Identification of Socio-Technical Risks and Their Correlations in the Context of Digital Transformation for the Manufacturing Sector

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***Abstract*—In order to remain competitive, many companies are undergoing the digital transformation to exploit the potential of digitization. However, digital transformation faces various risks that affect technology, employees, and organizations in equal measure. In the sense of the socio-technical systems approach, interactions prevail within the dimensions of human, technology and organization, which have to be considered as complexity drivers for risks. Currently, there is no transparent overview of existing socio-technical risks and their correlations that enables companies to enforce an efficient risk management for digital transformation. This paper identifies sociotechnical risks based on a literature review and examines their interactions.**

Keywords-digital transformation; digitalization; socio-technical system; risks; risk management; challenges, correlations

I. INTRODUCTION

The digital transformation offers many opportunities especially for the manufacturing industry [1]. Particularly against the background of rapidly increasing customer requirements leading to batch size 1 and shorter product life cycles, companies are forced to increase their technological standards [2, 3]. Technologies such as automated guided vehicles or the use of 3D printers help to increase flexibility and to secure and increase the competitiveness of the company [4, 5]. In order to exploit these advantages, companies are implementing suitable use cases [6]. The introduction of these use cases is accompanied by several changes that have an impact on the socio-technical system with the dimensions of human, technology and organization [7, 8]. These changes are triggers for a variety of risks, which often remain hidden [8, 9].

In this context, a study by *McKinsey & Company* [9] reveals that risk management has not yet been able to keep pace with digital transformation. The biggest pain point for the surveyed companies currently is in understanding the risks that arise during the digital transformation [9]. This requires answering the question of which risks arise during the digital transformation of companies. However, a holistic collection of risks is essential for the derivation of measures. In order to derive adequate measures for the risks, an understanding of the correlations between the individual risks is also essential.

In order to achieve this research objectives, the paper is structured as follows. Section II provides a brief overview of the mentioned topics digital transformation, socio-technical system and risk management. In section III, the methodological framework for answering the research questions is presented. Based on this, chapter IV identifies risks which occur during the introduction of digitization solutions through a literature analysis. The risks derived from this are validated by workshops with experts from various companies. In addition, the interdependencies of the risks are recorded with the help of an impact matrix. Section V presents the final conclusion, limitations and further research.

II. THEORETICAL BACKGROUND

A. *Digital Transformation*

The buzzword digital transformation is mainly understood as the process that embraces the digitization of the entire company, including products, services and the value creation system by implementing various technologies. It affects technical as well as social and organizational aspects, such as changes to the business model [10, 11]. Various terms are associated with the digital transformation. Thus, Industry 4.0 focuses on the use of digital technologies and solutions within the internal production of goods and services [12, 10]. The terms digital transformation, Industry 4.0, digitalization and digitization are often used synonymously [11]. In order to reduce the confusion regarding the different terms and definitions *Bockshecker, Hackstein and Baumöl* [11] have designed an approach to equalize the terms. Since a delineation of the terms is not within the scope of this paper, no further analysis is provided. However, knowledge about the existence of the different terms is highly relevant for the literature review in section IV to ensure a holistic coverage of risks in the context of the digital transformation.

B. *Socio-Technical System*

The risks that arise during digital transformation affect the entire company [7, 8]. This is because the technical changes, such as installing new sensor technology or setting up new databases, go beyond purely technical adjustments. For example, the competencies of employees have to be adapted to prepare them for handling the new technologies. In addition, the organization has to develop adequate processes to implement the new technologies and ensure that they are usable [13, 14]. Against this background, it is necessary to understand the digital transformation as a holistic socio-technical challenge and to consider the three dimensions of human, technology and organization. Thus, the dimensions cannot be considered in isolation, but only by considering their interactions [15, 16].

C. *Risk Management*

Section I points out that the digital transformation offers many advantages, but at the same time is a challenge for companies due to the risks that arise. Against this background risk management is very important for the successful introduction of technologies in the context of digital transformation. It supports organizations in dealing with emerging risks by establishing risk strategies to achieve defined objectives. Risk management is part of leadership and management and thus contributes to the improvement of management systems. The standard for risk management, the ISO 31000, specifies which methods and guidelines can be used to deal with risks. It comprises principles, a framework and an iterative risk management process, which essentially consists of the steps of risk identification, analysis, assessment, treatment and monitoring [17]. The phase of risk identification is particularly important, since measures can only be derived for risks that have already been identified. Thus, there is a high aspiration towards completeness [18]. Furthermore, it is important not to consider risks in isolation from each other, as they are interlinked by complex cause-effect chains and non-linear dependencies. This is because each risk is based on one or more causes and leads to various effects, which form a chain in their entirety. [18, 19]. This also applies to the dependencies between the dimensions from the socio-technical system explained above, as the individual risks can certainly be assigned to the dimensions [15, 16, 20]. Thus, the holistic identification of the socio-technical risks that arise, considering their correlations, is highly important to ensure a sustainable digital transformation.

The following section III presents the methodological framework for capturing risks and their interdependencies.

III. Methodology

The used methodology is based on the procedure for a structured literature review by *Denyer and Tranfield* [21]. The procedure is divided into the five steps 1) Question formulation, 2) Locating studies, 3) Study selection and evaluation, 4) Analysis and synthesis and 5) Reporting and using the results. In section I, the research questions (RQ's) have already been derived. RQ 1 is “What sociotechnical risks arise during digital transformation?” and RQ 2 “What dependencies occur between the individual risks?”. Based on *Schlüter and Hetterscheid* [22], detailed steps have been added for each of the remaining stages. To validate the risks derived from the literature, the procedure has been extended by workshops with experts from various companies in step four. In addition, an analysis of the interactions is carried out in step five using an influence matrix and a cluster analysis. The entire methodology is shown in Figure 1. On the basis of this method, socio-technical risks that occur during the digital transformation are to be recorded holistically. In addition, an analysis is carried out to identify the correlations between the risks. This forms the basis for deriving measures to avoid or reduce these risks.

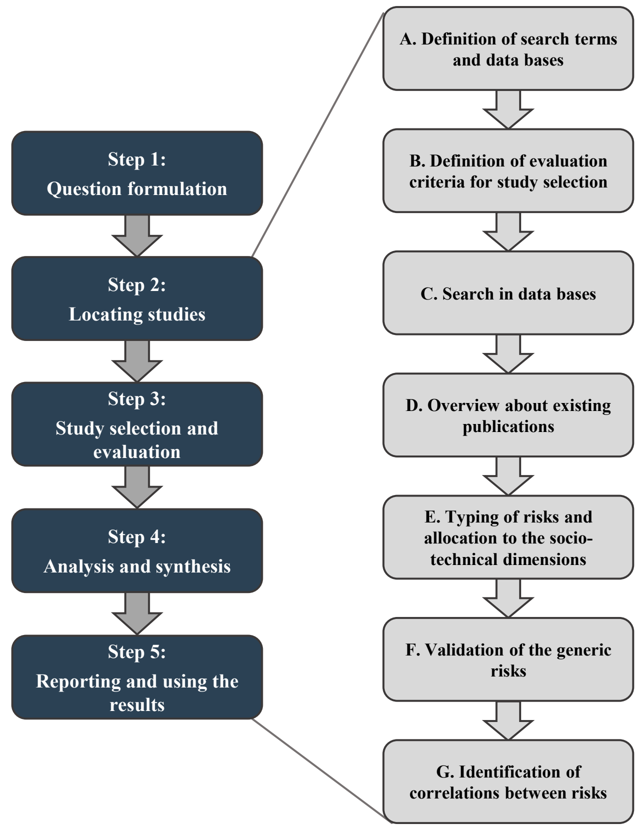

Figure 1. Steps of the conducted methodology

In the following section IV, the individual steps are carried out, beginning with step two.

IV. Research Overview and Analysis of the Selected Studies

A. *Definition of Search Terms and Data Bases*

To answer research question RQ1, suitable search terms have been selected initially. Various terms are used synonymously in the context of digital transformation. In addition, there is a high aspiration regarding the complete coverage of risks. Considering these prerequisites, the following search strings have been selected during a brainstorming session:

- „risks“ AND „digital transformation“
- „risks“ AND „Industry 4.0“
- „risks“ AND „digitalization“
- „risks“ AND „digitization“
- „risks” AND „smart factory“
- „risks” AND „production 4.0“

Since the digital transformation affects all areas of the company and in order to ensure completeness, the following additional areas of activity were added to the search strings according to Porter's value chain: "logistics", "production", "procurement", "marketing", "sales", "service" and "human resource management" [23, 24]. As the term "Industrie 4.0" [25] was coined in Germany, the search terms were additionally used in German.

Against the background of the criteria thematic affiliation, availability and accessibility, the following databases have been identified as suitable: Emerald, IEEExplore, Springer, Taylor and Francis, Scopus and Science Direct [26, 27].

B. *Definition of Evaluation Criteria for Study Selection*

The search in databases and study selection took place in August 2020. According to [21], selection criteria have to be formulated in order to check the relevance of the studies with regard to the research question:

- Criteria 1: Consideration of risks from the manufacturing sector
- Criteria 2: Reference to innovations in the context of digital transformation, i.e. buzzwords such as cyber physical systems have to be considered as well

Criterion 1 has been chosen because the scope of this paper is limited to the manufacturing sector. This is because the digital transformation, in the context of Industry 4.0, is focused on production and can provide the greatest benefit in this area [10]. Some publications also refer to a specific innovation in the context of digital transformation. The named risks, e.g., in relation to driverless transport systems, are relevant as well, even without the specific naming of the search terms. Both criteria have to be fulfilled.

C. *Search in Data Bases*

The search process is divided into three steps. The results are shown in Table 1. First, the search terms were entered into the respective database. In the next step, the headings and the abstract or, in the case of a book, the introduction were checked for suitability (first check). In the third step, the suitable publications were searched for specific risks (second check). If the publication contained one or more risks, it was included in the second check. The process always considers the previously defined criteria. Only publications from 2011 onwards were considered, as this was the year in which the term Industry 4.0 first appeared [25].

TABLE I. OVERVIEW OF SEARCH RESULTS

Database	1. Check	2. Check
Emerald	26	10
IEEExplore	17	4
Springer	55	22
Taylor and Francis	45	7
Scopus	31	4
Science Direct	21	5
Sum	**195**	**52**

D. *Overview about Existing Publications*

Figure 2 shows the results of the literature review. The respective socio-technical dimension is highlighted if one or more risks were found in the publication which can be assigned to this dimension. It becomes clear that only a few publications consider risks from only one dimension. In addition, most publications contain risks from the technology dimension. Risks from the organization dimension were found in the fewest publications.

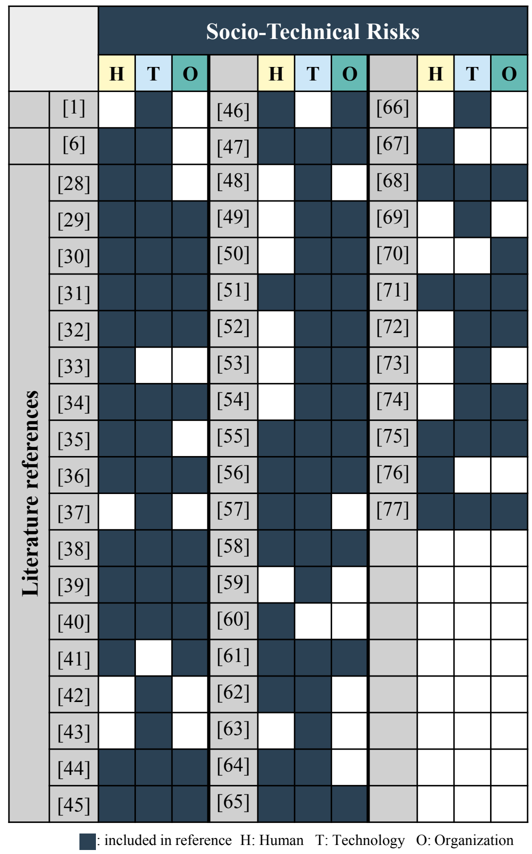

Figure 2. Overview of suitable publications

E. *Typing of Risks and Allocation to the Socio-Technical Dimensions*

During the analysis of the literature, it became clear that none of the publications has captured all risks that arise during the digital transformation. In addition, risks are often presented in varying degrees of detail. For example, on the one hand the lack of acceptance in general is addressed, but on the other hand the fear of job loss is emphasized [40, 31]. However, the fear of job loss is more likely to be the cause of the risk "lack of acceptance". Thus, effect, risk and cause are often used synonymously as risk. To address these problems, risk types were formed that describe the respective risk on a generic level. In addition, duplicates, e.g. in the form of synonyms, were removed in this step. The formation of the types is based on the definition according to *Disterer* [78], who describes the term risk as "the danger that events or circumstances will occur that cause negative consequences, especially negative deviations from targets or plans". In this context, these have an impact on various sociotechnical dimensions. Therefore, after the formation of the generic risks, they were assigned to the socio-technical dimensions. The assignment was based on the following exemplary questions:

- Technology: Does the risk related to IT systems? Does the risk relate to the implemented hardware?
- Human: Can the risk be attributed to humans, e.g. due to a lack of competencies or due to safety-related reasons?
- Organization: Is the risk caused by the structure of the company? Is the risk related to the business model or other competitors, or partners in the supply chain?

To review the created risk types, the risks identified from the literature were assigned to the respective generic risk either as "risk cause" or as "risk impact". If an assignment was not possible and it was not a synonym of the generic risk, a new generic risk was defined. The result is a collection of generic socio-technical risks that can arise during digital transformation. These are shown in Figure 3.

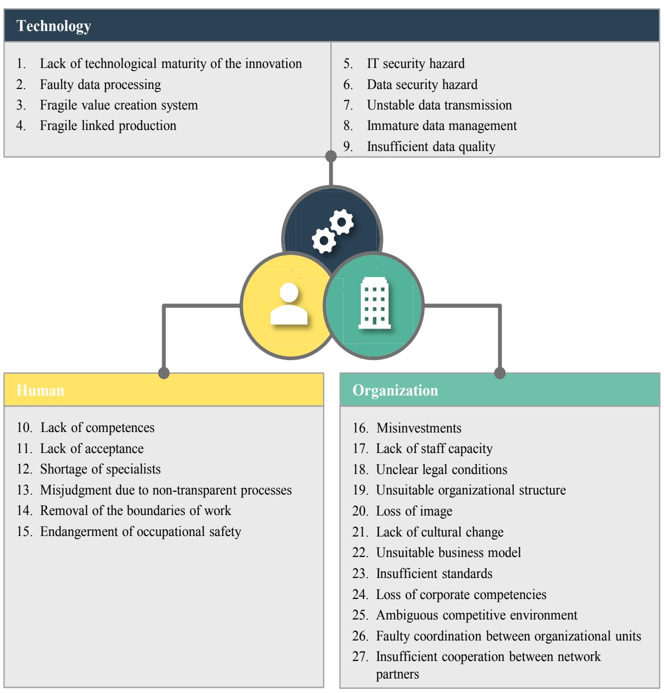

Figure 3. Generic socio-technical risks in the context of digital transformation

F. *Validation of the Generic Risks*

For the validation of the risk types, concrete risks from practice were collected with experts from various companies according to the procedure of *Schnasse et al.* [8]. The risks were related to a specific digitization solution. These were, for example, the introduction of a "warehouse management system with mobile devices for paperless warehouse management" and "data collection and analysis with machines to generate smart services". The identified risks have then been sorted into the risk chain as cause, generic risk or effect. In the case of an impossible assignment, additions have been made. Table II shows an exemplary excerpt of the assignment. Using this approach, a total of 27 generic risks have been identified within the socio-technical dimensions.

TABLE II. EXCERPT FROM THE VALIDATION

Characteristic causes	Generic socio-technical risks	Characteristic effects
• Individual employees fear loss of status and influence • Fear of job loss • Fear of new tasks due to lack of competencies • Negative experiences in the past regarding changes	Lack of acceptance	• Lack of willingness to take on new tasks • Data maintenance is not or only partially carried out • Employees are dissatisfied • Resistance from the workforce • Employees perform work with the new system inadequately • Changes are not accepted and rejected by employees
• Outdated IT structures • Unclear responsibilities • Unsecured interfaces	IT security hazard	• Gaps in information security occur • Vulnerability to hacker attacks
• Error culture is not lived • There is no commitment from management • Management does not support or only partially supports the introduction of innovations	Lack of cultural change	• Unwillingness to change • Return to old structures • Dissatisfaction of the employees

G. *Identification of Correlations between Risks*

To answer the 2nd research question, the identified risk types were analyzed in terms of their correlations. Socio-technical systems are characterized by complex interactions existing between the dimensions human, technology and organization [79, 80, 81]. Since these interactions cannot be applied generally to the identified risk types, an impact analysis is carried out in the following below and risk type clusters were then defined. These clusters contain risk types that strongly influence each other.

The clustering was performed using a weighted static design structure matrix (DSM). According to *Browning* [82] the procedure for using a DSM was divided into three steps: (1) decompose the system into elements, (2) understand and document the interactions between the elements and (3) analyze potential reintegration of the elements via clustering.

The first step of this procedure has already been carried out by identifying the risks. In this case, the elements mentioned by *Browning* [82] are the identified risk types. In the next step the risk types were first entered in the rows as well as in the columns of a matrix. Four experts were then asked independently of each other how they would rate the influence between the risk types. The evaluation of the influence was carried out according to the question: To what extent does the risk type in row A influence the risk type in column B? The rating scale ranges from 0 (no influence) to 1 (certain influence) to 2 (strong influence). Subsequently, the four independent evaluations were compiled and strongly differing evaluations were identified. These were discussed again between the experts in a round table. In order to reach a consensus, it was always helpful to clarify the understanding of the respective risk types and their possibility to influence each other for all participants. The impact analysis is shown in figure 4 in the form of the impact matrix. The risks correspond to the numbering from figure 3.

The impact analysis made it possible to gather initial findings even before clustering. There are two parameters that can be obtained directly from the matrix. One of these is the active sum. This is the sum of the row values of a risk type. The active sum describes how much a risk type influences other risk type. The higher this sum, the greater the influence on other risk types. The risk types with the strongest influence are *lack of competencies*, *lack of staff capacity*, *lack of acceptance* and *immature data management*. On the other hand, the passive sum can also be read directly from the matrix. This is calculated from the sum of the column values of a risk. This describes how much this risk type is influenced by others. The higher the sum, the more strongly the risk type is influenced by other risks. The risk types that are strongly influenced by others are *fragile value creation system*, *data security hazard, misjudgment due to non-transparent processes* and *misinvestments*.

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Active sum
1		0	2	0	1	1	1	1	1	1	1	1	1	0	1	2	0	0	1	1	0	0	0	1	2	0	0	19
2	0		1	1	0	1	1	1	1	1	2	0	1	0	1	0	0	0	0	0	1	0	0	1	1	1	1	16
3	0	0		0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	0	1	1	1	0	0	0	8
4	0	0	1		0	0	1	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	0	0	0	1	12
5	0	0	1	1		0	1	2	0	1	1	1	1	0	1	0	1	0	2	0	1	0	0	0	0	0	1	15
6	0	0	1	1	1		1	0	1	1	1	1	1	0	1	0	1	0	2	0	1	0	0	0	0	0	1	15
7	0	0	1	1	1	1		1	1	1	2	2	1	0	2	0	0	0	1	0	2	1	0	0	0	0	1	19
8	0	0	1	1	0	2	1		1	1	2	1	1	0	1	1	0	0	0	1	1	1	0	1	1	1	1	20
9	0	0	1	0	0	2	0	0		1	0	2	1	0	1	1	0	0	0	0	0	0	0	0	1	0	1	11
10	2	0	2	1	2	2	1	2	0		1	2	1	1	1	2	1	1	1	0	0	1	1	1	1	0	1	28
11	1	0	1	0	1	1	1	1	0	1		1	1	1	1	2	0	0	1	2	1	1	0	0	1	0	1	20
12	2	1	1	1	1	0	2	2	0	1	1		0	0	0	0	1	2	0	1	0	1	1	0	0	0	1	19
13	0	0	1	0	1	1	1	1	0	1	0	1		1	1	2	1	0	1	0	1	0	0	2	1	0	1	18
14	0	0	1	0	1	0	2	1	1	0	0	0	0		0	0	1	0	0	0	1	0	1	2	0	0	0	11
15	0	0	1	0	1	0	0	0	0	0	0	0	0	0		0	0	0	2	0	0	0	0	0	1	0	0	5
16	1	0	2	0	0	1	0	0	0	0	0	0	0	0	1		0	1	1	0	1	2	2	0	1	0	1	14
17	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0		1	0	1	1	0	1	1	0	0	1	22
18	0	0	0	0	1	1	1	1	0	0	0	0	2	0	0	2	0		1	1	2	1	0	0	0	0	1	14
19	0	0	2	1	0	1	0	0	0	1	0	0	1	1	0	1	0	0		2	2	0	0	2	0	0	0	14
20	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1		2	0	0	0	0	0	1	7
21	1	1	2	1	0	0	0	0	0	1	0	0	1	1	1	2	1	1	0	1		0	2	0	0	0	0	16
22	0	0	1	0	0	1	0	0	0	0	0	0	3	1	1	1	0	1	1	1	1		0	1	0	0	1	14
23	0	0	1	0	2	2	1	0	0	2	1	0	1	1	1	0	0	0	0	1	1	0		0	0	0	0	14
24	2	0	1	0	1	1	1	0	0	1	0	0	1	2	1	1	1	0	0	1	0	0	0		1	1	1	17
25	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2	1	0		1	0	7
26	1	0	1	0	0	1	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	2	0	0		0	9
27	2	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	0	0	0	1	0	0	1	2	0	1		18
Passive sum	14	7	29	10	15	21	18	16	9	17	16	15	22	14	17	21	9	8	17	15	20	11	13	15	11	5	17	

2 Strong influence 1 Certain influence 0 No influence

Figure 4. Impact analysis for each socio-technical risk type (no. 1 to 27)

Finally, based on this evaluation, a clustering algorithm according to *Thebeau* [83] (also known as the IGT-algorithm or IGTA) was performed. The MatLab tool was used to run that algorithm. The algorithm randomly selects an element and examines whether it leads to a better fit in another cluster. For this purpose, a fit value (ClusterBid) is calculated, which results from the evaluation of the impact analysis. The element is finally assigned to the cluster that achieves the highest fit value by adding the element. In addition, for each new element, the algorithm checks whether the last assigned cluster with the highest fit value is only a local optimum or a global optimum. This is determined by a so-called cost value, which measures the quality of the overall solution across all clusters [83, 84]. The results of the cluster analysis are shown in figure 5. A total of six clusters were identified. The contents of these clusters are socio-technical risks that strongly influence each other. The identified clusters were then designated according to the interactions prevalent within them. These are listed below:

- Cluster 1: Interactions due to system complexity
- Cluster 2: Interactions through human behavior
- Cluster 3: Interactions through the use of unknown technologies
- Cluster 4: Interactions through external actors
- Cluster 5: Interactions through increased use of data
- Cluster 6: Interactions due to changing competencies

		Cluster					
Socio-technical risk type	No.	1	2	3	4	5	6
Fragile linked production	4	X					
Misjudgment due to non-transparent processes	13	X					
Unclear legal conditions	18	X					
Loss of image	20	X					
Loss of corporate competencies	24	X					
Insufficient cooperation between network partners	27	X					
Lack of acceptance	11		X				
Removal of the boundaries of work	14		X				
Misinvestments	16		X				
Unsuitable organizational structure	19		X				
Lack of cultural change	21		X				
Faulty ccordination between organizational units	26		X				
Lack of technological maturity of the innovation	1			X			
Endangerment of occupational safety	15			X			
Insufficient standards	23			X			
Fragile value creation system	3				X		
Unsuitable business model	22				X		
Ambiguous competitive environment	25				X		
Faulty data processing	2					X	
IT security hazard	5					X	
Data security hazard	6					X	
Unstable data transmission	7					X	
Immature data management	8					X	
Insufficient data quality	9					X	
Lack of competences	10						X
Shortage of specialists	12						X
Lack of staff capacity	17						X

Figure 5. Identified clusters with their assigned socio-technical risk types

V. CONCLUSION, LIMITATIONS AND FURTHER RESEARCH

The paper provides a contribution for risk management in the context of digital transformation by identifying 27 socio-technical risks and analyzing them with regard to their interactions. The risks were derived from the results of a structured literature review and have been validated in expert workshops. To answer the second research question, the mutual influences of the identified risks were initially assessed by experts. An influence matrix was used for the evaluation. Based on the results of the influence analysis, a subsequent cluster analysis was conducted to identify six clusters in which dominant interactions prevail.

For researchers, the paper provides *key insights* for identifying sociotechnical risks at an appropriate level of detail. Existing literature was found to often only cover specific risks associated with a specific use case (e.g., the introduction of an automated guided vehicle) of a company from a specific industry. Due to the high level of detail, building upon these individual risks poses a problem in the development of a methodical approach for the derivation of measures. On the other hand, there are some publications that capture individual risks at a higher level, such as the need for competence development. However, these sources do not capture the risks holistically in the context of the sociotechnical systems approach. Another aspect is the impact of innovations, which are introduced to companies more frequently and affect numerous areas such as logistics or sales. As a result, there is a threat that the risks will be intensified by their interactions. These interactions have to be considered when deriving measures and monitoring risks.

These problems also occur in practice. For example, the companies involved in the research project were able to name individual risks but had difficulty placing them in an overall context and often got lost in the details. However, the identification of the interactions between cause, risk, and effect requires a high-level perspective and the ability to see the greater scheme of things. Therefore, the comparability of the individual risks has to be achieved in order to be able to analyze the mutual influences.

The conducted research was subject to some *limitations*. Although the risks derived from the literature were validated by expert workshops, it is possible that some risks remained hidden. Another limitation relates to the results of the impact analysis. Increasing the number of experts interviewed can improve the research results. Regarding the cluster analysis, an intensive analysis of the performance of further algorithms can show if there are more suitable algorithms for clustering. Furthermore, additional validation should be performed to verify the correlations in practice.

Regarding the ISO 31000 risk management process, *further research* is needed in the context of digital transformation in conjunction with the sociotechnical systems approach. The identified correlations of the risks can be used in the risk assessment to gain a better understanding of the probability of occurrence of the risks. In addition, further research activities can reveal whether the extent of damage from a sociotechnical risk is also partly due to its interactions. Furthermore, risk treatment measures can be developed according to the clusters, considering the identified interactions. In addition, indicators for risk monitoring can be derived based on the identified risks and their interactions.

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