A Taxonomy for Resistance Concepts in Manufacturing Networks

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Abstract. Manufacturing networks - global production networks and international manufacturing networks - are exposed to an increase in uncertainty, which can cause disturbances. To cope with these disturbances, scholars presented different concepts, such as robustness, resilience, responsiveness, flexibility, changeability, adaptability, and agility. However, these terms are not clearly and concisely defined and lack a common understanding. With this study, we intend to address this issue and contribute to a better understanding and differentiation. We develop a taxonomy with descriptive dimensions and characteristics for the different resistance concepts for manufacturing networks, which will provide a tool to better understand the differences and commonalities between them. It is a vital first step that creates a common ground for further investigations. Practitioners can use the taxonomy to build a sound understanding and improve their manufacturing network.

Keywords: Manufacturing Network Resilience, Robustness, Taxonomy.

1 Introduction

Globalization has significantly changed the economic landscape significantly for manufacturing companies over the last decades [1]. Increasing competition and opportunities led companies to create greater value by exploiting advantages, such as lower cost resources or access to new markets [2]. In consequence, companies of any size now operate as global production networks (GPNs) [1], which can be considered “one of the most critical forms of organization in the manufacturing sector” [1]. Intra-firm GPNs even account for one third of the global trade [1].

However, the growth of manufacturing networks (MNs) due to the challenge to create greater value increases their complexity and susceptibility to risk [3]. Such risks result from the current competitive and rapidly changing environment. Scholars in the field of operations management (OM) and supply chain management (SCM) called for, proposed, and investigated different concepts to deal with these uncertainties [4–6]. These concepts are, among others, the following: resilience, robustness, responsiveness, flexibility, agility, changeability, and adaptability.

However, they are often used interchangeable and not clearly distinguishable [5, 7]. Nevertheless, for research progress in any field, the establishment of a clear definition is a necessary first step [5]. Some authors already enhanced the understanding of some concepts by developing clearer and more distinguishable definitions. Nevertheless, to the best of our knowledge, there is yet no comprehensive approach, i.e. a taxonomy, to classify a larger number of the respective terms based on their constituent factors.

Taxonomies support researchers and practitioners in comprehending and analyzing complex issues by providing a structure and organization of a knowledge base for a certain research field [8, 9]. Therefore, we hypothesize that a taxonomy for resistance concepts for MNs will help to clarify and distinguish different concepts. The research question for this study is therefore as follows:

RQ: *What are key dimensions and characteristics of concepts that describe a form of resistance in manufacturing networks?*

We answer this research question by following the well-used and structured method from [9]. The development of a taxonomy intends to identify common characteristics of resistance concepts and make them distinguishable. Hence, the paper is organized as follows: After the introduction, we discuss the related literature on MNs and different concepts that describe a form of resistance in MNs. Second, we introduce our research methodology. Third, we present the final taxonomy. Lastly, we discuss the theoretical and practical implications of this paper, as well as its limitations and possible future research.

2 Research background

The MN theory originates from the OM field [10]. Historically, researchers categorize MNs as internal networks that are wholly owned by a single company. A MN can be defined as “a factory network with matrix connections, where each node (i.e. factory) affects the other nodes and cannot be managed in isolation” [10]. Due to the takeoff of globalization in the 1980s and 1990s, companies established more factories internationally and research on this topic increased [10]. Different subdomains emerged under the umbrella of MN research, i.e. GPNs and international manufacturing networks (IMNs). All nodes within an IMN are owned by a single company, whereas a GPN includes nodes owned by other companies.

Although such networks are beneficial in some areas, they increase the susceptibility to risks [3]. Risks are ever present in daily operations of companies worldwide [11] and can have different appearances: A distinction can be made between internal (e.g. machine failure) and external risks (e.g. environmental disaster). Additionally, change events can have the manifestation as disastrous, disruptive, or small. Hereinafter, we use the neutral term *change events* to describe any type of risks.

To cope with such change events, scholars introduced different terms and concepts [4–6]. These concepts are, among others, the following: resilience, robustness, responsiveness, flexibility, agility, changeability, and adaptability. However, the concepts to characterize a form of resistance are not defined in a clear and concise way, which is also well-acknowledged. This problem does not only exist in the specific field of MN, but in OM and SCM as well (e.g. see [4, 5]).

An example of a vague definition can be found for robustness: “robustness describes the stability against varying conditions” [7, 12]. It is often associated with a stable performance despite the impacts of change events [7, 12–14]. Some scholars classify robustness as a concept very close to resilience [7]. Conflicting views on both concepts exist. [7] categorize resilience and agility as robustness characteristics. In contrast, [15] state that resilience has robustness properties. Some scholars argue that resilience is the ability to resist even greater change events than robustness.

Additional controversies can be found for the terms flexibility and responsiveness. [16] defines flexibility as part of responsiveness, whereas [17] categorizes responsiveness as part of flexibility. While flexibility is a mature concept, responsiveness is still lagging a clear conceptualization [4]. Based on a literature review, [4] conceptualizes flexibility as the "ability of a system to change status within an existing configuration." Accordingly, [4] defines responsiveness as the "propensity for purposeful and timely behavior change in the presence of stimulating stimuli."

Another example of such a controversy is the subsumption of flexibility as part of agility (see [17–19]), whereas [20] categorizes agility as part of flexibility. [4] defines agility as the "ability of the system to rapidly reconfigure." Furthermore, agility is seen by [1] as a concept on network level to establish changeability.

Changeability as a concept is often referred to as "actions to adjust flexibility limits" [21]. The concept incorporates flexibility and rapidity and can be categorized as "a part of adaptability" [22]. According to [22] and [16] adaptability describes the ability of a system to change due to change events.

So far, scholars limited their research to the detailed definition of one concept (e.g. see [4]) or the distinction between a small number of specific concepts (e.g. see [5]).

3 Research approach

3.1 Taxonomy development process

We have adopted the approach developed by [9] for the development of our taxonomy. The method provides a rigor process and has been used in high-ranking journal articles and conference proceedings [8]. It consists of three stages: first, meta-characteristics and ending conditions are defined. Meta-characteristics depend on the purpose of the taxonomy. Objective and subjective ending conditions are provided by [9]. During the second stage, dimensions and characteristics of the taxonomy are developed: empirical-to-conceptual (E2C) and conceptual-to-empirical (C2E). During the E2C approach the researcher identifies subsets of objects and common characteristics. The C2E approach guides the researcher to develop dimensions and characteristics based on their own notions. The last stage compares the taxonomy to the ending conditions.

3.2 Taxonomy development

Meta-characteristic: Our contribution aims to provide a sound basis for future research and discussion by enabling the classification of a resistance concept based on its constituent factors. The meta-characteristics are "key-characteristics of concepts for MNs to withstand internal and external change events."

Ending conditions: For our taxonomy, we use the objective and subjective ending conditions from [9], as they provide a sound approach to evaluate the taxonomy.

First Iteration (E2C): To get a comprehensive overview of the concepts to describe resistance in MNs, we conducted an exhaustive systematic literature review. Literature reviews provide a vital and qualified mean [23] to summarize and progress the current state of knowledge in a certain field [24]. We chose the methodology from [25] because of its recipe alike process, which covers all important phases of a literature review.

To ensure a certain quality, the results were limited to peer-reviewed articles in scientific journals or conference proceedings [24]. The search was conducted using the three major databases Emerald, EBSCOhost and Science Direct and yielded 1369 results. After the removal of duplicates and the screening of titles and abstracts for relevance, the number of articles was reduced to 64. A forward and backward search identified 46 articles. 28 relevant articles remained after a full text analysis.

Table 1. Contributions of scholars to different terms and concepts

	Flexibility	Robustness	Changea-bility	Resilience	Agility	Respon-siveness	Adaptabil-ity	Reliability	Stability	Resistance
Papers	[26],[17], [20],[1], [18], [6], [27], [15], [28], [29], [30], [7]	[31], [13], [20], [1], [14], [32], [15], [12], [33], [7]	[21], [22], [1], [18], [19], [28], [34], [7]	[3],[11], [1],[35], [15], [7]	[17], [36], [37], [28], [7]	[26], [1], [15], [16]	[1]	[15]	-	-

First, we clustered the articles according to their contributions to different concepts (see **Table 1**). For the taxonomy development, we initially focused on the six concepts that were mentioned most often: flexibility, robustness, changeability, resilience, agility, and responsiveness. At this point we were able to identify a pattern: The definitions and descriptions often follow a systems perspective. They describe a form of input – a change event – which is mitigated by some form of capabilities of the network, in order to reach a desired system state. This is in consensus with the findings of [38]. We thus defined the meta-dimensions as *input*, *capabilities*, and *output/objectives*.

Second Iteration (E2C): We used a coding book (MS Excel) to extract and evaluate the information in more detail. We identified the constituent factors *severity of change*, *anticipation of change*, *pace of reaction*, *range of reaction* and *system state*.

Third Iteration (C2E): The extensive knowledge and experience of the researchers led to the development of the categories *area of reaction* and *measurement level*.

Fourth iteration (E2C): We applied definitions from related research areas, i.e. OM and SCM, since not all ending conditions were fulfilled after the third iteration. This step was necessary due to two factors: 1) The literature on different concepts is rather scarce and different understandings are not sufficiently discussed. 2) Concepts and definitions are discussed in more detail in OM and SCM (e.g. flexibility [5]). The OM area is suited for this application as it can be considered superordinate to MN research. Depending on the understanding of MNs (i.e. intra-firm networks or inter-firm networks), SCM can be considered a part of those [10]. We used review articles to ensure the rigorousness of the results.

Fifth iteration (E2C): Adding new dimensions in the fourth iteration required a fifth iteration [9]. We tested the taxonomy, using all existing definitions and description of concepts and found no dimensions or characteristics to add.

Ending conditions: After the fifth iteration, the taxonomy fulfilled all ending conditions proposed by [9]: 1) All articles from the literature review and additions from OM and SCM literature have been examined. 2) We did not split or merge objects in the last iteration. 3) Each characteristic of each dimension was classified with at least one object. 4) We did not add any new dimensions or characteristics in the last iteration. 5) Neither did we merge or split dimensions or characteristics. 6) There are no dimension duplications and each dimension is unique. 7) Similar, no characteristic duplications exist within one dimension. 8) Each combination of characteristics is unique; however, the various definitions may be broadly similar. 9) The taxonomy includes no unnecessary dimensions or characteristics and the number of dimensions falls into the proposed number of nine. 10) The existing dimensions and characteristics allow to differentiate every object. 11) It is comprehensive because all objects can be classified (see also iteration five). 12) The taxonomy can easily be extended by adding new dimensions or characteristics. 13) The taxonomy provides valuable and non-redundant information for the characterization of resistance concepts in MNs.

4 A taxonomy to describe concepts for MN resistance

The taxonomy consists of three meta-dimensions, eight dimensions with twenty-three characteristics (see **Table 2**). The column on the far-right provides additional information on whether a characteristic of a dimension is exclusive (E) or non-exclusive (N). We opted for a morphological box to visualize the taxonomy. This allows us to illustrate the set of relationships contained in a complex problem in an intuitive way.

4.1 Meta-dimension: Input

The first meta-dimension, *input*, considers the dimensions and characteristics of change events, which influence the MN. We identified the two dimensions *severity of change* and *anticipation of change* as constituent features.

The dimension *severity of change* describes possible impacts of an internal or external event that a MN must be able to withstand. [1] describe that robustness has to mitigate “disruptive internal and external changes.” [7] characterize resilience as the ability of a system to “tolerate disturbances.” They establish a dependency between the nature of change events and the appropriate mitigation actions. [3] describe resilience as the “speed of reaction to disruptions.” Hence, resilience is the ability to react to high severity events, which is indicated by the term “disruptions.” The *severity of change* is characterized for agility as well. [7] state that “agility enables for adoption to bigger disturbances.” Flexibility, however, is seen as the ability to deal with small changes [18]. Based on those definitions and descriptions, we derived the characteristics of *low, medium,* and *high*. The characteristics are non-exclusive, as a concept can be constructed to handle different severities.

The dimension *anticipation of change* refers to a second category of characteristics to describe change events. It differentiates between *foreseeable* and *unforeseeable* change events, which is based on the following definitions: [1] and [35] describe resilience as a concept reacting to unforeseeable events. Similar, [6] (flexibility), [19] (changeability), [22] (changeability) and [17] (agility) use this dimension to describe change events. [16] characterizes a responsive system as able to react to “predictable and unpredictable changes.” Therefore, we termed the dimension non-exclusive. Although there are different categorizations to characterize change events (see [3] and [7]), the chosen dimension is in conformance with all analyzed definitions.

Table 2. Taxonomy for manufacturing network resistance concepts visualized as a morphological box

<table>
<tr><th>Meta-dimension</th><th>Dimension</th><th colspan="12">Characteristics</th><th>E/N</th></tr>
<tr><td rowspan="2">Input</td><td>Severity of change</td><td colspan="4">Low</td><td colspan="4">Medium</td><td colspan="4">High</td><td>N</td></tr>
<tr><td>Anticipation of change</td><td colspan="6">Foreseeable</td><td colspan="6">Unforeseeable</td><td>N</td></tr>
<tr><td rowspan="4">Capabilities</td><td>Pace of reaction</td><td colspan="6">Rapid</td><td colspan="6">Purposeful</td><td>E</td></tr>
<tr><td>Range of reaction</td><td colspan="4">Persist</td><td colspan="4">Adapt</td><td colspan="4">Transform</td><td>E</td></tr>
<tr><td>Level of reaction</td><td colspan="4">Micro</td><td colspan="4">Meso</td><td colspan="4">Macro</td><td>N</td></tr>
<tr><td>Area of reaction</td><td colspan="4">Strategy</td><td colspan="4">Configuration</td><td colspan="4">Coordination</td><td>N</td></tr>
<tr><td rowspan="2">Output/ Objective</td><td>System state</td><td colspan="3">Stability/ Equilibrium</td><td colspan="3">Bounce-back</td><td colspan="3">New optimum</td><td colspan="3">Not applicable</td><td>N</td></tr>
<tr><td>Measurement level</td><td colspan="4">Operational</td><td colspan="4">Tactical</td><td colspan="4">Strategic</td><td>N</td></tr>
</table>

4.2 Meta-dimension: Capabilities

The second meta-dimension, *capabilities*, contains five dimensions. It describes how, to what degree, and where the MN reacts to change events.

The first dimension, *pace of reaction*, indicates the speed at which a certain concept reacts to the impact of change events. A majority of the concepts are characterized as rapid or fast (i.e. [3, 7] – resilience, [15] – responsiveness, [17, 29] – flexibility, [22] – changeability, [7, 17] – agility). [16] adds that a responsive system should make a “balanced response.” As a result, we differentiate between the characteristics *rapid* and *purposeful*. *Rapid* expresses the absolute need for a quick reaction of the system. On the contrary, *purposeful* expresses the need for a system to react in an acceptable time period to reach its objectives. The dimension is exclusive.

The dimension *range of reaction* describes to what extent the capabilities of the system can be altered in case of change events. The capabilities can *persist*, describing a reaction without significantly changing the capabilities. [28] describe agility as a concept that functions “without changing the network structure itself.” However, the capabilities can also *adapt*, which describes the readjustment of capabilities within predefined limits. See for example the definitions from [18] and [22], where flexibility corridors and enablers of change can be adapted. Transform refers to the adjustment of capabilities without predefined limits. [28], for example, state that “transformability is the tactical ability to adapt, i.e. the ability of an entire factory structure (physical, organizational, etc.) to switch to another product family." The dimension is exclusive.

The *level of reaction* refers to the production level where a reaction of the system's capabilities will occur. Flexibility can for example occur on the "*micro* level (single resources of a system) or *macro* level (whole system)" [30]. Related to MNs, the characteristics ranging from micro to macro level can be put into comparison with the range from workstation level to network level perspective. For a more precise classification, we added a *meso* level, describing e.g. flexibility on plant level [27, 29]. Since reactions can occur on several levels, the dimension is non-exclusive.

The dimension *area of reaction* allows to classify the reaction into an area of a MN. We grouped the areas following [2]: s*trategy, configuration, coordination*. A classification into one or more areas can be found in the works of several authors, such as [1, 7, 16, 26, 29, 36]. [1], for example, locate the adaptation of capabilities into the configuration area, whereas [7] locate it to the entire network; however, with a focus on coordination. Hence, the dimension is non-exclusive.

4.3 Meta-dimension: Output/Objective

The third meta-dimension is *output/objective*. It allows for the characterization of the output from a reaction of the capabilities to change events.

The outcome, which results from the application of a certain concept is described by the dimension *system state*. Some authors detailed a post-disruption system state in their definitions, i.e. [1, 5, 7, 11, 12, 15, 18]. According to [7, 12] robustness describes "the stability against different varying conditions." [1] however, applied the stability paradigm to resilience. [7] understands resilience more extensively and names three system states depending on the severity of the change event: stable performance, fast regain of the initial performance, and adaptation of a new optimal state. This leads to the characteristics *stability/equilibrium*, *bounce-back*, and *new optimum*. Several authors did not specify an outcome or used a vague description, such as [39] ("achieve its goals in the presence of disturbances") or [15] ("dampen the effects of demand changes"). Although we advise to define a system state, we included the characteristic *not applicable* to account for definitions without one. The dimension is non-exclusive, following [7].

The *measurement level* classifies the aggregation level of the KPIs, where the achievement ratio of the concept is measured. We developed the following characteristics: *operational* [28], *tactical* [17], and *strategic* [7, 13, 17, 28, 32, 33]. An example for strategic KPIs are the site roles, which determine the level of robustness [32, 33]. Flexibility can be measured on all levels. The dimension is thus non-exclusive.

5 Conclusion

We developed a taxonomy for MN resistance concepts, following the method from [9]. It consists of eight dimensions and twenty-three characteristics. Our work allows for a deeper and more transparent understanding of individual concepts, hence **contributing to scientific progress in the field of MNs**. It enables to clearly differentiate between various concepts. The results of this research can be the basis for the development of sound methods and processes for the increase of resistance in MNs. **Managerial contributions** of this study are the usage as an instrument to analyze and describe concepts. It can support practitioners by facilitating a better understanding and differentiation as a basis for the shift towards more resistance in MNs.

The **limitations** of our research are the number of publications in the field of MNs. To account for this deficiency, we included publications from OM and SCM. The data collection itself is open to interpretation, meaning that other researchers might derive other dimensions and characteristics depending on personal preferences. Furthermore, our taxonomy is a time-bound snapshot that needs to be updated to remain relevant. This is important due to the evolving nature of research on resistance in MNs.

Future research avenues are the development of archetypical patterns for different terms to establish a sound and distinguishable understanding. Second, dimensions and characteristics to describe solutions that might dissolve or prevent a performance decrease due to a change event could be added.

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