the pillars of the paradigm. Due to the importance of I4.0 and the findings from the state of research, this paradigm was also included in the search to consider related potential obstacles on the path to I5.0.

Step	Result
Literature analysis	List of factors influencing the progress of Industry 5.0
Axiomatic Design	I5.0SDD
Online survey	Evaluated influencing factors
Ishikawa diagram	Overview of major and minor influencing factors sorted by focus area

Figure 6: Overview of the methodological procedure

The results from the first step served as an input for the application of Axiomatic Design (AD) according to Suh [2]. AD follows the idea of breaking down a system into tuples of so-called functional requirements (FR) and design parameters (DP) [22]. An FR represents the functional demand of a system (e.g., 'clean the floor'), while a DP provides a physical solution to achieve the corresponding FR (e.g., 'vacuum'). Based on the list of influencing factors from the first step, the system of I5.0 was decomposed hierarchically into DPs and FRs, resulting in the so-called I5.0 System Design Decomposition (I5.0SDD). The I5.0SDD thus states the hypothesis that a company reaches the full potential of I5.0 by reaching all the single FRs on the lowest hierarchical level ('leaves') of the decomposition with implementing the corresponding DPs.

To identify the implementation status and thus the implementation barriers of I5.0, a survey was derived from the I5.0SDD in the third step. This was done similarly to Linck [23] by directly deriving the survey questions from the leave FRs and DPs of the I5.0SDD. Each question was thus stated as 'Our company FR, e.g., by PS'. In addition, statements about I4.0 as its predecessor were identified from the literature. The two previous steps of the methodological approach resulted in a total of 11 sustainability, 17 resilience, 15 human-centration and 8 I4.0 statements, which represented potential implementation barriers and were rated on a 5-point Likert scale. The response options for each statement are 'strongly agree', 'agree', 'neither agree nor disagree', 'disagree', 'strongly disagree', or 'I am not able to make a statement about this'. The statements were all formulated to assess the level of implementation of various elements of I5.0, so the response 'strongly disagree' indicates a significant implementation barrier. During the analysis, the response options were coded numerically from 1 ('strongly disagree') to 5 ('strongly agree') and the mean value was calculated for each of the resulting 51 statements. Any statement that was rated with an average agreement of more than 4 ('agree') was not regarded as an implementation barrier, as this element is already largely implemented in MCs. Statements with an average < 3.5 were labeled as major implementation barriers, and values between 3.5 and 4.0 as minor implementation barriers. In addition to this global view, local means were also calculated for 8 different countries involved.

Finally, to ensure transparency, the Ishikawa diagram was used in step 4 to visualize the factors influencing the transformation to I5.0. An Ishikawa diagram is a useful tool for illustrating cause-and-effect relationships [6, 24]. Here, the problem was the lack of implementation of I5.0, and the related influencing factors were deductively split according to the pillars of human-centration, resilience, and sustainability, as well as the possibility of inductive expansion. Furthermore, the influencing factors were rated according to their importance.

5. Results

The results of the four steps shown in Figure 6 are presented in the following.

5.1. Step 1: Influencing factors

As described in Chapter 4, the first step was to identify literature-based factors that influence the path to I5.0. Figure 7 shows an excerpt of the factors that can be assigned to the I5.0 pillars. Several influencing factors can be assigned to a superordinate factor. In the area of human-centration, for example, literature research has shown that the health of employees influences the successful implementation of I5.0. This includes both the mental and physical health of employees [25–29]. Thus, the goal is to minimize stress and negative effects on employees. In the area of resilience, for example, a company's flexibility has an impact on the success of the I5.0 transformation. This includes the ability to respond to disruptions in the supply chain [30, 31] and the ability to respond to fluctuations in market demand [18, 32, 33]. Risk management also plays a role, such as risk assessment or risk management strategies [30, 34]. Within the pillar of sustainability, the factors *ecological product design* and *energy-efficient process design* play an important role [33, 35–37], as well as the *use of renewable energy sources* and *energy consumption* [28, 31, 32, 35, 37].

In addition to the factors associated with the I5.0 pillars, some influencing factors have been identified that emerged from the I4.0, e.g., the *automation of production processes* [26, 38–40], or the *use of digital technologies in production* [15, 41–43].

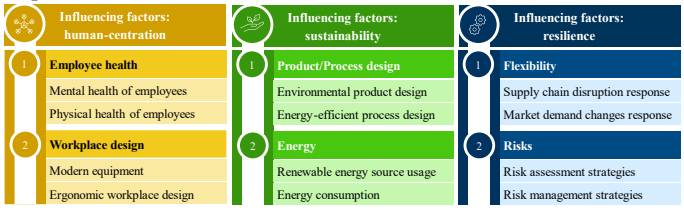

Figure 7: Influencing factors for the I5.0 pillars (excerpt)

5.2. Step 2: I5.0SDD

As described in Section 4, the second result is the I5.0SDD, which breaks down the system of I5.0 into distinct FRs and PSs which can be represented as a tree structure. The overall decomposition distinguishes the I5.0 pillars of resilience, sustainability, and human-centration. An excerpt is shown below in Figure 8.

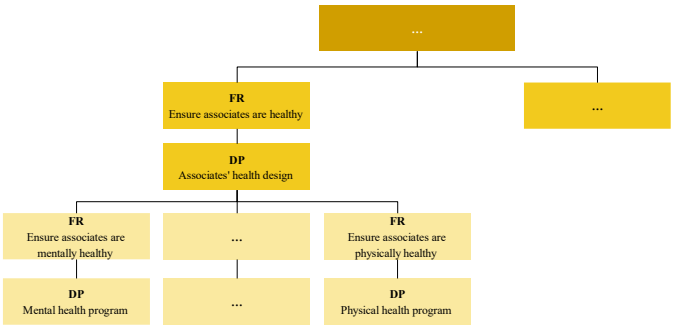

Figure 8: Excerpt from the I5.0SDD

5.3. Step 3: Evaluated influencing factors

Considering the international responses, the sustainability statements were rated with an average score of 3.5, reflecting a consensus between 'agree' and 'neither agree nor disagree'. The implementation statements for the resilience and human-centered principles received a higher mean score of 3.7, indicating general agreement that these principles are already implemented within the current production. Interestingly, the I4.0 statements were rated lower than the corresponding I5.0 pillars. This suggests that while I5.0 is emerging as a new revolution, the standards of I4.0 have yet to be fully implemented globally and continue to pose significant challenges for companies. Moreover, neither I4.0 nor I5.0 has not yet been fully adopted in practice, as the average rating has not yet reached 4.0, representing average agreement.

Based on our study, there was a strong global consensus on the implementation of six statements, resulting in their removal as implementation barriers. Currently, production companies support the adoption of improvement initiatives (resilience), offer products that meet customer demands (resilience), have the capacity to produce their full product portfolio (resilience), focus on achieving the company's overall goals (resilience), minimize the risk of cyber-attacks (human-centration), and ensure a safe working environment (human-centration).

5.4. Step 4: Influencing factor overview

The analysis of the survey results showed that a total of 45 factors influence the implementation and progress of I5.0 in MCs. Of these, 37 relate to the three dimensions of I5.0, and 8 relate to the I4.0. The results showed that, concerning the pillars of I5.0, 13 influencing factors can be assigned to human-centration, 13 to resilience, and 11 to sustainability.

In addition, in the context of I5.0, six minor and five major sustainability barriers, 11 minor and two major human-centration barriers, and 13 minor resilience barriers have been identified. For I4.0, five minor and three major barriers were noted. All barriers are listed in the resulting Ishikawa diagram in Figure 9, with major barriers highlighted in bold italics.

The most critical implementation barriers across the surveyed countries are the *degree of automation in production* with a mean score of 2.8 (I4.0), *cognitive assistance* with a mean score of 2.9 (human-centration), and an *interconnected production system* with a mean score of 3.1 (I4.0).

In an initial local analysis, eight countries were compared, with 8-38 survey participants per country: Argentina, Austria, Germany, Italy, Slovakia, South Africa, Thailand, and the United States. Countries with fewer than five participants were excluded from the analysis to ensure statistical relevance. The implementation of the sustainability pillar is rated comparatively lower in Germany and the United States, with mean scores of 2.9 and 3.1, respectively, compared to the mean score of other countries. In terms of resilience, South Africa (3.6) and Germany (3.5) show a lower level of implementation, while Austria demonstrates a higher level (4.0). Human-centered approaches are less implemented in the United States (3.5) and more widely implemented in Germany (3.9) and Austria (3.9). For the Industry 4.0 pillar, Italy (3.8) and Slovakia (4.0) scored relatively high, whereas South Africa scored relatively low (3.0).

6. Conclusion and outlook

With the advent of the fifth industrial revolution (I5.0), MCs are facing the challenge of successfully managing the transformation to sustainable, human-centered, and resilient production. To this end, this article first presented the results of an international survey to show the extent to which MCs are already familiar with the concept of I5.0, the importance they attach to this concept, the current state of implementation, and the target state they are aiming for. Based on this overview, factors that influence the introduction and implementation progress of I5.0 were presented and categorized. Therefore, a multi-stage methodological approach was used, including both a literature review and the structured creativity method of AD. The result is 45 influencing factors that were assigned to the three pillars of the I5.0 concept as well as to the I4.0 paradigm.

The statistical analysis of the survey results presents a limitation due to the potential for mean value bias associated with an ordinary Likert scale. This was mitigated as far as possible by avoiding the interpretation of distances between the mean values. Furthermore, the results showed, that in addition to the three pillars of I5.0, factors from I4.0 also play a role. The fact that the I4.0 paradigm was not explicitly included in the search code using a separate search term, due to the subject of the study, represents a limitation of the focus area 'Industry 4.0' regarding the completeness of the factors.

Based on the results presented, there is potential to examine the results in more detail regarding local similarities and differences. Furthermore, based on the identified barriers to implementation, a procedure for implementing I5.0 that takes the identified barriers into account can be developed.

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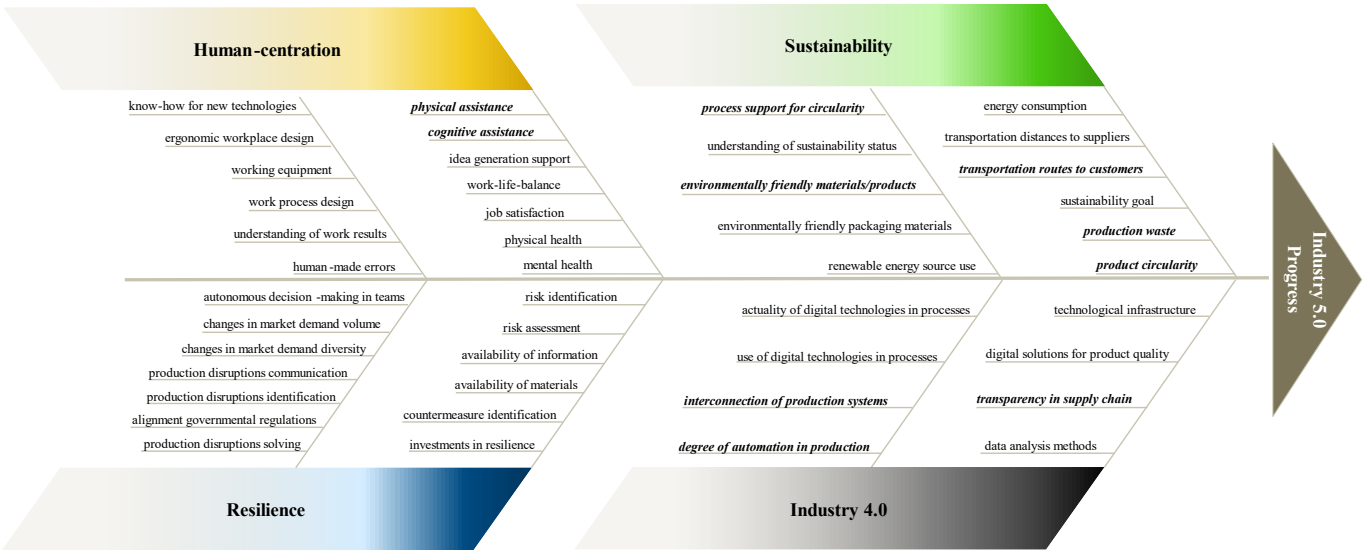

Figure 9: Ishikawa diagram with factors that influence the Industry 5.0 progress

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