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Resilience Maturity Assessment in Manufacturing Supply Chains

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Abstract

Industry 5.0 is a new vision for European industry with focus on human centricity, sustainability, and resilience. Due to that most research on Industry 5.0 concentrates on digital technologies, mainly because its relation to Industry 4.0, there is still limited and one-sided understanding of the concept. To enhance the competitiveness of manufacturing industries in Europe, companies need to develop their capabilities not only in digitalization, but also of human centricity, sustainability and resilience. Resilience, the capacity to withstand or to recover quickly from difficulties, is an important aspect due to war, pandemic, energy crisis and climate change crisis. Many manufacturing companies face major challenges in their supply chains, with limited availability of components, lack of critical virgin materials, high-cost growth, and high supply risk exposure. This research seeks to bring further understanding of the resilience dimension of the Industry 5.0 concept. It adds to the limited amount of research available on Industry 5.0. Also, manufacturing companies need to better understand how they can strengthen their resilience in the supply chains. This paper presents a tool that companies may use to evaluate their maturity, and identify improvement areas. The tool is assessed in three companies.

Keywords

Maturity assessment; Industry 5.0; Digitalization; Supply chain resilience; Tool development

1. Introduction

European industry is a main driver in the currently undergoing economic and societal transitions, and plays a key role in providing solutions to several major societal challenges including preservation of resources, climate change and social stability [1]. Industry 5.0 is a new concept launched by the European Union, which implies a novel approach for future industry that brings benefits for industry, for workers and for society [1]. The concept provides a vison that stretches beyond single goals of efficiency and productivity, and reinforces the role and the contribution of industry to society. The vision involves the transition to a sustainable, human-centric, and resilient European industry. It also complements the techno-economic vision of the Industry 4.0 concept, with emphasis on digitalization, including the transition towards a digital, data-driven, and interconnected industry [1]. While Industry 4.0 is technology driven, Industry 5.0 is assumed to be value driven, providing positive benefits to many stakeholders [2]. The twin transition involves a combined approach for achieving the green transition and the digital transition in society and industry, and for these two transitions to reinforce each other [3]. The aim is to achieve sustainability, combat climate change and environmental degradation, and future digital technologies may be key enablers for the green transition [3].

Recent multiple crises such as the climate change and environmental degradation crises, the covid-19 pandemic and the economic crisis have led to major challenges for the European industry [1]. Companies

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thus seek to create resilient organizations that can withstand or recover quickly from difficulties, and need to enhance their resilience capabilities [11]. Resilience in an Industry 5.0 setting may also involve aspects of sustainability and human centricity [1]. Companies need to be resilient to deal with not only unexpected environmental or climate change events, but also related to new environmental regulations, for instance. Moreover, humans are typically affected by the environmental and climate change impacts, and constitute important enabling resources to ensure resilience in companies by their creativity and flexible abilities.

To ensure systematic resilience management and improvement in manufacturing companies, powerful tools, and methods for measuring and evaluating the performance in terms of resilience are needed. These tools should also be ambitious regarding meeting future requirements, meaning that they should be aligned with the broad vision of industry transformation based on Industry 5.0 as well as of the narrower Industry 4.0 vision expressing ambitions for digital transformation.

Resilience has been a topic of high interest to researchers for several decades, which has resulted in a significant amount of research literature proposing resilience assessment frameworks and tools [19, 20]. Also, there is a rapidly growing body of research seeking to measure digital and Industry 4.0 maturity, see for instance literature reviews by [4–7]. However, there is a research gap on methods and models for resilience maturity measurement in Industry 5.0 including the enabling the role of digital technology. This is due to several reasons. First, Industry 5.0 is still a new concept in both European industry and academia. Therefore, there is limited general research on this new concept and thus also lack of research on resilience in an Industry 5.0 context. Second, despite a large body of research, the role of digital technology is rarely included in previous research on resilience. Third, the recently developed maturity models are concentrated to Industry 4.0 and digital technology, paying little attention to its importance for the Industry 5.0 dimensions. It is therefore suggested to extend existing digital maturity models in these areas [8]. In addition, self-assessment methods for small and medium sized companies (SMEs) to support their digital transformation are lacking, since current digital maturity models available in literature are developed for large companies and thus fail to meet specific requirements of SMEs [9].

With a starting point in the shortcomings of existing literature on resilience and maturity models described above, this research is expected to contribute with a better understanding of resilience maturity in manufacturing supply chains in an Industry 5.0 context. The manufacturing sector is an important industry in Europe. The aim is to support manufacturing companies, especially SMEs, to enhance their resilience capabilities in line with the Industry 5.0 vision and ambitions of digital transformation that are fundamental for the future of European industry. More specifically, this paper presents the outline of a new tool for assessing Industry 5.0 resilience maturity, which may be used to measure the maturity level of supply chain resilience in manufacturing SMEs. This includes a set of critical resilience maturity aspects in an Industry 5.0 context identified in literature, and the development of a resilience maturity assessment (RMA) tool that is assessed in three manufacturing SMEs.

2. Theoretical considerations

Industry 5.0 is a new vision for European industry with focus on human centricity, sustainability, and resilience [1]. The resilience concept is closely related with the capability and ability of a company to return to a stable state after a disruption [20]. In a business context, resilience can be defined as the capacity for an enterprise to survive, adapt, and grow in the face of change and uncertainty [18]. To improve in terms of resilience, companies may strengthen their capabilities related to resilience and resilience may be measured by a company's ability to deal with risk and reduce vulnerability [11].

Readiness and maturity can measure a company's status and progress towards a future state of resilience. Supply chain resilience (SCRES) is the adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost effective recovery, and progress to a better state of operations, and

can be assessed in view of the preparation for a disruptive event, response to an event, recovery from the event, and growth/competitive advantage after the event [10].

The tool is based upon a set of relevant categories and factors identified in literature that are listed in Table 1. Supply chain resilience maturity [11] is characterized by a collection of capabilities and vulnerabilities. Current potential global risks are identified based on the recent report published by the World Economic Forum [12]. A set of factors reflecting resilience aspects of human workers are identified based on [13]. A considerable number of models for measuring digital and Industry 4.0 maturity are identified, see [6, 14, 8]. Maturity models are concerned with measuring adoption of advanced digital technologies in firms and relevant items for enabling resilience capabilities and vulnerabilities are identified based on [14] and [15].

Table 1: Identified resilience maturity assessment factors

Category	Factors/sub-factors	Ref.
Vulnera-bilities	Turbulence; Environment characterized by frequent changes in external factors beyond your control Deliberate threats; Intentional attacks aimed at disrupting operations or causing human or financial harm External pressures; Influences, not specifically targeting the firm, which create business constraints or barriers Resource limits; Constraints on output based on availability of the factors of production Sensitivity; Importance of carefully controlled conditions for product and process integrity Connectivity; Degree of interdependence and reliance on outside entities Supplier/customer disruptions; Susceptibility of suppliers and customers to external forces or disruptions	[11]
Global risks	Economic, Environmental, Geopolitical, Societal, Technological	[12]
Capa-bilities	Flexibility in Sourcing; Ability to quickly change inputs or the mode of receiving inputs Flexibility in Order Fulfilment; Ability to quickly change outputs or the mode of delivery Capacity; Availability of assets to enable sustained production levels Efficiency; Capability to produce outputs with minimum resource requirements Visibility; Knowledge of the status of operating assets and the environment Adaptability; Ability to modify operations in response to challenges or opportunities Anticipation; Ability to discern potential future events or situations Recovery; Ability to return to normal operational state rapidly Dispersion; Broad distribution or decentralization of assets Collaboration; Ability to work effectively with other entities for mutual benefit Organization; Human resource structures, policies, skills, and culture Human workers; Ability of operators to use human creativity, ingenuity, and innovation, and their interaction with machines Market Position; Status of a company or its products in specific markets Security; Defence against deliberate intrusion or attack Financial Strength; Capacity to absorb fluctuations in cash flow	[11]
	Human workers; Ability of workers to use human creativity, ingenuity, and innovation, and their interaction with machines	[13]
Enabling digital technologies	Additive Manufacturing (AM), Artificial Intelligence (AI), Augmented Reality (AR) or virtualization, Automation and collaborative robots, Big data and Analytics, Blockchain, Cloud computing, Cyber-Physical Systems, Cybersecurity, Horizontal and Vertical systems integration, Internet of Things (IoT), Simulation and Modelling, Visualization Technology	[14], [15]

3. Methodology

The resilience maturity assessment (RMA) tool is based on a brief literature review. The objective was to establish a starting point for tool development rather than conducting a comprehensive review. It was concentrated to identifying relevant existing maturity assessment tools related to resilience, digital maturity and Industry 4.0. The review also included searches for literature within the field of Industry 5.0. Approaches by [16] and [17] were used, adopting a stepwise iterative approach with planning and formulating the problem and literature search.

A set of previous maturity assessment tools were identified. The SCRAM tool developed by [18] was selected as a starting point for the RMA tool. This tool includes an exhaustive list of vulnerability and capability parameters, is well defined and described and validated in seven companies. The tool was extended to also include specific aspects related to human centricity based on the concept of Resilient Operator 5.0 [13], global risks defined by the World Economic Forum [12] and enabling digital technologies see [15] and [14].

The RMA tool is developed in MS Excel and is still in a prototype stage. It includes a set of statements and questions in a survey type of format, where respondents are asked to indicate the extent of agreement or disagreement based on personal knowledge of products, organization, and operations. We believe that the survey or prototype constitutes the starting point of the development of a new tool, but that it should be further developed to become a complete web tool with practical guidelines that companies may use to measure and improve their maturity in terms of resilience.

For the statements related to vulnerabilities and capabilities, ratings are conducted by a 5-point Likert scale ranging from Strongly disagree (1) to Strongly agree (5). The severity of global risks is assessed by a 5-point Likert scale ranging from Low severity (1) to High severity (5). In addition, the alternative Do not know was included. Ratings of the importance of vulnerabilities and capabilities are conducted by a three-level scale, Critical, Important and Minor importance, also with the alternative Not relevant/Don't know.

Regarding the enabling digital technologies, respondents are asked to rate (the same scale 1-5 of degree of agreement as for vulnerabilities and capabilities) the use of advanced digital technologies to enable or enhance the company's preparedness to withstand vulnerabilities (factors 1-7), as well as to enable or enhance capabilities (factors 1-15). Also, respondents are asked to specify the type of technology (technology types 1-13) for each statement that is marked (strongly) agree (rate 4 or 5).

The RMA tool was first assessed among researchers at SINTEF before it was distributed by e-mail to three SMEs. The companies were selected due to their participation in ongoing research projects involving the development of manufacturing excellence in Europe, and their strong interest in the Industry 5.0 concept. Two of the companies manufacture agricultural equipment, with production facilities in Norway. Company A delivers products primarily to domestic customers, while the markets of Company B are outside Norway. The third company (Company C) is a recently established company in the renewable energy sector, with high export potential, planning to set up manufacturing facilities in Norway. All three companies are exposed to risks, experience vulnerabilities and are thus concerned with ensuring resilience in their operations and supply chains. The tool was sent to the main contact person of the research projects in respective company. All three companies filled out the tool and returned answers to all questions and parameters. The tool was filled out by one person at each company.

4. Examples of test results

This chapter presents a selection of results from assessing the RMA tool in the SMEs.

4.1 Company A

The results of the assessment of Company A regarding the vulnerabilities that currently challenge operations are shown in Figure 1 and results regarding to the severity of future global risks in Figure 2.

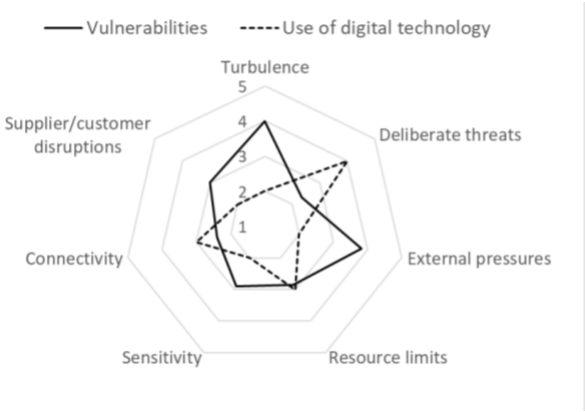

Figure 1: Vulnerabilities of Company A

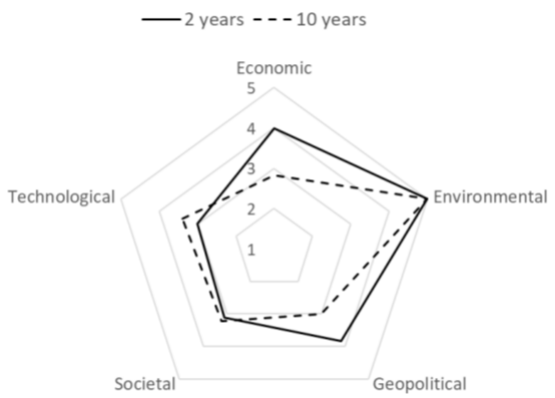

Figure 2: Severity of future global risks of Company A

Turbulence is the most challenging category, followed by external pressures (solid line, Figure 1). The use of advanced digital technology in the company to enable or enhance preparedness to withstand vulnerabilities seems to be low in general, except for the use of cyber physical systems that are used to withstand deliberate threats (dotted line, Figure 1). Turbulence and deliberate threats are critical. The company expects to be exposed to major environmental risks both on a short term (solid line, Figure 2) and long term (dotted line, Figure 2), as well as geopolitical and economic risks, especially in a short term. The company expects both economic and geopolitical risks to be reduced in the long-term.

Results regarding the rating of capabilities are shown in Figure 3.

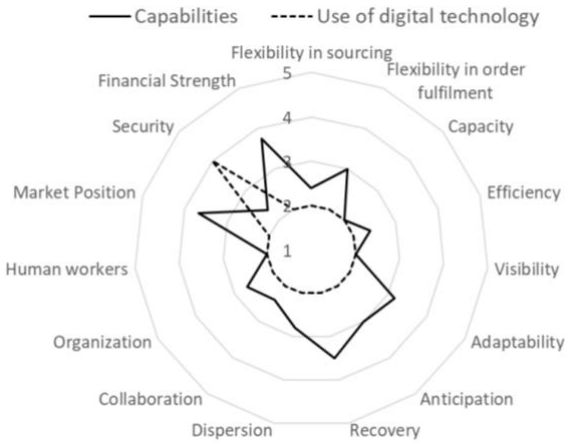

Figure 3: Capabilities of Company A

The capabilities with highest score are financial strength, market position, recovery and adaptability (solid line, Figure 3). However, most capabilities have low ratings indicating a weak resilience capability. Regarding the use of digital technology (dotted line, Figure 3), the score is low overall, except for security, where again cyber physical systems are used. Capacity is considered a critical capability.

4.2 Company B

Results of the assessment of Company B regarding the vulnerabilities that currently challenge operations and severity of future global risks are shown in Figure 4 and Figure 5.

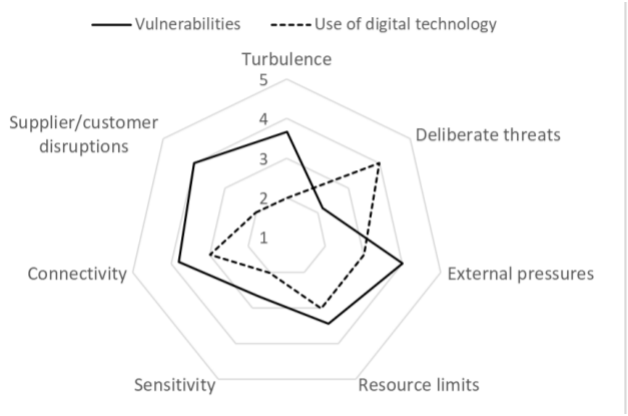

Figure 4: Vulnerabilities Company B

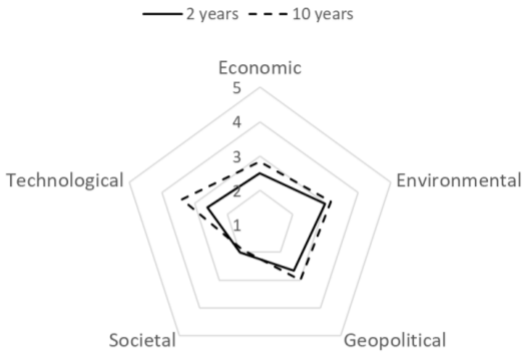

Figure 5: Severity of future global risks Company B

The categories supplier/customer disruptions and external pressures constitute the most challenging categories, followed by the connectivity category (solid line, Figure 4). The use of advanced digital technology to enable or enhance preparedness to withstand vulnerabilities seems to be low in general, except for the use of cybersecurity technology that is used to withstand deliberate threats (dotted line, Figure 4). None of the categories are critical to the company, and several categories are of minor importance. The company expects to be exposed to medium severe environmental risks on a short term (solid line, Figure 5) and long term, as well as increased geopolitical, economic and technological risks on a long term (dotted line, Figure 5). The company expects societal risks to be low, both on short and long-term. Results regarding the rating of capabilities are shown in Figure 6.

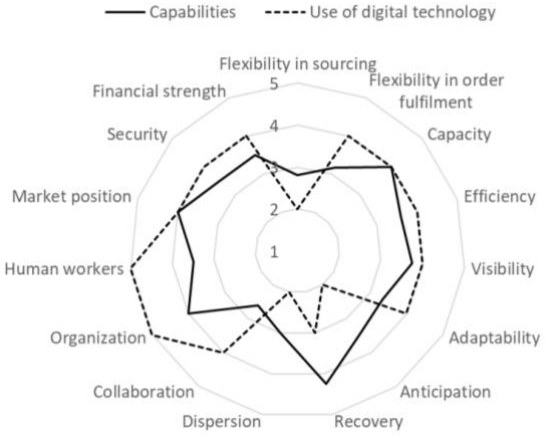

Figure 6: Capabilities Company B

The capabilities with highest score involve capacity, recovery, organization and market position (solid line, Figure 6). Most capabilities are scored between 3 and 4, which indicates a good general resilience capability. Regarding the use of digital technology, several capabilities are also enhanced by advanced technologies such as automation and collaborative robots, cyber-physical systems, and Internet of things (dotted line, Figure 6). Digital technologies are especially used to support the company's capabilities related to human workers and organization. Regarding the rating of importance, flexibility in sourcing, organization, human workers and market position are considered especially critical capabilities to the company.

4.3 Company C

The results of the assessment of Company C regarding vulnerabilities that currently challenge operations are shown in Figure 7 and results regarding severity of future global risks in Figure 8.

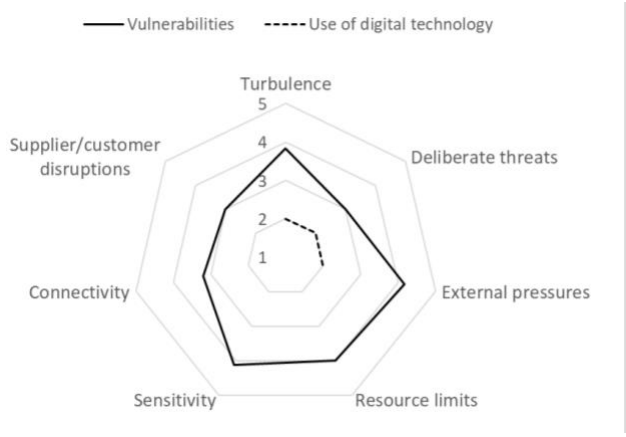

Figure 7: Vulnerabilities Company C

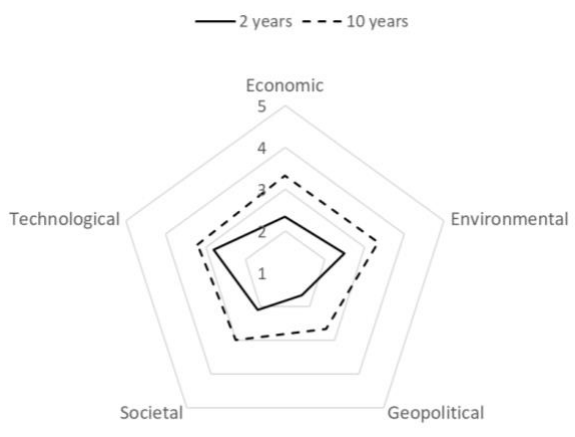

Figure 8: Severity of future global risks Company C

The categories external pressures, resource limits, and sensitivity are the most challenging, followed by turbulence (solid line, Figure 7). The company does not use advanced digital technology to enhance preparedness to withstand vulnerabilities (dotted line, Figure 7). None of the vulnerability categories are critical. Regarding the severity of future global risks, the company expects to be exposed to an overall insignificant risk on a short term (solid line, Figure 8). On a long term (dotted line, Figure 8), risks are expected to increase, especially economic, environmental and technological risks. Geopolitical risks are low on short and long term. The ratings of capabilities are shown in Figure 9.

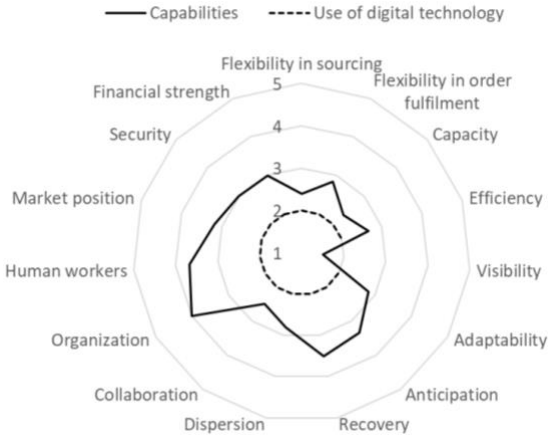

Figure 9: Capabilities of Company C

Capabilities related to flexibility in sourcing and flexibility in order fulfilment considered critical. However, capabilities related to organization, human workers and recovery have the highest score (solid line, Figure 9). The company does not use digital technology to enhance its resilience capabilities (dotted line, Figure 9).

4.4 Summary of test results

The results of the RMA tool tests in the three companies are summarised in Table 2.

Table 2: Summary of test results (DT = use of digital technology)

Category	Item	Company A	Company B	Company C
Vulnera-bilities	Ave. score	3,05	3,25	3,73
	Ave. score DT	2,57	2,71	2,00
	Critical categories	Turbulence, deliberate threats	-	-
	Categories highest score	Turbulence, external pressures	External pressures, supplier/ customer disruptions, connectivity	External pressures, resource limits, sensitivity

Global risks	Categories high severity 2 years	Economic, environmental, geopolitical	-	-
	Categories high severity 10 years	Environmental, technological	Technological, environmental	Economic, environmental, technological
Capa-bilities	Ave. score	2,73	3,48	2,91
	Ave. score DT	2,13	3,67	2,00
	Critical categories	Capacity	Flexibility in sourcing, organization, human workers, market position	Flexibility in sourcing, flexibility in order fulfilment
	Categories highest score	Financial strength, market position, recovery, adaptability	Capacity, recovery, organization, market position	Organization, human workers, recovery

5. Discussion and conclusion

The test of the RMA tool shows how it may be used to measure vulnerabilities, analyse current and expected future challenges and risks and assess resilience capabilities and the use of digital technology to build resilience and preparedness to deal with vulnerabilities and risks. Such tools are important to create a resilient European industry in line with Industry 5.0. While previous approaches are conceptual or concerned with traditional views of supply chain resilience only, the RMA tool extends the resilience concept by including elements from Industry 5.0, reflecting human centricity, sustainability and digital technology.

By conducting tests in three companies, the tool can be used to identify key areas of improvement for companies that seek to enhance resilience. It is expected that resilience is a key issue for many European companies, proposing that many companies may find the tool useful. The tool is primarily developed to provide support to manufacturing SMEs that typically have scarce resources and limited expertise available to conduct such assessments. The tool may also be further developed and adapted to specific settings of various manufacturing sectors. Variants of the tool can be developed, for example based on prioritization and selection of critical items or for specific industries.

The tool is intended to help companies identifying critical aspects for building resilience in their supply chains. It presents a set of criteria for assessment of a company perspective and should be used for developing capabilities by identifying the current situation (AS IS) and analysing improvement areas in view of a wanted future state (TO BE). Even though the tool is primarily developed to support individual companies, it can serve as a starting point for the development of more comprehensive maturity surveys including a larger sample of companies in manufacturing or in specific segments within the manufacturing sector. Also, further research is needed to better understand company specific circumstances explaining maturity results. This can be done by conducting multiple case studies, where test results can be compared, and similarities and differences can be explained. Such insight may constitute valuable input to the development of industry or sector specific RMA tools.

This paper presents a first version of the RMA tool and results of a first test round in three companies. A limitation of the tool at this stage is that it is based on few literature sources. A thorough literature review is thus needed to ensure that the new tool version includes a wider range of literature. Results of this first round of tests can be discussed in the companies to get better insights to underlying contextual factors and feedback on improvements. To ensure validity, the tool can be tested in companies representing a variety of industries.

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Biography

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