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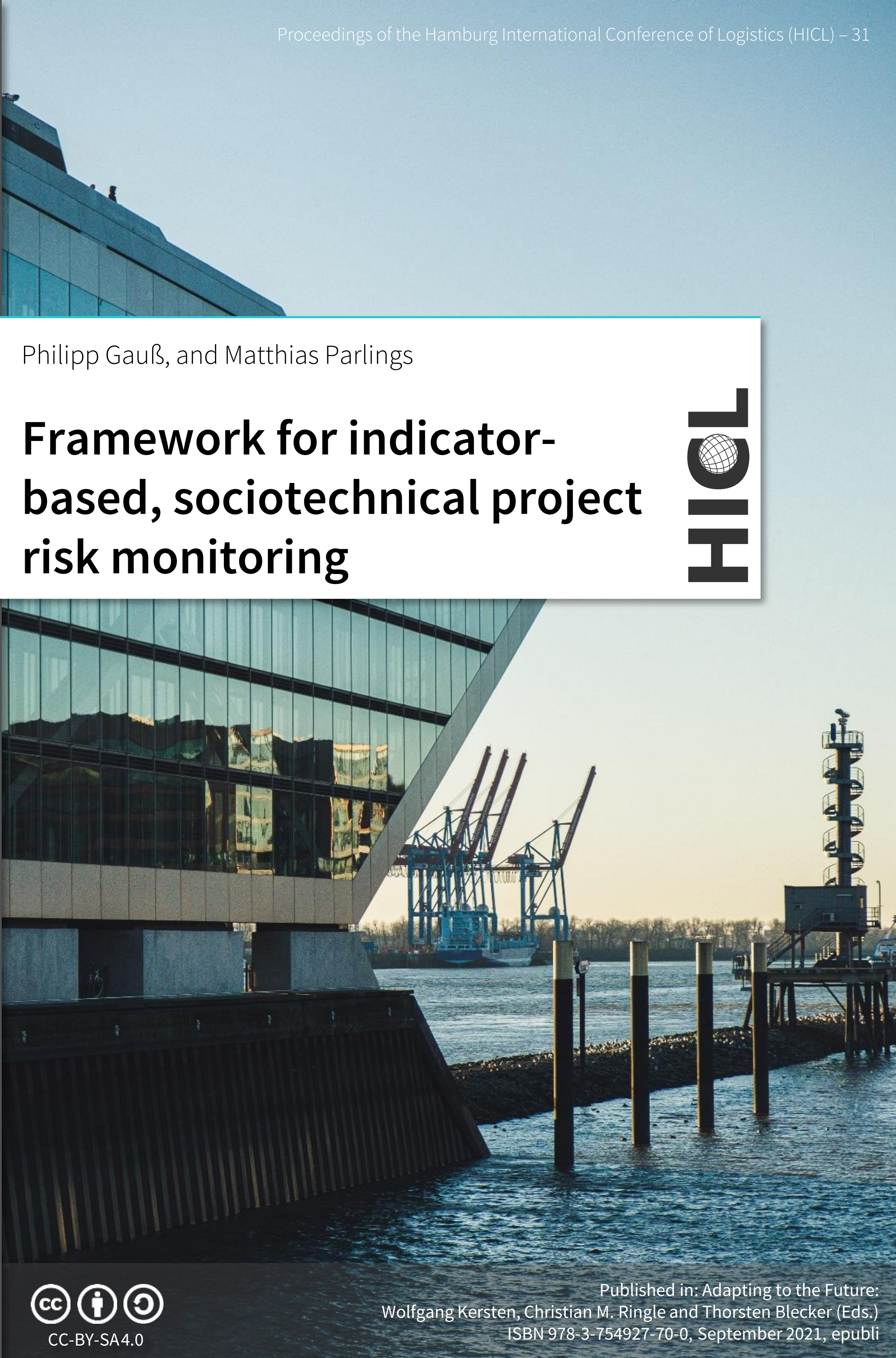

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Framework for indicator-based, sociotechnical project risk monitoring

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Purpose: *Many Industry 4.0 projects fail because impending sociotechnical risks are managed insufficiently. An indicator-based, sociotechnical risk monitoring can help to overcome this challenge. However, its effectiveness depends significantly on selecting appropriate risk indicators. This paper outlines a framework that helps decision-makers with the necessary structuring, allowing for subsequent indicator definition.*

Methodology: *Indicators must be embedded in specific contexts to be meaningful. The design of indicator-based monitoring systems, therefore, first requires an appropriate framework. For this purpose, specific requirements related to digitization projects are derived from both literature and practitioners' needs.*

Findings: *Risks in the context of Industry 4.0 projects are systemic risks. For efficient monitoring, new approaches are needed that can manage this high complexity. Systems theory is found suitable to develop a new framework for indicator-based, sociotechnical project risk monitoring. The framework considers the characteristics of projects and enterprises as complex, open, and sociotechnical systems.*

Originality: *Especially in complex projects like those of Industry 4.0, situational risk awareness can contribute crucially to project success. However, achieving this awareness always requires tailored approaches addressing the unique project characteristics. To help solve this challenge for digitization projects, the proposed framework sets both a science-based and practitioner-relevant foundation for subsequent derivation of sociotechnical risk indicators.*

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1 Introduction

Companies nowadays find themselves in an increasingly volatile, uncertain, complex, and ambiguous (VUCA) environment, characterized through e. g. shortening product lifecycles and fluctuating order volumes (Millar, Groth and Mahon, 2018, pp. 5–8; Romeike and Hager, 2020, pp. 9–10; Westkämper and Zahn, 2009, pp. 7–12). To remain competitive, a continuous adaption to changing conditions is necessary (Westkämper and Zahn, 2009; Gareis and Gareis, 2018, pp. 10–11). One lever for this purpose is the successful realization of Industry 4.0 projects (Kagermann, Wahlster and Helbig, 2013).

Industry 4.0 describes the utilization of new, digital technologies to achieve intelligent automation, vertical networking within companies, and horizontal connectivity along entire value chains. For companies, this opens up countless potentials for improving their competitiveness: through the development of new products, services, and business models, as well as through the optimization of their existing business processes (Kagermann, Wahlster and Helbig, 2013, pp. 9–11; Obermaier, 2019; Reinhart, 2017).

However, many companies fail to successfully take the step toward digital transformation (FUJITSU, 2017, pp. 2–5 and 22–24; Petit, et al., 2019, p. 20). The root of this issue, and the key to solving it, is the insight that Industry 4.0 projects are technology-driven, but have a direct impact on people, processes, and entire enterprises (FUJITSU, 2017, pp. 6–21; Petit, et al., 2019, pp. 20–37). This is also underlined by the sociotechnical systems approach to Industry 4.0. This concept is based on the understanding that enterprises are sociotechnical systems, consisting of the three interlinked, sociotechnical dimensions of human, technology, and organization (Ulich, 2011, pp. 198–201). Therefore, successful digitization projects require an integrated and equal consideration of the sociotechnical dimensions (Henke, et al., 2020, pp. 280–282; Hirsch-Kreinsen and Weyer, 2014; Hirsch-Kreinsen and ten Hompel, 2017; Ittermann, et al., 2016).

Against this background, the sociotechnical changes driven by Industry 4.0 provide a breeding ground for complex risks that endanger the projects' success (Gabriel, et al., 2021; Schnasse, et al., 2020; Schnasse, Menzefricke and Dumitrescu, 2021). These risks as well as their causes and effects affect all three sociotechnical dimensions (Gabriel, et al., 2021, pp. 244–245; Schnasse, Menzefricke and Dumitrescu, 2021, pp. 162–163). However, projects and enterprises are both open systems (e. g. DIN ISO 21500, 2016, pp. 9–10). Thus, the risks, causes, and effects are not limited to the core of the digitization project itself, but also relate to the project's environment and are not limited to the sociotechnical nature of enterprises (e. g. exogenous political risks) (Birkel, et al., 2019, pp. 6–22; Gabriel, et al., 2021, pp. 243–244; Schnasse, Menzefricke and Dumitrescu, 2021, pp. 161–162; Menzefricke, et al., in print, p. 2). Especially with regard to the intended horizontal and vertical networking by Industry 4.0 projects, this can lead to a multitude of complex causalities (Knoll, 2017, pp. 5–8).

To enable companies to meet these challenges and successfully realize their digitization projects, practical approaches to sociotechnical project risk management are needed.

1.1 Aim of the paper and observation scope limitation

Awareness that project risk management is a key success factor is well established in project management practice (e. g. DIN IEC 62198, 2002; Project Management Institute, 2017, pp. 395–457; 2019). However, no blanket guidance on how to implement an effective project risk management can be provided. Although the underlying processes are essentially identical in all project types, the actual design has always to be adapted to the specific circumstances (e. g. Project Management Institute, 2019, Chapter 2.4 (E-Book)).

With regard to the special requirements of digital transformation projects, a very recent exploration by Menzefricke, et al. (2021) found that especially for the sociotechnical risk analysis and assessment already various suitable approaches exist. At least initial approaches are available for risk treatment, yet they still should be further developed. At the same time, though, sociotechnical project risk monitoring is still highly underrepresented in current research (Menzefricke, et al., 2021, pp. 711–712).

To help bridge this gap, this paper focuses on this very sociotechnical project risk monitoring. In general, risk monitoring aims at tracking identified risks by identifying and analyzing risk-changing developments, and at reviewing the effectiveness of risk treatment measures (DIN IEC 62198, 2002, pp. 18–19; DIN ISO 21500, 2016, p. 36). To fulfill these tasks, early warning systems (EWS) have proven their value in various risk monitoring domains, e. g. healthcare (Umar, et al., 2019), climate change (Zommers and Singh, 2014), supply chain management (Sheffi, 2015), and corporate crisis management (Hahn and Krystak, 1984). EWS use qualitative and quantitative indicators that capture signals on risk-changing developments at an early stage, transform them into meaningful information, and, thus, create situational awareness and enable for proactive reaction (Hahn and Krystak, 1979, pp. 24–27; Romeike and Hager, 2020, 329--333).

However, the first step towards every indicator system for monitoring purposes is the establishment of an appropriate framework that defines the areas to be observed (Hahn and Krystak, 1979, pp. 24–25; lustat - statistik luzern, 2012, pp. 6–9). Against this background, the aim of this paper is to develop an integrated sociotechnical project risk monitoring framework that illustrates the dimensions to be monitored within Industry 4.0 projects. Thereby, systems theory is intended to serve as the basis for systematic development. As a first step towards an indicator-based, sociotechnical project risk monitoring, the result shall help decision-makers with the required pre-structuring, thus allowing for a subsequent indicator definition.

With respect to the iterative risk management process, this paper’s objective can be placed at the intersection between activity I (Risk framing), activity II (Risk analysis & assessment) and activity IV (Risk monitoring) (see Figure 1). It addresses the establishment of a framework (activity I) for use in risk monitoring (activity IV). The subsequent risk indicator definition, however, depends on input data on the cause-risk-effect-relations (lustat - statistik luzern, 2012, pp. 7–8). Since this information results from risk analysis and assessment (activity II) (DIN IEC 62198, 2002, pp. 12–15), the model to be developed in turn formulates demands on information needs to be collected during (a possibly extended or repeated run through) activity II.

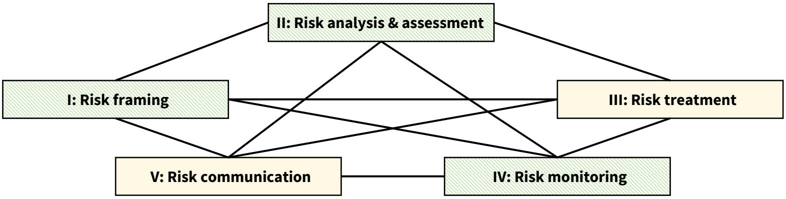

Figure 1: Fitting of the paper objective into the iterative project risk management activities (highlighted in green)

Since the intended indicator-based, socio-technical risk monitoring framework is a first attempt to solve the presented issues, the scope of application refers only to individual Industry 4.0 projects within a single company from the manufacturing industry. Project risk monitoring as part of digital transformation portfolio or program management, cross-company digitization projects, and other sectors are not yet the focus of this paper.

1.2 Research questions and structure of the paper

To guide the research, the following two research questions are formulated:

1. Which requirements have to be met by an integrated monitoring framework for Industry 4.0 projects to allow for a subsequent risk indicator definition?
2. How can an integrated sociotechnical project risk monitoring framework be designed that meets the requirements?

To address these research questions, the remainder of this paper is structured into four more sections. Section 2 provides an introduction on sociotechnical risks as systemic risks and the resulting need for new approaches to project risk monitoring that can handle this high level of complexity. In this context, the fundamentals of systems theory are also presented, which is very suitable as a solution approach.

The following section 3 then serves to define the requirements towards an integrated framework for indicator-based, sociotechnical risk monitoring (research question 1). On the one hand, content-related requirements are derived that describe the dimensions to be included in the targeted framework. Therefore, a literature-based review on the characteristics of projects and enterprises as open, complex, and sociotechnical systems is conducted. Second, based on experiences from real life case studies further application-related requirements are defined that are representing practitioners' needs.

Within section 4, a new developed sociotechnical project risk monitoring framework is presented (research question 2). First, the proposed model and its individual components are described and visually illustrated. Second, an exemplary case study is introduced to consider practical aspects and to give starting points for a validation.

The final section 5 summarizes the content of this paper, points out the limitations, and gives an outlook on future research possibilities.

2 Systems theory as a key to enable indicator-based monitoring of systemic, sociotechnical risks

As will be described in more detail in the course of this section, the risks in the context of Industry 4.0 projects are so-called systemic risks. According to Renn, et al. (2007, pp. 176–177), such systemic risks are characterized by the following four attributes:

- a high degree of complexity of the cause-effect chains,
- a high degree of uncertainty,
- a high degree of ambiguity, and
- Radiation to other, indirectly connected systems that are also put at risk.

However, before a deeper explanation of the connections to and challenges for building indicator systems for digitization projects is provided, a brief introduction to the fundamentals of systems theory is first given below to ensure a uniform understanding.

In general, a system is defined as an entity consisting of a set of elements. These elements have specific properties and can be both of material nature (e. g. buildings, machines, people) and immaterial nature (e. g. events, processes, departments). Between the different system elements, a set of relationships exists, giving the system a certain structure (Haberfellner, et al., 2019; Patzak, 1982, pp. 18–19; Rüegg-Stürm, 2004, pp. 65–66). According to Patzak (1982, pp. 39–54), two types of system structures can be distinguished in this context: a processual structure (input-output-relationships between system elements) and a hierarchical structure (static hierarchical ordering of the system elements).

Regarding the hierarchical structure, it should be taken into account that each system consists not only of elements that form lower-order subsystems, but is at the same time also an element of a higher-order suprasystem. Therefore, system boundaries can be defined to separate an observed system from its environment. If there are input-output relations between the system and its environment across the system boundary, then such a system is called an open system. If none of these relations exist, then it is considered to be a closed system (Haberfellner, et al., 2019, pp. 5–7; Patzak, 1982, p. 20).

The following Figure 2 schematically illustrates the fundamentals of the systems theory, using the example of an open system.

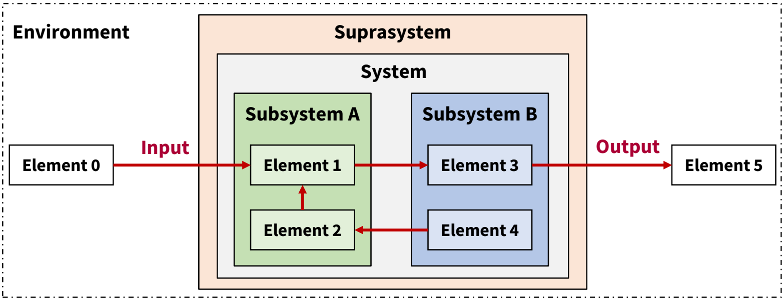

Figure 2: Fundamentals of the systems theory

The systems theory approach is very well suited to get deeper insights into complex constructs and their inner interrelationships. This concept opens the possibility to decompose a real issue and to abstract and restructure it in the form of a simplified model (Ehrlenspiel and Meerkamm, 2013, p. 21). With special regard to sociotechnical project risk monitoring, a deep understanding of the underlying cause-risk-effect relationships related to the intended change is particularly necessary and valuable.

This becomes more evident against the background of the fact that it is not always possible to assign isolated risk sources to a particular risk. Often a certain risk scenario only occurs through a combination of several causes. Moreover, one risk can also lead to a series of subsequent events. Thus, risks may not only be caused, but may themselves be causes for other risk occurrences (DIN ISO 31000, 2018, pp. 7–8; DIN 69901-5, 2009, p. 18; Romeike and Hager, 2020, p. 306).

These multi-layered interrelationships can trigger domino effects in which even initially minor events might lead to serious consequences. Such domino effects are also referred to as the before mentioned systemic risks (Romeike, 2018, pp. 206–209; Romeike and Hager, 2020, p. 306). With reference to systems theory, such systemic risks can occur in two different ways (Romeike and Hager, 2020, p. 306):

1. When an event that affects one system element due to its interactions also affects other system elements and, thus, affects the whole system or
2. when multiple events that affect individual, but interconnected system elements overlap in such a way that they affect the whole system.

For the early detection of risk-changing developments, it is necessary to know the underlying cause-effect chains in order to be able to define targeted indicators (Knappe, 1991, pp. 5–6; lustat - statistik luzern, 2012, pp. 7–8). The fact that risks relating to Industry 4.0 projects are at least partially systemic risks was demonstrated by Gabriel, et al. (2021, p. 245) using the example of the risk "lack of acceptance". Classical approaches used in risk management cannot handle this high degree of complexity (Romeike, 2018, p. 209). Systems theory with its holistic approach, nevertheless, provides a suitable approach to face this challenge and establish an appropriate EWS for digital transformation projects.

Below, Figure 3 shows a schematic visualization for such an envisioned indicator system designed to monitor sociotechnical risks. Thereby, sociotechnical risks are illustrated as complex, systemic risks, penetrating several subsystems of a closed overall system. The objective of the plotted indicators (black boxes) is to monitor the developments related to the exemplary presented causalities. However, it should be noted that projects and enterprises are open systems (DIN ISO 21500, 2016, pp. 9–10; Gareis and Gareis, 2018, pp. 3–6; Rüegg-Stürm, 2004). Under this view, there would also be cause-risk-effect relationships that go beyond the system boundary and do not necessarily have a company-internal, sociotechnical origin or sink.

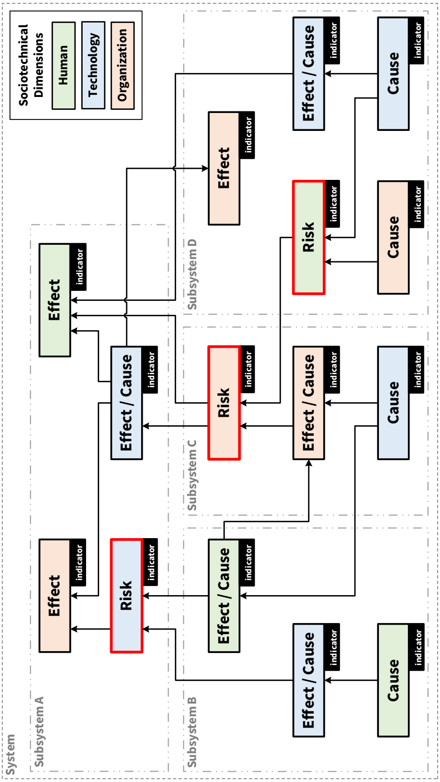

Figure 3: Schematical indicator system to monitor systemic, sociotechnical risks within a closed system

3 Requirements definition for an indicator-based, sociotechnical project risk monitoring framework

In this chapter, research question 1 is addressed. Thus, it aims at defining the requirements to be met by an integrated sociotechnical project risk monitoring framework to allow for a subsequent risk indicator derivation (see Figure 4). In general, the following rules apply in the context of indicator definitions (lustat - statistik luzern, 2012, p. 7):

- The better the definition of the dimensions to be observed, the better knowledge on inter-dimensional dependencies can be gained.
- The better the level of knowledge on dependencies, the better indicators can be formed.

According to this, to build an effective EWS the observation area has to be defined as precisely as possible. This step is critical because indicators can only become meaningful when they are embedded into a specific context (lustat - statistik luzern, 2012, p. 7).

The dimensions to be included in the targeted framework are identified based on a literature review on review on the characteristics of projects and enterprises as open, complex, and sociotechnical systems. The results are converted into content-related requirements R_C in parallel (section 3.1). Moreover, further application-related requirements R_A are derived based on insights from focus group discussions within the “SORISMA” research project and from numerous SME case studies in the context of the “Mittelstand 4.0 Kompetenzzentrum Dortmund” (section 3.2). For a final overview, the defined requirements are summarized in tabular form (section 3.3).

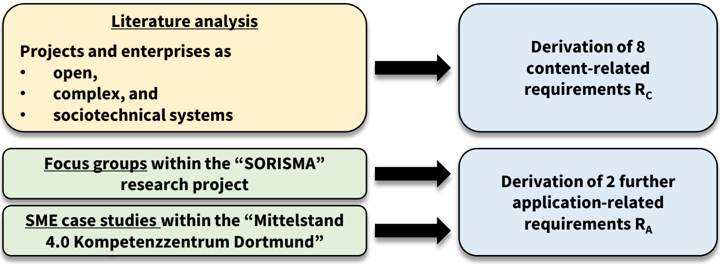

Figure 4: Definition of the framework requirements

3.1 Content-related requirements definition

According to (lustat - statistik luzern, 2012, p. 7), it has proven useful to base a dimensional analysis on a recognized theoretical concept. As already outlined in the previous section 2, systems theory is very well suited to the research questions addressed in this paper and is, therefore, the used approach here.

Throughout the next sections, the characteristics of projects and enterprises are explored as complex and open systems (section 3.1.1) and as sociotechnical systems (section 3.1.2). This approach is designed to provide a combined black-box and white-box perspective on projects and companies respectively as well as on their interrelationships. In this way, a structured decomposition and classification of the interwoven system elements affected by Industry 4.0 projects is intended to be made possible.

In the following, where necessary, there is a reference to "unique classification", which shall be made possible by the framework. This formulation was chosen since unambiguous classification is targeted to embed risks, causes, and effects into specific contexts.

3.1.1 Projects and enterprises as complex, open systems

According to the Project Management Institute (2017, p. 4), a project is defined as "[…] a temporary endeavor undertaken to create a unique product, service, or result." Projects are, hence, time limited with a defined start and end point. Between these two points in time, an objective is pursued while transforming a current as-is state into a designated to-be state (DIN ISO 10006, 2020, p. 9; Project Management Institute, 2017, pp. 4–6).

From a systems theory point of view, projects as well as enterprises represent complex, open systems. Thereby, single-enterprise projects, as considered in this paper, form a subsystem of an enterprise as they are embedded into it. Moreover, projects as well as enterprises consist of diverse, social relationships and interact with their environment (DIN ISO 21500, 2016, pp. 9–10; Gareis and Gareis, 2018, pp. 3–6; Rüegg-Stürm, 2004).

The mentioned openness allows the project environment to impact the success of the project. Thereby, a fundamental distinction can be made between risk factors internal to the company and risk factors external to the company. Such a differentiation typically forms the starting point for the development of any EWS (Hahn and Krystak, 1979, p. 24). This also makes sense in the context of project risk monitoring. External risk factors usually lie outside the influence sphere of companies and projects. However, for holistic project risk management they should still be considered (DIN ISO 21500, 2016, pp. 11–12).

Requirement R_C 1: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects are located internally or externally to the company.

Moreover, not even all internal risk factors can be directly influenced by project responsibles. Two examples for such internal factors are the enterprise strategy and culture (Project Management Institute, 2017, p. 38). However, as with the external factors, these non-influenceable internal factors should also be included for completeness.

Requirement R_C 2: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects, that are located internally to the company, can be directly influenced or not.

Because of their temporary attribute, projects are to be differentiated from lasting ongoing business operations (DIN ISO 21500, 2016, pp. 11–13; Project Management Institute, 2017, p. 16). For the execution of projects, often specific project organizations are created that only exist for the limited project duration (DIN ISO 21500, 2016, pp. 13–14; DIN 69901-5, 2009, p. 15). Such a temporary project organization is referred to as a project system in the following, in contrast to the lasting operating system for ongoing operations.

Project systems and operating systems can interact in several ways. For instance, the members of the project system can be members of the operating system at the same time, but they do not have to be (DIN 69901-5, 2009, p. 15). Another example is the case, that the project objective is to optimize an operations process. For this second example, it should be noted that the project object itself (the operations process) is, however, part of the operating system (Project Management Institute, 2017, p. 16). It is obvious, that these complex interrelationships can be seed for risks, causes, and effects. But since the people affected vary in the different areas, this can result in different causalities. For the creation of a meaningful context, differentiation should take place here for the subsequent indicator definition.

Requirement R_C 3: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects are located within the project system or the operating system.

The execution of activities in a company takes place in work systems (REFA-Institut, 2016, pp. 184–185). Different work systems are thereby interconnected via processes (REFA-Institut, 2016, pp. 177–178). As a result, changes in a work system that is transformed through an Industry 4.0 project might also have indirect effects on other work systems. Again, this can result in different cause-risk-effect chains, so another distinction should be made for a clear context.

Requirement R_C 4: The framework shall allow unique classification regarding the question of whether the risks, causes, and effects, located within the operating system, relate to a directly or indirectly affected operating subsystem.

However, not the entire operating system has to be directly or indirectly affected by a digital transformation project. There are also numerous other work systems in a company that might not be influenced at all. Nonetheless, it cannot be precluded that these operating subsystems will not also be involved in the cause-risk-effect-chains of

Industry 4.0 projects. In this regard, a further differentiation seems beneficial to be able to map an entire company in the project risk monitoring framework

Requirement R_C 5: The framework shall also consider those work systems, that are not affected by the Industry 4.0 project.

Digitization projects drive change. To do so, processes of three different hierarchies are applied within the project system (DIN ISO 21500, 2016, p. 16):

- Project management processes, contributing to the management and control of the project;
- Product processes, leading to the value creation of the project objectives;
- Support processes, providing assistance for product and project management processes.

A similar classification of processes can be made for operating systems (Rüegg-Stürm, 2004, pp. 110–118; Wagner and Patzak, 2015, pp. 2-3 and 56-58):

- Management processes, contributing to the management and control of the ongoing operations;
- Business processes, leading directly to the value creation of the company;
- Support processes, providing the necessary infrastructure and offering internal services.

Since this hierarchical classification can be done for both, project systems and operating systems, it may be useful to classify the risks, causes, and effects on which hierarchical level they are located to enable more precise classification for meaningful indicators.

Requirement R_C 6: The framework shall allow unique classification regarding the question on which hierarchical level the risks, causes, and effects are located within the project system or the operating system.

3.1.2 Projects and enterprises as sociotechnical systems

In addition to the so far mentioned characteristics, enterprises are sociotechnical systems, in which people perform certain tasks using technical aids while following particular structures (Rüegg-Stürm, 2004, p. 69; Ulich, 2011, pp. 198–201). Since the four components task, human, technology, and structure are closely interconnected, a change in one of the elements directly affects the others (Leavitt, 1965, pp. 1144–1146).

Thus, successful technology-driven change always requires the joint consideration of technological as well as social factors (Clegg, 2000, p. 464; Ulich, 2011, p. 111).

In this context, Ulich (2011) developed the sociotechnical Human-Technology-Organization (MTO) concept. The approach is based on the "primacy of the task", as it forms the core of the sociotechnical system. The task links the human being with the technology and characterizes the human-machine interface. In connection with the activities to be performed and defined hierarchies, the work task also links the human being with the organizational structure of the company (Ulich, 2011, pp. 198–203). The figure below illustrates the described, sociotechnical MTO concept.

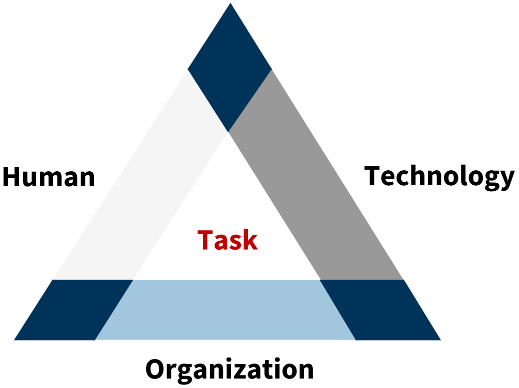

Figure 5: Sociotechnical MTO concept, based on Ulich (2011, p. 202)

Since projects are subsystems of enterprises, as described above, projects are to be considered as sociotechnical systems as well. With the special regard to Industry 4.0 projects in this paper, this attribute is of particular importance (see section 1) (Henke, et al., 2020, pp. 280–282; Hirsch-Kreinsen and Weyer, 2014; Hirsch-Kreinsen and ten Hompel, 2017; Ittermann, et al., 2016; Schuh, et al., 2020).

Requirement R_C 7: The framework shall allow unique classification regarding the question from which sociotechnical MTO dimension the risks, causes, and effects originate.

Henke, et al. (2020) also propose to consider a fourth dimension, information, in addition to the three classical MTO dimensions. The authors justify this with the increasing importance of big data and the availability of real-time information in the course of Industry 4.0 (Henke, et al., 2020, p. 281).

These considerations make sense in the context of sociotechnical project risk management against yet another background. Communication and information exchange play an essential role in both, risk management and project management, and are integral parts of the respective processes. Appropriate information sharing is essential to engage and inform all stakeholders involved (DIN ISO 21500, 2016, pp. 40–41; DIN ISO 31000, 2018, pp. 15–17; DIN IEC 62198, 2002, pp. 10–11). Conversely, it can be deduced that a lack of information exchange can lead to project failure.

Requirement R_C 8: The framework shall include the dimension information as a fourth, extended dimension of the sociotechnical system.

3.2 Application-related requirements definition

To supplement the content-related requirements from the previous section 3.1, this section defines additional application-related requirements R_A. These supplementary requirements are derived from two different origins.

First, within the “SORISMA” research project (Sociotechnical risk management in the introduction of Industry 4.0) regular focus groups take place. These focus groups have been taking place regularly at intervals of approximately two months since December 2019. The almost constant group of participants comprises 15-20 people each time, consisting of scientists from various research institutions and representatives from industrial companies. The latter are composed of a mixture of experienced project managers and members of the executive management, who again represent companies of different sectors and sizes – from SMEs to large international corporations.

Second, the findings from the discussions in the research project are additionally supported by experience from the "Mittelstand 4.0 Kompetenzzentrum Dortmund", where in recent years hundreds of SMEs were already supported in their digitization projects.

From all the lessons learned in the focus groups and the case studies, with reference to the framework to be developed, it can be derived that

- the framework to be developed should be as generic as possible to enable versatile application for a wide range of Industry 4.0 projects, according to the defined scope of application (see section 1.1) and that
- a framework development is an evolution that has to be conducted iteratively in order to regularly re-integrate new findings.

For this reason, two additional application-related requirements are defined. They are:

Requirement R_A 1: Universality - The framework shall allow the greatest possible versatility of use for individual and single-enterprise digitization projects within the manufacturing industry.

Requirement R_A 2: Modularity - The framework shall be composed of several subsystems and could be developed and expanded in modules. Thus, the framework could be adapted to new or changed conditions or findings.

3.3 Consolidation of the defined requirements

To summarize the previously elaborated results, the following Table 1 provides a concluding and condensed overview of the derived requirements.

Table 1: Consolidated overview of the defined requirements

Type	ID	Description – The framework shall …
Content-related	R_C 1	… allow unique classification whether the risks, causes, and effects are located internally or externally to the company.
	R_C 2	… allow unique classification whether the risks, causes, and effects, that are located internally to the company, can be directly influenced or not.
	R_C 3	… allow unique classification whether the risks, causes, and effects are located within the project system or the operating system.
	R_C 4	… allow unique classification whether the risks, causes, and effects, located within the operating system, relate to a directly or indirectly affected operating subsystem.
	R_C 5	… also consider those work systems, that are not affected by the Industry 4.0 project.
	R_C 6	… allow unique classification on which hierarchical level the risks, causes, and effects are located within the project system or the operating system.
	R_C 7	… allow unique classification from which sociotechnical MTO dimension the risks, causes, and effects originate.
	R_C 8	… include the dimension information as a fourth, extended dimension of the sociotechnical system.
Application-related	R_A 1	… allow the greatest possible versatility of use for individual and single-enterprise digitization projects within the manufacturing industry. (Universality)
	R_A 2	… be composed of several subsystems and could be developed and expanded in modules. Thus, the framework could be adapted to new or changed conditions or findings. (Modularity)

4 Proposed framework for indicator-based, sociotechnical project risk monitoring

In this section, the designed framework for indicator-based, sociotechnical project risk monitoring is presented (research question 2). The literature does not provide similar work yet, although efficient project risk management and monitoring is known to be a key to project success. This insight is also supported by the finding of Menzefricke, et al. (2021, pp. 711–712) according to whose study sociotechnical project risk management basically has not yet been part of the scientific discourse.

Below, the proposed framework with its individual building blocks is described as well as graphically illustrated (section 4.1). Subsequently, an exemplary case study from the SORISMA research project is presented, based on which first starting points for a validation with practical reference are given (section 4.2).

4.1 Introduction of the developed framework

In developing the framework, emphasis was placed on meeting all of the derived requirements (see section 3). Furthermore, it was intended to make the framework tangible by means of a visual representation. Here, care was taken to find a balance between a visualization that is simple, but does justice to the underlying complexity

The final model is illustrated in Figure 6 below. It consists of five major building blocks, defining the context to be explored for causalities for subsequent indicator derivation:

- enterprise subsystems,
- process-related hierarchy levels,
- sociotechnical dimensions,
- elements of order, and
- external actors.

The first three are placed in the center of the framework as a three-dimensional cube that simplified represents the internal structure of enterprises. In general, the basic setup of the model is inspired by the St. Gallen Management Model (Rüegg-Stürm, 2004, p. 70), a well-reputed reference framework in system-oriented management theory.

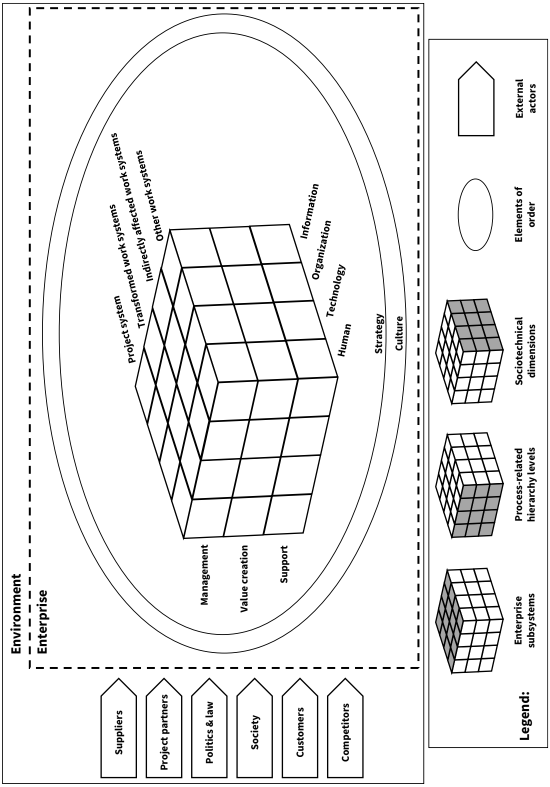

Figure 6: Proposed framework for indicator-based, sociotechnical project risk monitoring

As already stated above, the core of the designed model is a three-dimensional cube. Here, it was intended to bring the character of the risks in Industry 4.0 projects as systemic, sociotechnical risks to the center of attention to enable a context-specific classification of the risks, causes and effects. To this end, not only the related sociotechnical dimensions, but also the respective enterprise subsystems systems that are permeated by the cause-risk-effect chains as well as the hierarchical level of the processes affected therein shall be considered to enable a meaningful derivation of indicators.

The respective enterprise subsystems are illustrated on the top side of the cube. Next to the project system, the coexisting operating system is listed here (requirement R_C 3). However, in the framework the operating system is further divided into work systems that are transformed (the project object), indirectly affected, and not at all affected by the project activities (requirements R_C 4 and R_C 5). Thus, all operating work systems are considered in their entity.

On the left side of the cube, the different process-related hierarchy levels that can be found within an enterprise are plotted (requirement R_C 6). Here, a generic three-way split was made into management processes, value creation processes, and support processes as often found classification for projects as well as enterprises (e. g. DIN ISO 21500, 2016, p. 16; Rüegg-Stürm, 2004, pp. 110–118). A further subdivision, for instance into strategic, tactical, and operative management processes, has been omitted at this point for simplicity. The processes of all three hierarchy levels run through the entire enterprise subsystems.

The sociotechnical dimensions are represented on the right side of the cube. In addition to the classical MTO dimensions of human, technology, and organization, the dimension information is included as a fourth extended, sociotechnical dimension as initially suggested by Henke, et al. (2020, p. 281) (requirement R_C 7 and R_C 8). All enterprise subsystems (upper side) with the processes running through them (left side) each represent a separate, sociotechnical system with these four dimensions.

The central cube is held together by elliptically illustrated elements of order, which are essential for the viability of a company, but also represent internal risk factors that may not be immediately influenceable (requirement R_C 2). The elements of order listed here are the corporate strategy and the corporate culture, as frequently mentioned, non-tangible internal risk factors in the literature (e. g. DIN ISO 21500, 2016, p. 11; Project Management Institute, 2019, Chapter 7.1.1 (E-Book); Rüegg-Stürm, 2004, p. 70).

The cube and the elements of order together form the enterprise system, which is separated from its environment by a system boundary (requirement R_C 1). As external risk factors, suppliers, project partners, politics and law, society, customers as well as competitors are listed at the very left, as these were frequently mentioned in the literature (e.g. DIN IEC 62198, 2002, p. 5; DIN ISO 21500, 2016, p. 11; Gabriel, et al., 2021, p. 244).

The modular and generic structure of the five major elements as well as the unspecific naming without reference to any particular Industry 4.0 projects are chosen to ensure compliance with the application-related requirements R_A 1 and R_A 2.

4.2 Case study application of the proposed framework

In this section, first starting points for a validation of the developed framework are given. For this purpose, the framework is applicated to an exemplary and real-life case study from the SORISMA research project. As a first step in the evaluation process, the goal here is to map a sociotechnical risk to the framework and, thus, to embed it into a concrete context. The findings as well as further evaluation steps will be discussed afterwards.

Case study introduction: The objective of the examined Industry 4.0 project, which is being pursued by a family-owned SME, is to implement an automated guided vehicle (AGV) system. The AGVs are to convey load carriers with raw materials which are manually provided from a high-bay warehouse to the production department and to transport finished goods from there back to a finished goods warehouse.

For this use case, nine primary risks were initially identified, out of which the risk "lack of competencies" is examined in more detail here to provide a first step towards the framework evaluation.

Mapping the risk to the framework: The risk "lack of competencies" can be generally assigned to the sociotechnical dimension “Human” (Gabriel, et al., 2021, p. 244). However, to allow for a more specific context and to ensure a meaningful indicator derivation, further investigations are necessary. Therefore, further consultations with the industry partner were held, during which it became apparent that different groups of people can be associated with the risk “lack of competencies”. Three examples on who is affected are provided below.

1. First, the employees whose previous transport tasks are substituted by the AGVs and who are to be retrained as control station users and control station key users.
2. Second, the production workers who in the future need to trigger digital transport orders for the AGVs. Currently, the finished goods transports are triggered by verbal call.
3. Third, the employees in the high-bay warehouse, who need to pay increased attention to damaged load carriers in order to avoid errors in the sensitive AGV process.

The previous descriptions already show that the AGV project influences several work systems. But this is true to varying degrees.

The transport system, which is being transformed by the industry 4.0 project, is directly affected. Thus, example 1 reflects to the framework dimension “Transformed work systems” of the enterprise subsystems.

The two work systems high-bay warehouse and production are also affected by the change, but only indirectly. Within the framework, the examples 2 and 3 are accordingly assigned to the enterprise subsystems dimension "Indirectly affected work systems".

Regarding the mapping to the process-related hierarchy levels, it is important to note that the risk “lack of competencies” relate to the desired target state. For this reason, the classification with respect to the process-related hierarchy levels should also refer to this target state. Example 1 above makes it clear that the risk here stems from the changing work profile, from value creation to operational management.

Following this, example 1 relates to the process-related hierarchy level dimension of “Management”, while examples 2 and 3 relate to the dimension of “Value creation”.

In the following Figure 7, the results of the described mapping process are illustrated. Thereby, example 1 is visually highlighted in green, example 2 in orange and example 3 in blue.

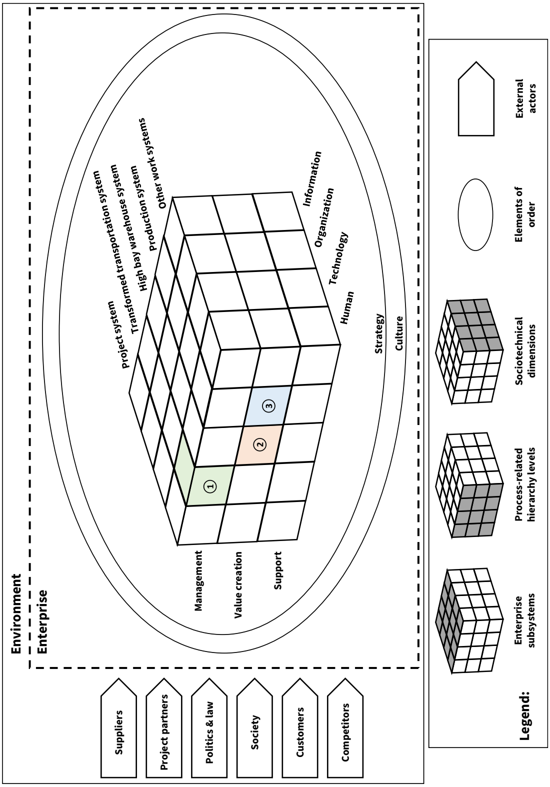

Figure 7: Case study application results – The unspecific risk “lack of competencies” evolved into three specific, contextual risks

Findings on the model: As a first result, it was found that the framework could be smoothly tailored to the specific use case under consideration. Due to the modular and generic structure of the model, the one non-specific dimension "Indirectly affected work systems" could be transformed into the two case study specific operating subsystems "High bay warehouse system" and “Production system”. This gives a first indication that the framework indeed meets the application-related requirements R_A 1 and R_A 2.

With a view on the objectives of the framework, it was found that by applying the framework, it was possible to bring the unspecific risk “lack of competencies” into a more specific context for the particular use case under consideration. Guided by the proposed dimensions of the framework, it was found that this very risk affects several enterprise subsystems on different hierarchy levels. So, the one initial risk “lack of competencies” in this example evolved into three specific risks.

As a next step, it would be necessary to investigate the underlying causalities of the three specific risks and to map them to the framework as well. The insights from the presented case study form a solid foundation for this analysis, as they give guidelines on where to start and on what to focus (e. g. the control stations users to-be in example 1).

The elements of order and the external actors were not relevant for mapping the examined risk “lack of competencies”. However, this does not mean that they cannot still become so with reference to the causes and effects of this risk.

The presented results from the case study, as well as the forthcoming results on specific causalities, should finally enable the derivation of suitable indicators on the basis of the contextual information obtained.

5 Conclusion, limitations, and further research

Many companies still fail on their digital transformation endeavors. The fact that Industry 4.0 projects affect entire enterprises as a sociotechnical system provides a breeding ground for various risks. Project risk monitoring as integrated part of project management is key to successful projects. However, the special requirements of project risk monitoring for Industry 4.0 projects have not yet been the focus of scientific investigations.

In general, indicator-based early warning systems have proven themselves in various risk monitoring domains. Since indicators can only become meaningful when brought into a specific context, the first step towards building any indicator-based monitoring system is to establish an appropriate framework that defines the area under consideration. Accordingly, as a first step towards closing the research gap, this paper aimed at the development of such a framework for indicator-based, sociotechnical project risk monitoring.

To find a suitable approach, in section 2 the sociotechnical risks endangering digitization projects have been examined in more detail. As a result, they were characterized as cascading, systemic risks. To be able to handle the underlying high degree of complexity, systems theory with its holistic concept is found as a promising solution approach.

In a next step, requirements have been derived that shall be met by the framework to be designed. A total of ten requirements was defined in section 3: eight content-related and additional two application-related requirements. To derive the former, projects and enterprises were both explored as complex, open, and sociotechnical systems by conducting a literature analysis. The latter were derived based on insights gained in focus groups within the SORISMA research project as well as in numerous previous SME case studies.

In the following section 4, the framework developed in accordance with the set requirements was presented. The proposed model consists of five major building blocks to embed risks, causes, and effects into a specific context, namely: enterprise subsystems, process-related hierarchy levels, sociotechnical dimensions, elements of order, and external actors. The basic framework structure was inspired by the St. Gallen Management Model as renowned reference framework in system-oriented management theory. Furthermore, the designed framework was subjected to an initial evaluation using a real-life case study. However, so far only initial starting points for an evaluation could be given. In this regard, limitations as well as further research possibilities have to be considered.

First, limitations have to be considered with respect to the framework itself. The building blocks and especially the elements of order and the external actors were identified hands-on by analyzing the literature used for this paper. To enrich the proposed framework and to evolve it in an iterative process, further research could focus on in depth investigation of the building blocks, e. g. by performing structured literature analyzes.

In addition, the scope of application has been limited in section 1.1 since the proposed framework is a first attempt to help bridge the existing research gap. In this regard, it could be examined if or to which degree the designed framework is applicable to those excluded application domains, e. g. the monitoring of digitization portfolios or programs.

Moreover, it was not possible to provide an overall evaluation since it was not yet possible to actually derive indicators for tracing the underlying cause-risk-effect relationships. To be able to do this, the causalities must be known in the first place. And obtaining this information on risks and their cause-and-effect chains is the task of Risk analysis and assessment (see section 1.1). Accordingly, the designed framework formulates information demands on the risk analysis and assessment to finally allow for a subsequent indicator derivation.

However, since sociotechnical project risk monitoring was not in the focus of the scientific discourse so far, implications of this new information demand on existing approaches to sociotechnical risk analysis and assessment should be analyzed in further research.

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